The Effect of Pulse Crop Rotation and Controlled-Release Urea on the Nitrogen Accumulation and End-Use Quality of Canada Western Red Spring Wheat

BY

DAVID WILLIAM ANDREW PRZEDNOWEK

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION PAGE

THE EFFECT OF PULSE CROP ROTATION AND CONTROLLED-RELEASED UREA ON THE NITROGEN ACCUMULATION AND END-USE QUALITY OF CANADA WESTERN RED SPRING WHEAT

BY

DAVID WILLIAM ANDREW PRZEDNOWEK

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

of Manitoba in partial fulfillment of the requirements of the degree

of

Master of Science

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS.......... ii

LIST OF TABLES.......... iv

LIST OF FIGURES.......... xxiii

ABSTRACT.......... xxxii

FOREWARD.......... xxxiv

1.0 INTRODUCTION.......... 1

1.1 Objectives.......... 5

2.0 LITERATURE REVIEW.......... 6

2.1 Importance of Soil Nitrogen to Crop Productivity.......... 6
2.2 Major Forms of Nitrogen in the Soil.......... 7
2.2.1 Nitrate Nitrogen.......... 7
2.2.2 Ammonium Nitrogen.......... 8
2.3 Nitrogen Supplying Power of Soils.......... 9
2.3.1 Residual Inorganic Soil Nitrogen.......... 9
2.3.1.1 Effect of Water Use Pattern of Previous Crop on Residual Soil Nitrogen.. 10
2.3.1.2 Effect of Moisture Availability on Wheat Rooting Depth.......... 11
2.3.1.3 Effect of Soil Nitrogen Availability on Wheat Rooting Depth.......... 11
2.3.2 Nitrogen Mineralization.......... 12
2.3.2.1 Effect of Temperature on Mineralization.......... 13
2.3.2.2 Effect of Soil Moisture on Mineralization.......... 13
2.3.2.3 Effect of Substrate Availability and Quality on Mineralization.......... 14
2.3.2.4 Crop Residue Quality and Placement.......... 15
2.3.2.5 Nitrogen in Microbial Biomass.......... 16
2.3.3 Fertilizer Nitrogen.......... 17
2.3.3.1 Urea.......... 17
2.3.3.2 Ammonium Nitrate.......... 18
2.3.3.3 Nitrogen Use Efficiency.......... 19
2.4 Physiological Aspects of Nitrogen Uptake.......... 19
2.5 Pattern, Rate, and Duration of Dry Matter Production and Nitrogen Uptake..... 21
2.6 Factors Affecting Nitrogen Uptake.......... 22
2.6.1 Effect of Dry Matter Production on Nitrogen Uptake.......... 23
2.6.2 Effect of Soil Moisture Availability on Nitrogen Uptake.......... 24
2.6.3 Effect of Temperature on Nitrogen Uptake.......... 25

2.7 Effect of Crop Management Practices on Nitrogen Availability and Uptake.... 26
2.7.1 General Effects of Annual Legumes on Wheat Yield, Nitrogen Availability and Nitrogen Uptake.... 26
2.7.2 Nitrogen and Non-Nitrogen Benefits of Annual Legumes.... 27
2.7.3 Direct Nitrogen Benefits of Annual Legumes.... 28
2.7.3.1 Nitrogen Fixation.... 28
2.7.3.2 Nitrogen in Crop Residues.... 29
2.7.4 Indirect Nitrogen Benefits.... 31
2.7.4.1 Conservation of Soil Nitrogen.... 32
2.7.4.2 Increased Nitrogen Uptake from Non-Legume Sources.... 33
2.7.5 Relative Contribution of Nitrogen and Non-Nitrogen Benefits.... 34
2.8 Controlled-Release Fertilizers.... 35
2.8.1 Use of Controlled-Release Urea in Field Crop Production.... 36
2.9 Protein Content.... 37
2.9.1 Relationship Between Yield and Protein Content.... 37
2.9.2 Translocation of Nitrogen and Carbohydrates to the Grain.... 39
2.9.3 Effect of Fertilizer Nitrogen Application Rate on Protein Content.... 40
2.9.4 Effect of Soil Moisture on Protein Content.... 41
2.9.4.1 Effect of Timing of Moisture Stress on Protein Content.... 42
2.9.5 Effect of Temperature on Protein Content.... 43
2.9.6 Effect of Fertilizer Nitrogen Source and Timing on Protein Content.... 43
2.9.6.1 Effect of Delayed Fertilizer Nitrogen Application on Protein Content.... 45
2.10 Influence of Protein Content on End-Use Quality.... 46
2.10.1 Effect of Protein Content on Flour Water Absorption.... 47
2.10.2 Effect of Protein Content on the Rheological Properties of Dough.... 48
2.10.3 Effect of Protein Content on Loaf Volume.... 49
2.11 Protein Quality.... 50
2.12 Protein Classification and Nomenclature.... 50
2.12.1 Albumin and Globulin Fraction.... 52
2.12.2 Characterization of Gliadin.... 52
2.12.3 Characterization of Glutenin.... 53
2.13 Effects of Individual Protein Fractions on Dough Rheological Properties.... 55
2.13.1 Effect of Gliadin on Dough Rheological Properties.... 55
2.13.1.1 Effect of Individual Gliadin Fractions on Dough Rheological Properties 56
2.13.2 Effect of Glutenin on Dough Rheological Properties.... 56
2.13.2.1 Contribution of HMW-GS and LMW-GS to Dough Rheological Properties.... 57
2.13.2.2 Effect of Average Polymer Size on Dough Rheological Properties.... 58
2.14 Effects of Individual Protein Fractions on Loaf Volume.... 59
2.14.1 Effect of Gliadin on Loaf Volume.... 59
2.14.1.1 Effect of Individual Gliadin Fractions on Loaf Volume.... 60
2.14.2 Effect of Glutenin on Loaf Volume.... 61
2.15 Effect of the Ratio of Gliadin to Glutenin on End-Use Quality.... 62
2.16 Protein Accumulation in the Developing Grain.... 63
2.16.1 General Pattern of Protein Accumulation.... 64
2.16.2 Accumulation of Albumin/Globulin Fraction.... 65

2.16.3 Accumulation of Gliadin. 65
2.16.3.1 Accumulation of Individual Gliadin Fractions. 66
2.16.4 Accumulation of Glutenin. 66
2.16.4.1 Synthesis of LMW and HMW Glutenin Subunits. 67
2.16.4.2 Polymerization of Glutenin. 68
2.17 Modification of Protein Composition by Environment and Fertilization. 69
2.17.1 Contribution of Genotype and Environment to Protein Quality. 69
2.17.2 Effect of Increasing Nitrogen Supply on Gliadin Content and Composition. 70
2.17.3 Effect of Increasing Nitrogen Supply on Glutenin Content and Composition 71
2.17.4 Effect of Sulphur Fertility on Protein Composition. 72
2.17.5 Effect of Temperature Stress on Gliadin Composition. 73
2.17.6 Effect of Environment on Glutenin Polymerization. 74

3.0 THE EFFECT OF CROP ROTATION AND FERTILIZER N SOURCE ON SOIL NITROGEN STATUS AND NITROGEN ACCUMULATION OF CANADA WESTERN RED SPRING WHEAT. 77

3.1 Abstract. 77
3.2 Introduction. 78
3.3 Materials and Methods. 81
3.3.1 Field and Analytical Techniques. 83
3.3.2 Statistical Analysis. 87
3.4 Results and Discussion. 88
3.4.1 Soil Water Status During the Growing Season. 88
3.4.2 Soil N Status Prior to Planting. 90
3.4.3 Soil N Status at Anthesis. 93
3.4.4 Soil N Status at Harvest. 94
3.4.5 Evolution of Plant Recoverable N during the Growing Season. 97
3.4.6 Evolution of Apparent Net Mineralized N During the Growing Season. 98
3.4.7 Nitrogen Uptake and Partitioning. 101
3.4.7.1 General Pattern of N Uptake. 101
3.4.7.2 Effect of Previous Crop on N Accumulation Pattern. 106
3.4.7.3 Effect of Fertilizer N Source on N Accumulation Pattern. 107
3.4.8 Harvest Measurements. 110
3.5 Conclusions. 113

4.0 THE EFFECT OF CROP ROTATION AND FERTILIZER N SOURCE ON THE BREADMAKING QUALITY OF CANADA WESTERN RED SPRING WHEAT. 115

4.1 Abstract. 115
4.2 Introduction. 116
4.3 Materials and Methods. 118
4.3.1 Grain Analysis. 119
4.3.2 Milling. 119
4.3.3 Mixograph. 120

4.3.4 Micro-extension Test. 120
4.3.5 Farinograph Absorption and Baking. 121
4.3.6 Statistical Analysis. 121
4.4 Results and Discussion. 122
4.4.1 Effect of Agronomic Practices on Flour Protein Content. 125
4.4.2 Relationships among Quality Attributes. 128
4.4.3 Effect of Previous Crop and Fertilizer Nitrogen Source on End-Use Quality Across a Similar Range of Flour Protein Content. 131
4.5 Conclusions. 141

5.0 THE EFFECT OF NITROGEN MANAGEMENT PRACTICES ON THE PROTEIN COMPOSITION AND TECHNOLOGICAL QUALITY OF CANADA WESTERN RED SPRING WHEAT. 144

5.1 Abstract. 144
5.2 Introduction. 145
5.3 Materials and Methods. 147
5.3.1 Quality Testing 148
5.3.2 Statistical Analysis. 149
5.4 Results and Discussion. 150
5.4.1 Effect of Agronomic Practices on the Quantity of Individual Protein Fractions. 150
5.4.2 Relationships Among Flour Protein Content and Protein Composition Parameters. 157
5.4.3 Relationships Among Quality Attributes. 167
5.4.4 Effect of Previous Crop on End-Use Quality Across a Similar Range of Flour Protein Content. 170
5.5 Conclusions. 174

6.0 GENERAL DISCUSSION AND CONCLUSIONS 176

7.0 REFERENCES. 184

8.0 APPENDICES. 215

8.1 Appendix A – Meteorological Information and Select Agronomic Information for the Carman, Brandon, and Swift Current Experimental Sites. 215
8.2 Appendix B – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Selected Measurements Associated with Dry Matter at the Carman, Brandon, and Swift Current Experimental Sites. 218
8.3 Appendix C – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Tissue N Concentration at the Carman, Brandon, and Swift Current Experimental Sites. 249

8.4 Appendix D – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Selected Measurements Associated with Plant N Yield at the Carman, Brandon, and Swift Current Experimental Sites.... 265
8.5 Appendix E – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Soil NH_4-N and NO_3-N at the Carman, Brandon, and Swift Current Experimental Sites.....................292
8.6 Appendix F – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Soil Water Content at the Carman, Brandon, and Swift Current Experimental Sites............................ 326
8.7 Appendix G – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Selected Harvest Measurements at the Carman, Brandon, and Swift Current Experimental Sites.................355
8.8 Appendix H – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Selected Soil Nitrogen Budget Data at the Carman, Brandon, and Swift Current Experimental Sites............363
8.9 Appendix I –Materials and Methods for the Swift Current Experimental Sites...374
8.10 Appendix J – Materials and Methods for Selected Grain Quality Analyses.... 376
8.11 Appendix K – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Selected Grain And Flour Nitrogen and Sulphur Analyses at the Carman, Brandon, and Swift Current Experimental Sites...383
8.12 Appendix L – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on General End-Use Quality Analyses at the Carman, Brandon, and Swift Current Experimental Sites........ 398
8.13 Appendix M – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Mixograph Analyses at the Carman, Brandon, and Swift Current Experimental Sites....................411
8.14 Appendix N – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Micro-extension Test Analyses at the Carman, Brandon, and Swift Current Experimental Sites................436
8.15 Appendix O – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Baking Quality Analyses at the Carman, Brandon, and Swift Current Experimental Sites....................449
8.16 Appendix P – Analysis of Variance, LSDs, and Contrasts for the Effects of Previous Crop and Fertilizer Nitrogen Treatments on Protein Quality Analyses at the Carman, Brandon, and Swift Current Experimental Sites....................460
8.17 Appendix Q – Results of Correlation Analysis for the Carman, Brandon, and Swift Current Experimental Sites.................................... 481
8.18 Appendix R – Plots of Select End-Use Quality Parameters versus Flour Protein Content for the Carman-00, Swift Current-00, Brandon-01, and Swift Current-01 Sites as Affected by Previous Crop....................................487
8.19 Appendix S – Description of Sampling Methodology and Location of Immature Head Samples Collected at the Carman-00, Carman-01, Brandon-01, and Swift Current-01 Sites...495

8.20 Appendix T – Scatterplots of Select End-Use Quality Parameters versus Select Protein Composition Parameters for the Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 Sites. 496

ACKNOWLEDGMENTS

I would like to gratefully acknowledge the following individuals and institutions that helped make this thesis and research project possible.

Sincere thanks are due to the Canadian Wheat Board, which made it possible for me to return to the University of Manitoba to undertake my Master's Degree in the first place. The other major financial contributors to this project to whom thanks are also extended are the Agriculture and Agri-Food Canada Matching Industry Initiative (AAFC-MII), the Agri-Food Research Development Initiative (ARDI), and Agrium, Inc. Dr. Byron Irvine (Brandon Research Centre) deserves a great deal of credit for securing the funding that made this project possible. Dr. Brian McConkey of the Semiarid Prairie Agricultural Research Centre is also to be commended for joining onto the research project at short notice and for providing strong technical support.

Special thanks go to my advisor, Dr. Don Flaten for his keen interest in this research project, for treating me as an equal, and for making every effort to make this research the best product possible. His attention to detail and organizational skills made this a strong thesis from both an academic and practical standpoint.

Dr. Martin Entz is to be commended for getting this research project off the ground when research funds were scarce. His systems-oriented approach to research was key to the approach we took to this research program.

The involvement of Dr. Harry Sapirstein in the wheat end-use quality aspect of the research was greatly appreciated in terms of lab and labour resource allocation, input to the analytical approaches, and his openness to new ideas.

Without the love and support of my parents I could never have dreamed to getting to the point where I am today. My father instilled in me a strong work ethic, strong attention to detail, and a life-long love for agriculture that I live with and believe in to this day. I will be forever grateful for my mother's encouragement and strong commitment to education. This thesis is dedicated to her memory.

I want to thank my love, Nicole Rosevere, for her unyielding support in good times and bad, for understanding when hours were long and deadlines were short, and for loving me unconditionally. You truly make me a better person.

Finally, my highest and most sincere thanks are to God for giving me the strength and perseverance to see this research through to its conclusion.

LIST OF TABLES

Table Page

3-1. Meteorological Data for the Experimental Sites. 83

3-2. Agronomic Information for the Experimental Sites 84

3-3. Physical and Chemical Soil Characteristics at the Experimental Sites. 85

3-4. Distribution of Estimated NO_3-N (kg ha^{-1}) in the Soil Profile Prior to Planting as Affected by Previous Crop. 91

3-5. Recoverable N (kg ha^{-1}) at Anthesis and Harvest at the Experimental Sites as Affected by Previous Crop and Fertilizer N Treatment. 98

3-6. Apparent Net Mineralized N During the Growing Season as Affected by Previous Crop 100

3-7. Pre-anthesis N uptake, Post-anthesis N uptake, and Per Cent N Uptake Post-Anthesis at the Experimental Sites as Affected by Previous Crop and Fertilizer N Treatment 105

3-8. Grain Yield, Protein Content (14% Moisture Basis), and N Yield (DM Basis) at the Experimental Sites as Affected by Previous Crop and Fertilizer N Treatment. 111

4-1. Meteorological Data for the Experimental Sites. 123

4-2. Selected Quality Attributes of the Experimental Sites. 124

4-3. Flour Protein Content (14% moisture basis) at the Manitoba Experimental Sites as Affected by Previous Crop and Fertilizer N Treatment. 126

4-4. Agronomic Information for the Experimental Sites. 127

4-5. Flour Protein Content (14% moisture basis) at the Swift Current Experimental Sites as Affected by Previous Crop and Fertilizer N Rate. .128

4-6. Coefficients of Correlation (*r*) for Selected Quality Attributes for the Pooled Dataset (n = 110). 130

4-7. Coefficients of Determination (r^2) of the Pooled Dataset for Flour Protein Content (FPC) and Selected Quality Attributes, as well as Degree of Significance for the Interaction between Previous Crop and FPC for the Pooled Dataset and the Pooled Dataset Excluding Swift Current-01 Data. 133

4-8. Coefficients of Determination (r^2) for Pooled Data from the Carman-00 and Brandon-01 Sites for Flour Protein Content (FPC) and Selected Quality Attributes, as well as Degree of Significance for the Interaction between Fertilizer N Source and FPC. 141

5-1. Effect of Previous Crop and N Fertilizer Treatment on Protein Composition at the Carman-00 Site. 151

5-2. Effect of Previous Crop and N Fertilizer Treatment on Protein Composition at the Swift Current-00 Site. 152

5-3. Effect of Previous Crop and N Fertilizer Treatment on Protein Composition at the Carman-01 Site. 153

5-4. Effect of Previous Crop and N Fertilizer Treatment on Protein Composition at the Brandon-01 Site. 154

5-5. Effect of Previous Crop and N Fertilizer Treatment on Protein Composition at the Swift Current-01 Site. 155

5-6. Coefficients of Correlation (*r*) among Selected Protein Composition Parameters for the Pooled Dataset (n = 110). 162

5-7 Summary of the Flour Protein Composition Characteristics of the Experimental Sites. 164

5-8. Coefficients of Correlation (*r*) between Selected Protein Composition Parameters and FPC for the Carman-00, Swift Current-00, Brandon-01, and Swift Current-01 Sites. 165

5-9. Coefficients of Correlation (*r*) among Selected Quality Attributes for the Pooled Dataset (n = 110). 168

5-10. Degree of Significance of the Interaction between Previous Crop and Protein Compositon Parameters for Selected Quality Attributes. 171

5-11. Degree of Significance of the Interaction between Previous Crop and Protein Composition for Selected Protein Composition Parameters 173

LIST OF TABLES IN APPENDIX A

Table Page

A-1. Mean Monthly Air Temperature at the Experimental Sites. 215

A-2. Mean Monthly Precipitation at the Experimental Sites. 215

A-3. Meteorological Data for the Swift Current Experimental Sites. 216

A-4. Agronomic Information for the Swift Current Experimental Sites. 216

A-5. Soil Physical and Chemical Characteristics at the Swift Current-01 Site. 217

LIST OF TABLES IN APPENDIX B

Table Page

B-1. Dry Matter Yield of the Stem/leaf Fraction at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 219

B-2. Dry Matter Yield of the Stem/leaf Fraction 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 220

B-3. Dry Matter Yield of the Stem/leaf Fraction 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 221

B-4. Dry Matter Yield of the Stem/leaf Fraction 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 222

B-5. Dry Matter Yield of the Stem/leaf Fraction 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 223

B-6. Dry Matter Yield of the Stem/leaf Fraction 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 224

B-7. Dry Matter Yield of the Stem/leaf Fraction at Various Sampling Dates at the Swift Current-01 Site. 225

B-8. Dry Matter Yield of the Head Fraction at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 226

B-9. Dry Matter Yield of the Head Fraction 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 227

B-10. Dry Matter Yield of the Head Fraction 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 228

B-11. Dry Matter Yield of the Head Fraction 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 229

B-12. Dry Matter Yield of the Head Fraction 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 230

B-13. Dry Matter Yield of the Head Fraction 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 231

B-14. Dry Matter Yield of the Head Fraction at Various Sampling Dates at the Swift Current-01 Site. 232

B-15. Aboveground Plant Dry Matter Yield at the Flag Leaf Stage at the Carman-00, Carman-01, and Brandon-01 Sites. 233

B-16. Aboveground Plant Dry Matter Yield at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 234

B-17. Aboveground Plant Dry Matter Yield 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 235

B-18. Aboveground Plant Dry Matter Yield 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 236

B-19. Aboveground Plant Dry Matter Yield 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 237

B-20. Aboveground Plant Dry Matter Yield 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 238

B-21. Aboveground Plant Dry Matter Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 239

B-22. Aboveground Plant Dry Matter at various sampling dates at the Swift Current-01 Site. 240

B-23. Aboveground Plant Dry Matter Accumulation between Anthesis and 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 241

B-24. Post-anthesis Aboveground Dry Matter Accumulation as a Percentage of Aboveground Dry Matter Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 242

B-25. Ratio of Head Dry Matter Yield to Aboveground Plant Dry Matter Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 243

B-26. Ratio of Head Dry Matter Yield to Stem/leaf Dry Matter Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 244

B-27. Average Head Mass 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 245

B-28. Average Number of Heads per m^2 35 at the Carman-00, Carman-01, and Brandon-01 Sites 246

B-29. Lodging Score (0-9) at the Carman-00, Carman-01, and Brandon-01 Sites . . . 247

B-30. Select Agronomic Data for the Swift Current-01 Site. 248

LIST OF TABLES IN APPENDIX C

Table Page

C-1. Whole Plant Tissue N Concentration at the Flag Leaf Stage at the Carman-00, Carman-01, and Brandon-01 Sites. 250

C-2. Tissue N Concentration of the Stem/leaf Fraction at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 251

C-3. Tissue N Concentration of the Stem/leaf Fraction 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 252

C-4. Tissue N Concentration of the Stem/leaf Fraction 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 253

C-5. Tissue N Concentration of the Stem/leaf Fraction 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 254

C-6. Tissue N Concentration of the Stem/leaf Fraction 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 255

C-7. Tissue N Concentration of the Stem/leaf Fraction 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 256

C-8. Tissue N Concentration of the Stem/leaf Fraction at Various Sampling Dates at the Swift Current-01 Site. 257

C-9. Tissue N Concentration of the Head Fraction at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 258

C-10. Tissue N Concentration of the Head Fraction 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 259

C-11. Tissue N Concentration of the Head Fraction 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 260

C-12. Tissue N Concentration of the Head Fraction 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 261

C-13. Tissue N Concentration of the Head Fraction 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 262

C-14. Tissue N Concentration of the Head Fraction 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 263

C-15. Tissue N Concentration of the Head Fraction at Various Sampling Dates at the Swift Current-01 Site. 264

LIST OF TABLES IN APPENDIX D

Table Page

D-1. N Yield of the Stem/leaf Fraction at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 266

D-2. N Yield of the Stem/leaf Fraction 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 267

D-3. N Yield of the Stem/leaf Fraction 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 268

D-4. N Yield of the Stem/leaf Fraction 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 269

D-5. N Yield of the Stem/leaf Fraction 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 270

D-6. N Yield of the Stem/leaf Fraction 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 271

D-7. N Yield of the Stem/leaf Fraction at Various Sampling Dates at the Swift Current-01 Site. 272

D-8. N Yield of the Head Fraction at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 273

D-9. N Yield of the Head Fraction 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 274

D-10. N Yield of the Head Fraction 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 275

D-11. N Yield of the Head Fraction 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 276

D-12. N Yield of the Head Fraction 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 277

D-13. N Yield of the Head Fraction 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 278

D-14. N Yield of the Stem/leaf Fraction at Various Sampling Dates at the Swift Current-01 Site. 279

D-15. Aboveground Plant N Yield at the Flag Leaf Stage at the Carman-00, Carman-01, and Brandon-01 Sites 280

D-16. Aboveground Plant N Yield at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 281

D-17. Aboveground Plant N Yield 7 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 282

D-18. Aboveground Plant N Yield 14 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 283

D-19. Aboveground Plant N Yield 21 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 284

D-20. Aboveground Plant N Yield 28 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 285

D-21. Aboveground Plant N Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 286

D-22. Aboveground Plant N Yield at Various Sampling Dates at the Swift Current-01 Site. 287

D-23. Aboveground Plant N Accumulated between 0 and 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 288

D-24. Post-anthesis Aboveground N Accumulation as a Percentage of Aboveground Plant N Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 289

D-25. N Yield of the Head Fraction as a Percentage of Total Aboveground Plant N Yield 35 Days After Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites. 290

D-26. Selected N Uptake Parameters at the Swift Current-01 Site. 291

LIST OF TABLES IN APPENDIX E

Table Page

E-1. Distribution of Estimated NH_4-N (kg ha^{-1}) in the Soil Profile Prior to Planting as Affected by Previous Crop. 293

E-2. Estimated Quantity of NH_4-N in the 0-10 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 294

E-3. Estimated Quantity of NH_4-N in the 10-30 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 295

E-4. Estimated Quantity of NH_4-N in the 30-50 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 296

E-5. Estimated Quantity of NH_4-N in the 50-70 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 297

E-6. Estimated Quantity of NH_4-N in the 70-90 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 298

E-7. Estimated Quantity of NH_4-N in the 90-110 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 299

E-8. Estimated Quantity of NH_4-N in the 0-110 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 300

E-9. Estimated Quantity of NH_4-N at Anthesis at Various Soil Depths at the Swift Current-01 Site 301

E-10. Estimated Quantity of NO_3-N in the 0-10 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 302

E-11. Estimated Quantity of NO_3-N in the 10-30 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 303

E-12. Estimated Quantity of NO_3-N in the 30-50 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 304

E-13. Estimated Quantity of NO_3-N in the 50-70 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 305

E-14. Estimated Quantity of NO_3-N in the 70-90 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 306

E-15. Estimated Quantity of NO_3-N in the 90-110 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 307

E-16. Estimated Quantity of NO_3-N in the 0-110 cm Depth at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 308

E-17. Estimated Quantity of NO_3-N at Anthesis at Various Soil Depths at the Swift Current-01 Site 309

E-18. Estimated Quantity of NH_4-N in the 0-10 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 310

E-19. Estimated Quantity of NH_4-N in the 10-30 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 311

E-20. Estimated Quantity of NH_4-N in the 30-50 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 312

E-21. Estimated Quantity of NH_4-N in the 50-70 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 313

E-22. Estimated Quantity of NH_4-N in the 70-90 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 314

E-23. Estimated Quantity of NH_4-N in the 90-110 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 315

E-24. Estimated Quantity of NH_4-N in the 0-110 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 316

E-25. Estimated Quantity of NH_4-N at Harvest at Various Soil Depths at the Swift Current-01 Site 317

E-26. Estimated Quantity of NO_3-N in the 0-10 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 318

E-27. Estimated Quantity of NO_3-N in the 10-30 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 319

E-28. Estimated Quantity of NO_3-N in the 30-50 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 320

E-29. Estimated Quantity of NO_3-N in the 50-70 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 321

E-30. Estimated Quantity of NO_3-N in the 70-90 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 322

E-31. Estimated Quantity of NO_3-N in the 90-110 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 323

E-32. Estimated Quantity of NO_3-N in the 0-110 cm Depth at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 324

E-33. Estimated Quantity of NO_3-N at Harvest at Various Soil Depths at the Swift Current-01 Site 325

LIST OF TABLES IN APPENDIX F

Table Page

F-1. Volumetric Water Content of the 0-10 cm Depth at the Carman-00 Site. 327

F-2. Volumetric Water Content of the 10-30 cm Depth at the Carman-00 Site. 328

F-3. Volumetric Water Content of the 30-50 cm Depth at the Carman-00 Site...... 329

F-4. Volumetric Water Content of the 50-70 cm Depth at the Carman-00 Site...... 330

F-5. Volumetric Water Content of the 70-90 cm Depth at the Carman-00 Site...... 331

F-6. Volumetric Water Content of the 90-110 cm Depth at the Carman-00 Site..... 332

F-7. Total Soil Water Content in the 0-110 cm Depth at the Carman-00 Site........333

F-8. Volumetric Water Content of the 0-10 cm Depth at the Carman-01 Site....... 334

F-9. Volumetric Water Content of the 10-30 cm Depth at the Carman-01 Site...... 335

F-10. Volumetric Water Content of the 30-50 cm Depth at the Carman-01 Site..... 336

F-11. Volumetric Water Content of the 50-70 cm Depth at the Carman-01 Site..... 337

F-12. Volumetric Water Content of the 70-90 cm Depth at the Carman-01 Site..... 338

F-13. Volumetric Water Content of the 90-110 cm Depth at the Carman-01 Site.... 339

F-14. Total Soil Water Content in the 0-110 cm Depth at the Carman-01 Site.......340

F-15. Volumetric Water Content of the 0-10 cm Depth at the Brandon-01 Site......341

F-16. Volumetric Water Content of the 10-30 cm Depth at the Brandon -01 Site.... 342

F-17. Volumetric Water Content of the 30-50 cm Depth at the Brandon -01 Site.... 343

F-18. Volumetric Water Content of the 50-70 cm Depth at the Brandon -01 Site.... 344

F-19. Volumetric Water Content of the 70-90 cm Depth at the Brandon -01 Site.... 345

F-20. Volumetric Water Content of the 90-110 cm Depth at the Brandon -01 Site... 346

F-21. Total Soil Water Content in the 0-110 cm Depth at the Brandon -01 Site......347

F-22. Volumetric Water Content of the 0-10 cm Depth at the Swift Current-01 Site. .348

F-23. Volumetric Water Content of the 10-30 cm Depth at the Swift Current-01 Site.349

F-24. Volumetric Water Content of the 30-50 cm Depth at the Swift Current-01 Site.350

F-25. Volumetric Water Content of the 50-70 cm Depth at the Swift Current-01 Site. 351

F-26. Volumetric Water Content of the 70-90 cm Depth at the Swift Current-01 Site. 352

F-27. Volumetric Water Content of the 90-110 cm Depth at the Swift Current-01 Site. 353

F-28. Total Soil Water Content in the 0-110 cm Depth at the Swift Current-01 Site. . 354

LIST OF TABLES IN APPENDIX G

Table Page

G-1. Grain Yield (14% moisture basis) at the Carman-00, Carman-01, and Brandon-01 Sites. 356

G-2. Grain Protein Content (14% Moisture Basis) at the Carman-00, Carman-01, and Brandon-01 Sites. 357

G-3. Grain N Yield (14% Moisture Basis) at the Carman-00, Carman-01, and Brandon-01 Sites. 358

G-4. Total Plant N Uptake per Unit Grain Protein Content (Dry Matter Basis) at the Carman-00, Carman-01, and Brandon-01 Sites 359

G-5. Total Grain Yield per Unit Total Plant N Uptake (Dry Matter Basis) at the Carman-00, Carman-01, and Brandon-01 Sites 360

G-6. Grain Yield, Protein Content, and N Yield (14% Moisture Basis) at the Swift Current-01 Site 361

G-7. Grain Yield, Grain Protein Content, Grain N Yield (14% Moisture Basis), Plant N Uptake per Unit Protein Content, and Grain Yield per Unit Total Plant N Uptake (DM basis) at the Swift Current-01 Site 362

LIST OF TABLES IN APPENDIX H

Table Page

H-1. Change in NO_3-N Status in the Soil Profile between Anthesis and Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 364

H-2. Change in NO_3-N Status in the Soil Profile between Planting and Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 365

H-3. Apparent Net Mineralized Nitrogen (NMN) between Planting and Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 366

H-4. Apparent Net Mineralized Nitrogen (NMN) During the Growing Season at the Carman-00, Carman-01, and Brandon-01 Sites 367

H-5. Apparent Net Mineralized Nitrogen (NMN) between Anthesis and Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 368

H-6. Change in NO_3-N Status in the Soil Profile during the Growing Season at the Swift Current-01 Site 369

H-7. Apparent Net Mineralized Nitrogen (NMN) During the Growing Season at the Swift Current-01 Site 370

H-8. Recoverable N at Anthesis at the Carman-00, Carman-01, and Brandon-01 Sites 371

H-9. Recoverable N at Harvest at the Carman-00, Carman-01, and Brandon-01 Sites 372

H-10. Recoverable N at Anthesis and Harvest at the Swift Current-01 Site 373

LIST OF TABLES IN APPENDIX K

Table Page

K-1. Per cent Grain N at the Carman-00, Carman-01, and Brandon-01 Sites 384

K-2. Per cent Grain N at the Swift Current-00 and Swift Current-01 Sites 385

K-3. Per cent Grain S at the Carman-00, Carman-01, and Brandon-01 Sites 386

K-4. Per cent Grain S at the Swift Current-00 and Swift Current-01 Sites 387

K-5. Ratio of Grain N to Grain S at the Carman-00, Carman-01, and Brandon-01 Sites 388

K-6. Ratio of Grain N to Grain S at the Swift Current-00 and Swift Current-01 Sites 389

K-7. Per cent Flour N at the Carman-00, Carman-01, and Brandon-01 Sites 390

K-8. Per cent Flour N at the Swift Current-00 and Swift Current-01 Sites 391

K-9. Per cent Flour S at the Carman-00, Carman-01, and Brandon-01 Sites 392

K-10. Per cent Flour S at the Swift Current-00 and Swift Current-01 Sites 393

K-11. Ratio of Flour N to Flour S at the Carman-00, Carman-01, and Brandon-01 Sites 394

K-12. Ratio of Flour N to Flour S at the Swift Current-00 and Swift Current-01 Sites 395

K-13. Flour Protein Content (14% Moisture Basis) at the Carman-00, Carman-01, and Brandon-01 Sites. 396

K-14. Flour Protein Content (14% Moisture Basis) at the Swift Current-00 and Swift Current-01 Sites. 397

LIST OF TABLES IN APPENDIX L

Table Page

L-1. Grain test weight (kg hl^{-1}) at the Carman-00, Carman-01, and Brandon-01 Sites. 399

L-2. Grain test weight (kg hl^{-1}) at the Swift Current-00 and Swift Current-01 Sites. . 400

L-3. Thousand kernel weight (g) at the Carman-00, Carman-01, and Brandon-01 Sites. 401

L-4. Thousand kernel weight (g) at the Swift Current-00 and Swift Current-01 Sites. 402

L-5. SDS Sedimentation Value (ml) at the Carman-00, Carman-01, and Brandon-01 Sites. 403

L-6. Per cent Fusarium-damaged Kernels at the Carman-00, Carman-01, and Brandon-01 Sites. 404

L-7. Grain Deoxynivalenol Content (Parts per Million) at the Carman-00, Carman-01, and Brandon-01 Sites. 405

L-8. Flour Deoxynivalenol Content (Parts per Million) at the Carman-00, Carman-01, and Brandon-01 Sites. 406

L-9. Particle Size Index (%) at the Carman-00, Carman-01, and Brandon-01 Sites. . 407

L-10. Particle Size Index (%) at the Swift Current-00 and Swift Current-01 Sites. . . .408

L-11. Milling Yield (%) at the Carman-00, Carman-01, and Brandon-01 Sites. 409

L-12. Milling Yield (%) at the Swift Current-00 and Swift Current-01 Sites. 410

LIST OF TABLES IN APPENDIX M

Table Page

M-1. Mixograph Dough Development Time (min) at the Carman-00, Carman-01, and Brandon-01 Sites. 412

M-2. Mixograph Dough Development Time (min) at the Swift Current-00 and Swift Current-01 Sites. 413

M-3. Mixograph Peak Dough Resistance (% torque) at the Carman-00, Carman-01, and Brandon-01 Sites. 414

M-4. Mixograph Peak Dough Resistance (% torque) at the Swift Current-00 and Swift Current-01 Sites. 415

M-5. Mixograph Work Input to Peak (% torque*min) at the Carman-00, Carman-01, and Brandon-01 Sites. 416

M-6. Mixograph Work Input to Peak (% torque*min) at the Swift Current-00 and Swift Current-01 Sites. 417

M-7. Mixograph Peak Band Width (% torque) at the Carman-00, Carman-01, and Brandon-01 Sites. 418

M-8. Mixograph Peak Band Width (% torque) at the Swift Current-00 and Swift Current-01 Sites. 419

M-9. Mixograph Dough Breakdown Resistance at the Carman-00, Carman-01, and Brandon-01 Sites. 420

M-10. Mixograph Dough Breakdown Resistance at the Swift Current-00 and Swift Current-01 Sites. 421

M-11. Mixograph Dough Strength Index at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 422

M-12. Mixograph Dough Strength Index at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 423

M-13. Mixograph Dough Development Time (min) at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 424

M-14. Mixograph Dough Development Time (min) at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 425

M-15. Mixograph Peak Dough Resistance (% torque) at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 426

M-16. Mixograph Peak Dough Resistance (% torque) at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 427

M-17. Mixograph Work Input to Peak (% torque*min) at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 428

M-18. Mixograph Work Input to Peak (% torque*min) at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 429

M-19. Mixograph Peak Band Width (% torque) at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 430

M-20. Mixograph Peak Band Width (% torque) at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 431

M-21. Mixograph Dough Breakdown Resistance at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 432

M-22. Mixograph Dough Breakdown Resistance at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 433

M-23. Mixograph Dough Strength Index at the Carman-00, Carman-01, and Brandon-01 Sites (with the Addition of 2% Salt). 434

M-24. Mixograph Dough Strength Index at the Swift Current-00 and Swift Current-01 Sites (with the Addition of 2% Salt). 435

LIST OF TABLES IN APPENDIX N

Table Page

N-1. Maximum Dough Resistance to Extension (Rmax) at the Carman-00, Carman-01, and Brandon-01 Sites. 437

N-2. Maximum Dough Resistance to Extension (Rmax) at the Swift Current-00 and Swift Current-01 Sites. 438

N-3. Dough Extensibility at Rmax (E_{Rmax}) at the Carman-00, Carman-01, and Brandon-01 Sites. 439

N-4. Dough Extensibility at Rmax (E_{Rmax}) at the Swift Current-00 and Swift Current-01 Sites. 440

N-5. Extensigram Area at the Carman-00, Carman-01, and Brandon-01 Sites. 441

N-6. Extensigram Area at the Swift Current-00 and Swift Current-01 Sites. 442

N-7. Dough Extensibility at Point of Dough Rupture (E) at the Carman-00, Carman-01, and Brandon-01 Sites. 443

N-8. Dough Extensibility at Point of Dough Rupture (E) at the Swift Current-00 and Swift Current-01 Sites. 444

N-9. Ratio of Rmax to E_{Rmax} at the Carman-00, Carman-01, and Brandon-01 Sites. . 445

N-10. Ratio of Rmax to E_{Rmax} at the Swift Current-00 and Swift Current-01 Sites. . . 446

N-11. Ratio of Rmax to E at the Carman-00, Carman-01, and Brandon-01 Sites. 447

N-12. Ratio of Rmax to E at the Swift Current-00 and Swift Current-01 Sites. 448

LIST OF TABLES IN APPENDIX O

Table Page

O-1. Farinograph Absorption (%) at the Carman-00, Carman-01, and Brandon-01 Sites. 450

O-2. Farinograph Absorption (%) at the Swift Current-00 and Swift Current-01 Sites. 451

O-3. GRL Mixer Dough Mixing Time (min) at the Carman-00, Carman-01, and Brandon-01 Sites. 452

O-4. GRL Mixer Dough Mixing Time (min) at the Swift Current-00 and Swift Current-01 Sites. 453

O-5. GRL Mixer Work Input (Whr kg^{-1}) at the Carman-00, Carman-01, and Brandon-01 Sites. 454

O-6. GRL Mixer Work Input (Whr kg^{-1}) at the Swift Current-00 and Swift Current-01 Sites. 455

O-7. Loaf Volume (cm^3) at the Carman-00, Carman-01, and Brandon-01 Sites. 456

O-8. Loaf Volume (cm^3) at the Swift Current-00 and Swift Current-01 Sites. 457

O-9. Loaf volume per Unit flour Protein Content at the Carman-00, Carman-01, and Brandon-01 Sites. 458

O-10. Loaf volume per Unit flour Protein Content at the Swift Current-00 and Swift Current-01 Sites. 459

LIST OF TABLES IN APPENDIX P

Table Page

P-1. Quantity (% of Flour) of 50% 1-propanol Soluble Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 461

P-2. Quantity (% of Flour) of 50% 1-propanol Soluble Protein at the Swift Current-00 and Swift Current-01 Sites. 462

P-3. Quantity (% of Flour) of 50% 1-propanol Soluble Protein as a Percentage of Total Flour Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 463

P-4. Quantity (% of Flour) of 50% 1-propanol Soluble Protein as a Percentage of Total Flour Protein at the Swift Current-00 and Swift Current-01 Sites. 464

P-5. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin at the Carman-00, Carman-01, and Brandon-01 Sites. 465

P-6. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin at the Swift Current-00 and Swift Current-01 Sites. 466

P-7. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin as a Percentage of Total Flour Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 467

P-8. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin as a Percentage of Total Flour Protein at the Swift Current-00 and Swift Current-01 Sites. 468

P-9. Quantity (% of Flour) of 50% 1-propanol Insoluble Residue Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 469

P-10. Quantity (% of Flour) of 50% 1-propanol Insoluble Residue Protein at the Swift Current-00 and Swift Current-01 Sites. 470

P-11. Quantity (% of Flour) of 50% 1-propanol Insoluble Residue Protein as a Percentage of Total Flour Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 471

P-12. Quantity (% of Flour) of 50% 1-propanol Insoluble Residue Protein as a Percentage of Total Flour Protein at the Swift Current-00 and Swift Current-01 Sites. 472

P-13. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin at the Carman-00, Carman-01, and Brandon-01 Sites. 473

P-14. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin at the Swift Current-00 and Swift Current-01 Sites. 474

P-15. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin as a Percentage of Total Flour Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 475

P-16. Quantity (% of Flour) of 50% 1-propanol Insoluble Glutenin as a Percentage of Total Flour Protein at the Swift Current-00 and Swift Current-01 Sites. 476

P-17. Ratio of 50% 1-propanol Soluble Protein to 50% 1-propanol Insoluble Glutenin at the Carman-00, Carman-01, and Brandon-01 Sites. 477

P-18. Ratio of 50% 1-propanol Soluble Protein to 50% 1-propanol Insoluble Glutenin at the Swift Current-00 and Swift Current-01 Sites. 478

P-19. Ratio of 50% 1-propanol Soluble Protein to 50% 1-propanol Insoluble Protein at the Carman-00, Carman-01, and Brandon-01 Sites. 479

P-20. Ratio of 50% 1-propanol Soluble Protein to 50% 1-propanol Insoluble Protein at the Swift Current-00 and Swift Current-01 Sites. 480

LIST OF TABLES IN APPENDIX Q

Table Page

Q-1. Significant Coefficients of Correlation (*r*) for Selected Quality Attributes for the Carman-00 Dataset (n = 40). 482

Q-2. Significant Coefficients of Correlation (*r*) for Selected Quality Attributes for the Swift Current-00 Dataset (n = 18). 483

Q-3. Significant Coefficients of Correlation (*r*) for Selected Quality Attributes for the Carman-01 Dataset (n = 40). 484

Q-4. Significant Coefficients of Correlation (*r*) for Selected Quality Attributes for the Brandon-01 Dataset (n = 40). 485

Q-5. Significant Coefficients of Correlation (*r*) for Selected Quality Attributes for the Swift Current-01 Dataset (n = 18). 486

LIST OF FIGURES

Figure Page

3-1. Evolution of Soil Volumetric Water Content in the Soil Profile at the Carman-00, Carman-01, and Brandon-01 Sites. 89

3-2. Estimated NO_3-N (kg ha^{-1}) in the Soil Profile at Anthesis as Affected by Previous Crop. 95

3-3. Estimated NO_3-N (kg ha^{-1}) in the Soil Profile at Harvest as Affected by Previous Crop. 96

3-4. Plant N Accumulation of the Stem/leaf, Head, and Total Aboveground Plant Fractions during the Growing Season at the Carman-00 Site as Influenced by Previous Crop. 102

3-5. Plant N Accumulation of the Stem/leaf, Head, and Total Aboveground Plant Fractions during the Growing Season at the Carman-01 Site as Influenced by Previous Crop. 103

3-6. Plant N Accumulation of the Stem/leaf, Head, and Total Aboveground Plant Fractions during the Growing Season at the Brandon-01 Site as Influenced by Previous Crop. 104

3-7. Total Aboveground Plant N Accumulation during the Growing Season at the Carman-00, Carman-01, and Brandon-01 Sites as Influenced by Fertilizer N Source 108

4-1. Effect of Previous Crop on Mixograph Dough Development Time (A) and Work Input-To-Peak (B). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 134

4-2. Effect of Previous Crop on Mixograph Strength Index (A) and Dough Extensibility (B). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis 135

4-3. Effect of Previous Crop on Farinograph Water Absorption (A) and Loaf Volume (B). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 136

5-1. Effect of Previous Crop on Flour Soluble Protein Content (A) and Insoluble Glutenin Content (B). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 158

5-2. Effect of Previous Crop on Flour Residue Protein Content (A) and Insoluble Protein Content (B). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 159

5-3. Effect of Previous Crop on the Ratio of Soluble Protein to Insoluble Glutenin (A) and the Ratio of Soluble Protein to Insoluble Protein (B). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 160

5-4. Effect of Previous Crop on Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) as a Proportion of Total Flour Protein Content. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 161

LIST OF FIGURES IN APPENDIX R

Figure Page

R-1. Effect of Previous Crop on Mixograph Peak Dough Resistance. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 488

R-2. Effect of Previous Crop on Mixograph Peak Band Width. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 489

R-3. Effect of Previous Crop on Dough Breakdown Resistance. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 490

R-4. Effect of Previous Crop on Dough Maximum Resistance to Extension. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 491

R-5. Effect of Previous Crop on Dough Extensibility at Rmax. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 492

R-6. Effect of Previous Crop on Extensigram Area. Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 493

R-7. Effect of Previous Crop on Dough Visco-elastic ratio (Rmax/E). Closed Symbols Represent Flax/durum Stubble while Open Symbols Represent Pea Stubble. Data are Plotted for Carman-00, Swift Current-00, Brandon-01, and Swift Current-01. The Independent Variable is Flour Protein Content. Data Falling Outside the Common Range of Flour Protein Content were Excluded from Analysis. 494

LIST OF FIGURES IN APPENDIX T

Figure Page

T-1. Scatterplots of Mixograph Dough Development Time versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 497

T-2. Scatterplots of Mixograph Dough Development Time versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 498

T-3. Scatterplots of Mixograph Dough Development Time versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 499

T-4. Scatterplots of Mixograph Peak Dough Resistance versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 500

T-5. Scatterplots of Mixograph Peak Dough Resistance versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 501

T-6. Scatterplots of Mixograph Peak Dough Resistance versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 502

T-7. Scatterplots of Mixograph Work Input-to-Peak versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 503

T-8. Scatterplots of Mixograph Work Input-to-Peak versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 504

T-9. Scatterplots of Mixograph Work Input-to-Peak versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 505

T-10. Scatterplots of Mixograph Peak Bandwidth versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 506

T-11. Scatterplots of Mixograph Peak Bandwidth versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 507

T-12. Scatterplots of Mixograph Peak Bandwidth versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 508

T-13. Scatterplots of Mixograph Breakdown Resistance versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 509

T-14. Scatterplots of Mixograph Breakdown Resistance versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 510

T-15. Scatterplots of Mixograph Breakdown Resistance versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01 511

T-16. Scatterplots of Mixograph Dough Strength Index versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 512

T-17. Scatterplots of Mixograph Dough Strength Index versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 513

T-18. Scatterplots of Mixograph Dough Strength Index versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 514

T-19. Scatterplots of Dough Maximum Resistance to Extension (Rmax) versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 515

T-20. Scatterplots of Dough Maximum Resistance to Extension (Rmax) versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. . . . 516

T-21. Scatterplots of Dough Maximum Resistance to Extension (Rmax) versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 517

T-22. Scatterplots of Dough Extensibility at Rmax versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 518

T-23. Scatterplots of Dough Extensibility at Rmax versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 519

T-24. Scatterplots of Dough Extensibility at Rmax versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 520

T-25. Scatterplots of Extensigram Area versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. . . . 521

T-26. Scatterplots of Extensigram Area versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 522

T-27. Scatterplots of Extensigram Area versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 523

T-28. Scatterplots of Extensibility at Dough Rupture versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 524

T-29. Scatterplots of Extensibility at Dough Rupture versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 525

T-30. Scatterplots of Extensibility at Dough Rupture versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 526

T-31. Scatterplots of the Ratio of Dough Extensibility to Rmax versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 527

T-32. Scatterplots of the Ratio of Dough Extensibility to Rmax versus Soluble Protein (A), Insoluble Glutenin (B), Residue Protein (C), and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 528

T-33. Scatterplots of the Ratio of Dough Extensibility to Rmax versus Flour Protein Content (A), the Ratio of Soluble Protein to Insoluble Glutenin (B), and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00, Swift Current-00, Carman-01, Brandon-01, and Swift Current-01. 529

T-34. Scatterplots of Farinograph Water Absorption versus Soluble Protein (A). Insoluble Glutenin (B). Residue Protein (C). and Insoluble Protein (D) Content. Data are Plotted for Carman-00. Swift Current-00. Carman-01. Brandon-01. and Swift Current-01 . . . 530

T-35. Scatterplots of Farinograph Water Absorption versus Soluble Protein (A). Insoluble Glutenin (B). Residue Protein (C). and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00. Swift Current-00. Carman-01. Brandon-01. and Swift Current-01 . . . 531

T-36. Scatterplots of Farinograph Water Absorption versus Flour Protein Content (A). the Ratio of Soluble Protein to Insoluble Glutenin (B). and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00. Swift Current-00. Carman-01. Brandon-01. and Swift Current-01 . . . 532

T-37. Scatterplots of Loaf Volume versus Soluble Protein (A). Insoluble Glutenin (B). Residue Protein (C). and Insoluble Protein (D) Content. Data are Plotted for Carman-00. Swift Current-00. Carman-01. Brandon-01. and Swift Current-01 . . . 533

T-38. Scatterplots of Loaf Volume versus Soluble Protein (A). Insoluble Glutenin (B). Residue Protein (C). and Insoluble Protein (D) Content as a Proportion of Total Flour Protein Content. Data are Plotted for Carman-00. Swift Current-00. Carman-01. Brandon-01. and Swift Current-01 . . . 534

T-39. Scatterplots of Loaf Volume versus Flour Protein Content (A). the Ratio of Soluble Protein to Insoluble Glutenin (B). and the Ratio of Soluble Protein to Insoluble Protein (C). Data are Plotted for Carman-00. Swift Current-00. Carman-01. Brandon-01. and Swift Current-01 . . . 535

ABSTRACT

Przednowek, David William Andrew. M. Sc., The University of Manitoba, January, 2003. The Effect of Pulse Crop Rotation and Controlled-Release Urea on the Nitrogen Accumulation and End-Use Quality of Canada Western Red Spring Wheat.
Professor; Donald N. Flaten.

The main goal of this study was to evaluate the effect of pulse crop rotation and controlled-release urea (CRU) on soil nitrogen (N) status and N accumulation of Canada Western Red Spring (CWRS) wheat. Spring wheat (*Triticum aestivum* L. cv. AC Barrie) was grown at Carman and Brandon, MB, on field pea (*Pisum sativum* L.) and flax (*Linum usitatissimum* L.) stubble at three rates (0, 30, and 90 kg N ha^{-1}) of N from two fertilizer N sources, ammonium nitrate (AN) and CRU, a polyurethane-coated urea with an N content of 43 per cent. Wheat was grown at Swift Current, SK, on field pea and durum wheat stubble at three rates of N (34, 50, and 78 kg N ha^{-1}) based on soil test recommendations. The effect of previous crop on N uptake pattern was more consistent than the effect of fertilizer N source. Significantly higher soil NO_3-N at planting on field pea stubble at two of three Manitoba sites resulted in higher wheat plant and grain N yield. Contrary to a number of similar western Canadian studies, apparent net mineralized N during the growing season and per cent post-anthesis N uptake were higher for what grown on flax stubble (F-W) compared to wheat grown on field pea stubble (P-W) at the two sites; the result was attributed to rapid N mineralization following field pea harvest. Wheat end-use quality was assessed with the Mixograph, dough micro-extension tests, and the Canadian Short Process bake test. At the same flour protein content (FPC), flour from wheat grown on field pea stubble had significantly lower Mixograph work input-to peak and dough strength index, as well as shorter dough

development time at FPC < 14 per cent. Samples from Swift Current in 2001 produced much weaker, more extensible dough than samples from the other four site years, indicating that growing season conditions can have a pronounced effect on end-use quality. A protein extraction method based on the differential solubility of flour protein in 50 per cent 1-propanol yielding soluble protein, insoluble glutenin, and residue protein was used to evaluate flour protein composition. As a proportion of total FPC, each protein fraction quantified remained relatively stable as N supply and FPC increased. Unexplainable differences in protein composition among site years were also observed. Protein composition could not be used to explain the differences in end-use quality attributed to previous crop and environment; a more precise method such as size exclusion-high performance liquid chromatography (SE-HPLC) might provide more useful information in explaining differences in end-use quality.

FOREWARD

This thesis has been prepared in manuscript format as described in the Department of Plant Science guidelines. The Canadian Journal of Plant Science is used as the referencing style in this document. Chapter 3 will be submitted to the Canadian Journal of Plant Science for publishing, while Chapter 4 and 5 will be submitted to Cereal Chemistry. I will be head author for both papers, and co-authorship will be designated accordingly.

2.0 LITERATURE REVIEW

2.1 Importance of Soil Nitrogen to Crop Productivity

Nitrogen (N) is the most frequently limiting nutrient to crop production (Havlin et al. 1999). Soils are more commonly deficient in N than any other nutrient (Salisbury and Ross 1992). While N on a plant weight basis represents a very small portion of total dry weight, it is critical to plant function, since over 90% of N in the wheat plant is found as protein (Borghi 1999). N is a key component of proteins, chlorophyll, enzymes, and amino acids, is essential for carbohydrate utilization (Olson and Kurtz 1982), and plays a key role in metabolic processes (Havlin et al. 1999). Given the critical nature of N in higher plants, an understanding of crop N requirements is important when considering yield goals.

When the Prairies were first cultivated, crop yield responses to N were not observed, since inherent soil N fertility was high (Cowell and Doyle 1993a). Yield responses to N fertilizer were first observed in western Canada on a greater scale in the 1950s, although N fertilization had little effect on wheat PC (Hedlin et al. 1957). Since 1970, wheat and barley yield responses to N fertilizer have averaged 40% or more in Manitoba, and 35% or more in Saskatchewan (Cowell and Doyle 1993a). The importance of N fertilization to increased crop productivity has grown to a point where N fertilizers are applied regularly and in large quantities.

2.2 Major Forms of Nitrogen in the Soil

The amount of N available to plants depends not only on total soil N content, but also the forms of soil N. The two major types of N in soil are organic N and inorganic N. Organic N refers to N present as proteins, amino acids, and amino sugars, all of which are found in soil organic matter (SOM). Organic N is estimated to represent 90 to 95% of total soil N (Havlin et al. 1999; Stevenson 1982), and is not readily available to plants. Therefore, organic N must be converted to an inorganic form via mineralization in order to facilitate plant uptake.

The six forms of inorganic N in the soil are ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitrous oxide (N_2O), nitric oxide (NO), and elemental N (N_2) (Young and Aldag 1982). With respect to the N nutrition of higher plants NO_3^- and NH_4^+ are the most important inorganic forms of soil N, since they exist in a readily available form for plant uptake.

2.2.1 Nitrate Nitrogen

The amount of NO_3^- available for plant uptake depends on the concentration of NO_3^- in the soil, which in turn depends in part on the availability of fertilizer N. Availability of NO_3^- also depends on mineralization and the subsequent conversion of NH_4^+ to NO_3^- via nitrification. Wheat takes up more NO_3^- than NH_4^+, except in the case of waterlogged conditions or where high levels of NH_4^+–containing fertilizers are applied (Borghi 1999). Since NO_3^- is readily mobile and does not adhere to soil particles, NO_3^- is readily carried along by water via mass flow to satisfy the transpirational demands of the plant (Olson and Kurtz 1982). Although the movement of NO_3^- to the plant roots depends on plant water demand, NO_3^- uptake is a highly regulated process that depends on soil NO_3^- concentration and plant metabolic processes (Tourraine and Gojon 2001).

2.2.2 Ammonium Nitrogen

Like NO_3^-, NH_4^+ is an inorganic form of N that can be supplied via the addition of fertilizer N or through mineralization. Because NH_4^+ is positively charged and soil is negatively charged, NH_4^+ can be retained on the surfaces of soil colloids at points called exchange sites (Nommik and Vahtras 1982). Ammonium held on soil colloids in this manner is still reasonably readily available to plants and is protected from leaching. While NH_4^+ is preferentially absorbed when ample supplies of NO_3^- and NH_4^+ are available to the root surface (Olson and Kurtz 1982), NH_4^+ does not move readily with water through soil since it is held on exchange sites.

Conversely, non-exchangeable NH_4^+ is not readily available for plant uptake. The ability of the soil to fix NH_4^+ in this manner depends in part on the presence of 2:1 clay minerals (Nommik and Vahtras 1982). Along with potassium (K^+), NH_4^+ saturates the interlayers of 2:1 clay minerals, causing the collapse of the interior layers and trapping the K^+ and NH_4^+ ions. Although the proportion of non-exchangeable NH_4^+ in the soil is typically high in western Canada, its release over time is slow (Havlin et al. 1999). Therefore, exchangeable NH_4^+ is the NH_4^+ form of primary interest when evaluating plant N availability.

2.3 Nitrogen Supplying Power of Soils

Total plant-available N supply is strongly related to yield (Soper and Huang 1963; Soper et al. 1971) and N uptake (Alkier et al. 1972; Olson et al. 1976; Sanford and Hairston 1984). For non-leguminous crops, there are three major sources of plant-available N during the growing season, namely residual inorganic nitrogen in the soil at seeding, mineralization of organic N during the growing season, and the application of organic or inorganic N-fertilizers (McGill 1967; Schoenau 1995). The relative contribution of each of these three N sources to total plant N uptake depends on crop management and environmental factors, and varies throughout the growing season.

2.3.1 Residual Inorganic Soil Nitrogen

Residual soil N is defined as N that is not utilized by the crop in a given season and which carries over to the period of growth of the succeeding crop (Broadbent 1984). The amount of residual N available at planting can represent an important source of N for a crop during the growing season, and has been positively related to yield and N uptake in many studies involving cereals (McGill et al. 1967; Olson et al. 1976; Rhoads 1984; Soper and Huang 1963; Stanford and Legg 1984). In semiarid and subhumid areas such as western Canada and the U.S. Great Plains, residual soil N is an important consideration when planning a fertilizer management program, since the likelihood of removal of NO_3^- from the profile during the fall and winter as a result of leaching or denitrification is relatively low (Stanford 1982).

2.3.1.1 Effect of Water Use Pattern of Previous Crop on Residual Soil Nitrogen

The amount of residual soil N available to a crop at seeding is in part related to the rooting depth of the previous crop. In a recent review of crop water usage in western Canada, Johnston et al. (1996) reported spring wheat rooted to a depth of 91 to 130 cm, although the majority of wheat roots are typically found in the top 60 cm (Campbell et al. 1977a). Bauer et al. (1989) found almost no available water in the upper 90 cm of soil at harvest after spring wheat was grown, and that some available water remained at depths greater than three feet. When wheat is grown in semiarid environments, it is expected to exhaust the soil water in at least the top 60 to 90 cm.

Since wheat does not typically follow wheat in rotation, the rooting depth of other crops grown prior to wheat is of great consideration with respect to residual N levels. Johnston et al. (1996) reported flax rooted to a depth of 61 to 76 cm, and field pea rooted to a depth of 61 to 100 cm. Campbell and Zentner (1996) found flax left more soil N and water below a depth of 60 cm compared to wheat, while Lafond et al. (1992) reported that spring wheat grown on pea stubble had more available water at a depth of 60 to 120 cm compared to spring wheat grown on cereal stubble. Miller et al. (1998a) observed significantly lower water usage by field pea compared to spring wheat in a soil profile of 0-120 cm, but especially at the 60-90 cm and 90-120 cm depths. Miller et al. (2002b) reported that between 60 and 120 cm, plots sown to field pea and dry bean held 7 and 10 mm more water, respectively, than wheat stubble. Crops will not extract NO_3^- at a depth below the rooting zone; therefore shallow-rooted crops may leave more residual soil N than deep-rooted crops.

2.3.1.2 Effect of Moisture Availability on Wheat Rooting Depth

Plant N uptake depends on mass flow. Crops will extract the greatest amount of water (along with NO_3^-) from areas where the rooting density is the greatest. For a given crop, rooting depth is expected to vary from year to year, since crop water demand is a function of dry matter yield, which in turn is positively related to N uptake (Clarke et al. 1990; Sanford and Hairston 1984). Dry matter production increases in response to increasing water availability by increasing shoot and root dry mass (Campbell et al. 1993; Nuttall et al. 1979; Rhoads 1984; Steppuhn and Zentner 1987). Under drier conditions, plants develop a more extensive and intricate root morphology in order to take advantage of soil water throughout the soil profile compared to plants grown under ideal moisture conditions (Sharma and Ghildyal 1977). Wheat that is subjected to excessive moisture conditions during the vegetative phase of development develops a shallower root system and may not necessarily take advantage of N available at deeper depths.

2.3.1.3 Effect of Soil Nitrogen Availability on Wheat Rooting Depth

Increased plant N availability also increases water usage in response to crop demand (Black et al. 1982; Bond et al. 1971; Brown 1971; Campbell et al. 1993). N-fertilized wheat does not necessarily root deeper, but instead extracts a greater amount of soil water from the same soil depth compared to unfertilized wheat. Rapid growth early during plant development allows the root system move deeper into the profile and increase in density, particularly at shallower depths (Borghi 1999). When soil moisture is limiting in the upper soil profile, particularly later in the growing season in semiarid environments, NO_3^- present in significant quantities deeper in the soil profile can be a significant source of plant N as the plant utilizes water at deeper depths (Cochran et al. 1978; Lotfollahi et al. 1997).

2.3.2 Nitrogen Mineralization

The amount N available to a crop as a result of mineralization is difficult to quantify (Schoenau 1995; Thicke et al. 1993), since its contribution to plant-available N is variable and depends on a number of environmental and crop management factors (El-Haris et al. 1983; Jansson and Persson 1982; Schoenau 1995; Stanford and Smith 1972). A thorough understanding of the contribution of mineralization to the N-supplying power of soils is essential in making informed crop management decisions.

N mineralization is defined as the transformation of N from the organic state into NH_4^+ or NH_3 (Jansson and Persson 1982). Mediated by heterotrophic soil microorganisms, mineralization proceeds in two steps (Havlin et al. 1999). Aminization is the first step of mineralization, where soil-derived proteins are broken down into secondary organic N compounds such as amino acids, amines, and urea. Ammonification, the second step of mineralization, is the conversion of secondary organic N compounds to NH_4^+ or NH_3.

Immobilization, defined as the transformation of inorganic N compounds (NH_4^+, NH_3, NO_3^-, NO_2^-) into the organic state (Jansson and Persson 1982), proceeds at the same time as mineralization. Therefore, the relative rate and balance of mineralization and immobilization influences plant-availability of N. Mineralization may generate large quantities of inorganic N, but if immobilization is proceeding at a similar rate, plant N availability attributed to mineralization may appear to be low.

2.3.2.1 Effect of Temperature on Mineralization

The two major environmental factors that influence the rate of mineralization are temperature and soil moisture (Cassman and Munn 1980; Havlin et al. 1999; Schoenau 1995). Generally, a rise in temperature results in an increase in mineralization (Biederbeck and Campbell 1973; Campbell and Biederbeck 1972; Cassman and Munn 1980). Furthermore, Biederbeck and Campbell (1973) observed that microbial activity was considerably higher at constant temperature compared to diurnally fluctuating temperatures. The importance of temperature to the contribution of mineralization to soil N-supplying power is especially relevant to western Canada, since in the spring, soils take longer to warm up relative to areas with higher average ambient temperatures. In evaluating the contribution of mineralization to soil N supply in southern Manitoba, McGill (1967) determined that 60% of spring wheat N uptake occurred before mineralization had even started.

2.3.2.2 Effect of Soil Moisture on Mineralization

Soil moisture exerts a significant influence on mineralization, since soil moisture regulates the relative proportions of aerobic and anaerobic soil activity (Havlin et al. 1999). As the proportion of anaerobic activity increases as a result of excessive soil moisture, microbial efficiency decreases. Dry soils also have low levels of microbial activity. In a laboratory incubation experiment, Cassman and Munn (1980) found that as soil water content decreased, N mineralization decreased in a linear fashion. Furthermore, Jowkin and Schoenau (1995) observed significantly higher plant N availability in chemical fallow plots in the absence of a crop as a result of higher soil moisture levels compared to conventional fallow plots.

Since the majority of soil microbial activity is concentrated near the soil surface, and since soil moisture in the upper soil profile is quickly utilized early in the growing season, topsoil moisture availability later in the growing season influences the contribution of late season mineralization to plant N availability. In an experiment carried out with winter wheat in Georgia, the contribution of mineralization to plant N supply increased as the season progressed, due largely to favorable topsoil moisture conditions during the filling period (Harper et al. 1987).

2.3.2.3 Effect of Substrate Availability and Quality on Mineralization

The carbon to nitrogen ratio (C/N ratio) has been widely used to characterize the quality of organic materials added to soils, since it determines in part whether net mineralization or immobilization occurs (Grenier 1992; Jansson and Persson 1982; Janzen and Kucey 1988; Mooleki et al. 1997). A C/N ratio of 20:1 is considered to be the dividing line between whether mineralization or immobilization will occur, although other estimates range from 25:1 or 30:1 (Smith and Peterson 1982, cited in Grenier 1992). Residue N concentration (Janzen and Kucey 1988; Rees et al. 1993) and biochemical composition (Fox et al. 1990, cited in Fu et al. 1999) have also been used to evaluate residue quality. Understanding the dynamics of N timing and availability from plant residues is a critical consideration in managing soil N fertility.

When residues are added to soil, soil microbial activity is stimulated due to the increase in the amount of available carbon. Addition of grain straw, which typically has a C/N ratio of 80:1 (Havlin et al. 1999) usually results in an initial net reduction of plant available N (immobilization), since there is a lack of N relative to carbon to meet the nutritional demands of the microbial population (Schoenau 1995). Conversely, legume residues have a lower C/N ratio compared to cereal residues (Bremer and van Kessel 1992; Janzen and Kucey 1988; Ladd et al. 1983). The C/N ratio of legume residue is in the range of 11:1 (Ladd et al. 1983) to 37:1 (Janzen and Kucey 1988), depending on soil N status and whether the residue added is fresh or mature. Residues with a low C/N ratio usually result in net N mineralization, in turn increasing N availability.

The C/N ratio is also an indicator of the length of time required until a portion of the residue N is made available, which in turn affects the temporal distribution of residue N availability. Upon residue addition, N is made available from residues with a low C/N ratio more quickly compared to residues with a high C/N ratio, resulting in net initial mineralization (Havlin et al. 1999). Mooleki et al. (1997) observed that at three of four sites in Saskatchewan, N derived by spring wheat from lentil residue was higher throughout the growing season compared to N derived from wheat residue, and was also made available earlier in the growing season.

2.3.2.4 Crop Residue Quality and Placement

Lohnis (1926, cited in Jansson and Persson 1982) suggested the addition of fresh green manure rich in readily available sources of energy and N resulted in enhanced mineralization and immobilization of soil organic N and C. A number of researchers have noted fertilizer N uptake efficiency as measured by the difference method (Tomar and Soper 1981b) is higher than that measured by using labeled-N, suggesting that there is more organic N mineralized in fertilized plots (Fu et al. 1999). This observation is referred to as the "priming effect" (Cowell and Doyle 1993; Fu et al. 1999; Jansson and Persson 1982; Tomar and Soper 1987; Yaacob and Blair 1980). The contribution of the priming effect to soil inorganic N supply depends on the nature of the amendment as well as characteristics of the soil system to which the amendment is added (Yaacob and Blair 1980). Of importance to the overall inorganic N supply is whether net mineralization or immobilization occurs, since mineralization and immobilization are both enhanced upon the addition of residues to a soil system.

Residue quality and placement may also affect the availability of applied fertilizer N as a result of fertilizer N immobilization. When the C/N ratio is high and soil microorganisms exhaust the residue N supply, fertilizer N can be immobilized. Tomar and Soper (1987) investigated the effect of crop residue and ^{15}N-labeled urea placement method on ^{15}N recovery of canola, and observed that because of the interaction of residues and fertilizer (in the presence of soil microorganisms), recovery of ^{15}N in canola that received point injected urea was higher than when urea was mixed throughout the soil. N fertilizer that is broadcast is generally more prone to immobilization than N fertilizer that is banded due to increased contact of the fertilizer with the crop residue and soil (Harapiak et al. 1987).

2.3.2.5 Nitrogen in Microbial Biomass

Mineralization of plant residue N is not the only source of mineralized N. While soil microorganisms facilitate the decomposition of crop residues and mineralization of organic N, soil microorganisms are also a large N sink (Bremer and van Kessel 1992).

Smith and Paul (1990, cited in Bremer and van Kessel 1992) estimated the microbial N content of Prairie soils to vary between 48 to 385 kg ha^{-1}. Changes in microbial population composition and size during the course of the growing season will therefore exert a significant effect on soil N status.

2.3.3 Fertilizer Nitrogen

As inherent soil N-supplying power has declined in western Canada, greater reliance has been placed on the use of synthetic N fertilizers. At present, N is by far the most important fertilizer nutrient used by western Canadian producers (Harapiak et al. 1993). For example, in the year ending June 30, 2001, 2.463 million tones (MT) of N fertilizer was applied in western Canada (Canadian Fertilizer Institute 2001). Urea represents 50% of total N fertilizer usage, followed by anhydrous ammonia (22%), ammonium sulfate (14%), and ammonium nitrate (< 1%).

2.3.3.1 Urea

The N content of granular urea is roughly 46% (Havlin et al. 1999). Hydrolysis of urea ($CO(NH_2)_2$) by the urease enzyme takes place when soil moisture is favorable, resulting in the formation of ammonium carbamate (NH_4COONH_2) (Koelliker and Kissel 1988). Because it is unstable, ammonium carbamate dissociates into ammonia (NH_3) and carbon dioxide (CO_2).

$$CO(NH_2)_2 + 2H_2O \rightarrow NH_4COONH_2 \rightarrow 2NH_3 + CO_2$$

The NH_3 formed as a result of the dissociation of ammonium carbamate enters equilibrium with NH_4^+ in soil solution. As soil pH increases, the proportion of ammoniacal N present as NH_4^+ decreases (Nelson 1982). NH_4^+ may be temporarily bound to soil particles or nitrified to form NO_3^-. When conditions are favorable for crop growth (i.e. adequate soil moisture and warm temperatures), completion of urea hydrolysis occurs in a few days (Harapiak et al. 1987).

The urease enzyme is an important consideration when urea is applied, as the rate of urea hydrolysis is directly affected by the activity of urease (Kissel and Cabrera 1988). However, urease activity typically does not limit urea hydrolysis, since urease functions effectively in any soil in which plants can grow (Fenn and Hossner 1985). Urease activity is also related to soil temperature and soil moisture. Enzymatic reactions are enhanced at higher temperatures while urease activity decreases as moisture becomes more limiting (Kissel and Cabrera 1988).

Urea can be broadcast or banded in granular form. The volatile loss of NH_3 is generally higher when urea is broadcast, reducing fertilizer efficiency (Malhi et al. 1996; Raczkowski and Kissel 1989). Conventional urea may be modified to inhibit urea hydrolysis and delay plant N availability. Urease inhibitors such as NBPT (N-(n-butyl) thiophosphoric triamide) have been demonstrated to reduce the rate of urea hydrolysis and volatile NH_3 losses, as well as increase N recovery (Grant et al. 1996). Granular urea can also be coated with sulphur or polymer coatings in order to delay N availability and improve N recovery (Hauck 1985).

2.3.3.2 Ammonium Nitrate

The N content of ammonium nitrate (AN) is between 33 and 34% (Havlin et al. 1999). AN is a unique granular N source, since it contains 50% of its N in the NO_3^- form and 50% of its N in the NH_4^+ form (Harapiak et al. 1987). Because 50% of the N is already in the NO_3^- form, it is the fastest acting granular N fertilizer and most readily available to plants (Harapiak et al. 1987). Its enhanced plant availability makes AN the most popular granular N source for topdressing, although AN can be both broadcast and banded (Havlin et al. 1999).

2.3.3.3 Nitrogen Use Efficiency

Fertilizer nitrogen use efficiency (NUE) is expressed as the percentage of fertilizer N utilized by the crop (Cowell and Doyle 1993b), and rarely exceeds 50% due to a number of factors. Depending on fertilizer N source, N losses may be due to immobilization by soil microorganisms (Cowell and Doyle 1993b; Ladd and Amato 1986; Tomar and Soper 1987), NH_4^+ fixation (Nommik and Vahtras 1982; Olu Obi et al. 1986); denitrification (Firestone 1982), NO_3^- leaching (Nyborg et al. 1993), and NH_3 volatilization (Nelson 1982; Terman, 1979). Therefore, the goal of fertilizer N application should be to minimize the amount of N lost from the cropping system through these processes. When fertilizers are placed properly and application (and availability) is timed as much as possible to coincide with crop uptake, different fertilizer sources are similar in effectiveness (Olson and Kurtz 1982), since the potential of N losses from the system are reduced.

2.4 Physiological Aspects of Nitrogen Uptake

N is unique among plant nutrients, since it can be taken up either in the anion (NO_3^-) or cation (NH_4^+) form (Goos et al. 1999). For annual crops, N is taken up primarily as NO_3^-, since NH_4^+, whether applied as N fertilizer or made available as a result of mineralization, is quickly nitrified to NO_3^- in most circumstances (Borghi 1999; Olson and Kurtz 1982). A combination of NO_3^- and NH_4^+ is generally optimal for plant growth (Camberato and Bock 1990a; Camberato and Bock 1990b; Goos et al. 1999; Wang and Below 1992).

Since NO_3^- moves via mass flow, the rate of NO_3^- uptake is dependent on the concentration of NO_3^- in the soil solution and the volume of water utilized by the plant (Olson and Kurtz 1982). Therefore, the rate of NO_3^- uptake is closely related to the rate of plant growth and is therefore regulated by a complex array of repressive and derepressive signals in the plant rather than solely being a function of NO_3^- concentration in proximity to the roots (Tourraine and Gojon 2001). Roots are able to control the amount of NO_3^- uptake based on signals transported to roots from shoots via the phloem that indicate the nutritional status of the plant as a whole (Tourraine and Gojon 2001).

Plant uptake of NO_3^- is against an electrochemical gradient (Abrol et al. 1984). In order to prevent a buildup of negative charge as a result of NO_3^- uptake, the plant concurrently takes up cations such as calcium, potassium, and magnesium, and excretes bicarbonate (HCO_3^-) and hydroxyl (OH^-) groups, increasing the pH of the rhizosphere. Upon absorption, NO_3^- is reduced to NH_4^+ in roots or shoots in a process catalyzed by two enzymes, namely nitrate reductase and nitrite reductase (Naik et al. 1982; Borghi 1999). Since accumulation of NH_4^+ is toxic to plants (Salisbury and Ross 1992), NH_4^+ is converted to glutamine, a reaction catalyzed by glutamine synthetase. Glutamate synthase then transfers the amide group of glutamine to one of the carbon molecules of α-ketoglutarate, forming two molecules of glutamate. Glutamate undergoes transamination reactions to form a variety of amino acids (principally glutamic acid, aspartic acid, and arparagine) that can be transported to vegetative tissues (Salisbury and Ross 1992).

2.5 Pattern, Rate, and Duration of Dry Matter Production and Nitrogen Uptake

A number of researchers have evaluated the evolution of dry matter (DM) production and plant N uptake over the course of the growing season in winter wheat (Darroch and Fowler 1990; Entz and Fowler 1989; Karlen and Whitney 1980; Spiertz and Ellen 1978; Waldren and Flowerday 1979) and spring wheat (Bauer et al. 1987a; Bauer et al. 1987b; Boatwright and Haas 1961; Campbell et al. 1977a; Campbell et al. 1977b; Campbell et al. 1979; Campbell et al. 1990; Clarke et al. 1990; Frank et al. 1989; McNeal et al. 1968; Miller et al. 1994). The relationship between DM production and N accumulation is important in understanding the dynamics of yield and PC, especially in relation to environmental factors and crop management practices.

Spring wheat aboveground DM and N accumulation follow a sigmoidal pattern (Boatwright and Haas 1961; Johnston and Fowler 1990; Spratt and Gasser 1970). However, the point at which accumulation rate significantly increases differs for DM and N. In the early stages of development, N accumulation rate exceeds DM production (Campbell et al. 1977a; Cowell and Doyle 1993b; Darroch and Fowler 1990). Campbell et al. (1977a) demonstrated that N accumulated in spring wheat plants at the flag leaf stage represented 70% of total N uptake at harvest, while only 50 to 65% of DM had accumulated. In winter wheat, Waldren and Flowerday (1979) reported DM production was 40 % of total DM production by the flag leaf stage, while N accumulation reached

70% of total N. In no-till winter wheat, Darroch and Fowler observed that on average, 70% of total DM (varying between 57 to 89%) and 89% of total N (varying between 70 to 106%) was present in the plant by anthesis. Johnston and Fowler (1991) determined that no-till winter wheat reached maximum plant N content by the mid-boot stage. DM production reached 62% of maximum by mid-boot stage and reached its maximum at mid-anthesis. Therefore, N availability early in the growing season is essential to overall plant N uptake, since a large portion of N uptake occurs before anthesis.

The rate of DM and N accumulation changes temporally, varying with crop stage and environmental conditions. Johnston and Fowler (1991b) determined winter wheat DM accumulation rate reached its maximum between Zadoks 30 (pseudo-stem erection) and 45 (swollen boot). However, when low precipitation and high evaporative demand occurred during that period, maximum DM accumulation rate occurred between Zadoks 45 and 65 (mid-anthesis). N accumulation rate reached its maximum during the earliest growth stage that was monitored (Zadoks 22, or seedling with 2 tillers). Campbell et al. (1977a) found the highest rate of spring wheat N uptake was observed during the greatest period of crop water usage, namely between tillering and the flag leaf stage.

2.6 Factors Affecting Nitrogen Uptake

Given the results reported by Darroch and Fowler (1990), the quantity and percentage of N taken up after anthesis varies greatly. Post-anthesis N uptake depends on a number of environmental factors, and can have a considerable impact on the relationship between yield and PC. In general, N taken up prior to the boot stage promotes DM production and grain yield, while N taken up after the boot stage contributes more to PC (Darwinkel 1983; Selles et al. 1997; Wuest and Cassman 1992a;).

N made available to the plant near or after anthesis as N fertilizer (Alcoz et al. 1993; Hogg and Brown 1997; Miceli et al. 1992; Tran and Tremblay 2000; Wuest and Cassman 1992a), mineralized N, or residual N (Broadbent 1984; Cochran et al. 1978; Lotfollahi et al. 1997; Olson 1984) is more effectively transported to grain than N supplied at planting. Environmental conditions such as moisture availability (Campbell et al. 1977b; Campbell et al. 1990; Darroch and Fowler 1990) and temperature (Campbell and Davidson 1979; Campbell et al. 1981) also affect the efficiency of N applied near or after anthesis.

2.6.1 Effect of Dry Matter Production on Nitrogen Uptake

Plant N uptake is positively related to DM production and available water (Clarke et al. 1990), since NO_3^- movement to the plant depends on mass flow, which in turn is dependent in part on plant water demand. Campbell et al. (1990) evaluated the dynamics of kernel N and DM accumulation of four spring wheat cultivars grown under dryland or irrigated conditions. Kernel N accumulation was dependent on kernel DM response, since increased water availability increased DM production and facilitated N uptake. Compared to dryland wheat, the duration of the filling period was extended by 33% with irrigation, permitting plant N uptake and DM production to increase considerably after anthesis for irrigated wheat. Under dryland conditions, Johnston and Fowler (1991b) also found that increased moisture availability during the filling period permitted growth and N uptake to occur for a longer period, and delayed maximum N and DM accumulation.

Soil N fertility also exerts a significant influence on N uptake and DM production. Campbell et al. (1977a) observed differences in water usage related to N fertilizer rate as early as the tillering phase, where available water decreased with increasing N fertility. Darroch and Fowler (1990) found winter wheat N fertilization increased both DM and N yield, particularly where residual soil N levels were intermediate to high. Boatwright and Haas (1961) determined the crop stage at which N content reached its maximum differed for spring wheat subjected to different N regimes. Wheat fertilized with N reached maximum DM and N accumulation at the soft dough stage, while wheat that did not receive N fertilizer reached the same maxima at maturity. The authors speculated that N deficiency in unfertilized plots reduced DM accumulation and that unfertilized wheat depended more on soil N during grain filling.

2.6.2 Effect of Soil Moisture Availability on Nitrogen Uptake

Given favorable moisture conditions, plants are able to produce more DM and accumulate a greater amount of N compared to when soil moisture is lacking. Campbell et al. (1977b) reported wheat accumulated only 25 to 40% of total DM and 33 to 60% of total N by the flag leaf stage in a wet environment, compared to 50-65% and 70%, respectively, for a dry environment. McNeal et al. (1968) found 92% of plant N was accumulated by anthesis for wheat grown under dryland conditions compared to 80% for wheat grown under irrigated conditions. The amount of available N will be depleted more rapidly under more optimal moisture conditions, since the rate of DM accumulation is elevated (Campbell et al. 1977b).

Soil moisture availability after anthesis also has a dramatic effect on N uptake. Clarke et al. (1990) evaluated the N uptake of two spring wheat and two durum wheat cultivars grown under dryland conditions at Swift Current. Between 67 to 102% of total plant N was accumulated by anthesis, similar to the results reported by Darroch and Fowler (1990) for no-till dryland winter wheat. Post-anthesis uptake of N was greater under moist environments relative to dry environments, and total N uptake was proportional to available water. In conditions where late season soil water and N supplies are ideal, the proportion of N taken up after anthesis can be as high as 44 to 51% (Spiertz and Ellen 1978).

2.6.3 Effect of Temperature on Nitrogen Uptake

Temperature interacts with soil moisture and N fertility to influence N uptake, and indirectly affects N uptake by influencing yield. As reported in a series of studies carried out by Campbell et al., Manitou spring wheat was grown under three combinations of day/night temperature regimes (27/12°C, 22/12°C, and 17/12°C), three fertilizer N rates and three degrees of moisture stress of varying lengths (Campbell and Davidson 1979; Campbell et al. 1981; Davidson and Campbell 1984). Temperature affected photosynthesis and growth the most; temperature and moisture affected the N status of the plant by affecting yield, while the effect of N rate on plant N status was direct.

Furthermore, the effect of N availability on protein content was twice as important as the effect of temperature, and 15 times more important than the effect of moisture (Campbell et al. 1981). Temperature was the main factor that influenced the number of spikelets, seed weight, and time to maturity, thereby affecting yield. Although grain PC increased from approximately 10 to 10.3% when the temperature regime changed from 17/12°C to 22/12°C, PC increased to 14.8% when the 27/12°C temperature regime was imposed, due to the effect of increased temperature on enhanced moisture stress and its subsequent effect on reduced carbohydrate synthesis.

2.7 Effect of Crop Management Practices on Nitrogen Availability and Uptake

The effect of cropping practices, both in terms of crop rotation and fertilizer management, clearly have a profound impact on the N-supplying power of the soil. Environmental factors, such as weather variables or soil properties, regulate N availability. This section deals with the effects of crop rotation on the N-supplying power of cropping systems and crop N uptake.

2.7.1 General Effects of Annual Legumes on Wheat Yield, Nitrogen Availability and Nitrogen Uptake

Production of annual grain legumes such as field peas, lentils, and chickpeas has increased considerably in western Canada over the past 15 years (Biederbeck et al. 1996). The most recognized benefit to the production of a cereal following the production of an annual legume is an increase in yield (Evans et al. 1991; Felton et al. 1998; McDonald 1989; Stevenson and van Kessel 1996). In northern Alberta, Wright (1990) found that compared to barley grown after barley, barley yield was increased an average of 21% when grown after field pea, faba bean, or lentil. Using producer yield data from Manitoba, Bourgeois and Entz (1996) found the yield of wheat grown after pea was 25% higher compared to the yield of wheat grown after wheat. Similar results have been reported in Australia in comparing the yield of wheat grown after wheat versus wheat grown after field peas (Evans et al. 1991; Silsbury 1990; Strong et al. 1986), lentil (Heenan et al. 1998), lupin (Chalk et al. 1993; Doyle et al. 1988; Evans et al. 1991; Reeves et al. 1984; Rowland et al. 1988), and chickpea (Felton et al. 1998; Holford and Crocker 1997; Marcellos 1984; Strong et al. 1986).

Along with increases in yield, increases in wheat N uptake (Beckie et al. 1997; Doyle et al. 1988; Fu et al. 1999; Holford and Crocker 1997; Miller et al. 1998b; Miller et al. 2002b; Mooleki et al. 1997; Reeves et al. 1984; Strong et al. 1986b; Wright et al. 1990) and soil N availability (Beckie et al. 1997; Chalk et al. 1993; Evans et al. 1991; Felton et al. 1988; Fu et al. 1999; Miller at al. 2002b; Mooleki et al. 1997; Rowland et al. 1988; Strong et al. 1986a) have been demonstrated when wheat grown on legume stubble is compared to wheat grown on non-legume stubble.

2.7.2 Nitrogen and Non-Nitrogen Benefits of Annual Legumes

The N residual effect is defined as the amount of fertilizer N required for a non-legume crop grown on non-legume stubble to produce the same yield as that of the non-legume grown on legume stubble (Beckie and Brandt 1997). Estimates of the N residual effect of legumes vary from 27 kg ha^{-1} (Beckie and Brandt 1997) to 100 kg ha^{-1} (Wright 1990), and can be attributed to both N and non-N benefits.

When the difference in yield potential for a cereal following a cereal in rotation versus a cereal following a legume can be made up for with the addition of N fertilizer, yield differences are considered to be due to the N benefit (Beckie and Brandt 1997). The non-N benefit is defined as the remainder of the rotational benefit that cannot be compensated for by N fertilizer (Stevenson and van Kessel 1995), which can include breaks in disease cycles (Evans et al. 1991; Felton et al. 1998; Reeves et al. 1984; Stevenson and van Kessel 1996), reduction in weed populations (Stevenson and van Kessel 1996), and the sparing of soil water (Elliott et al. 1987; Miller et al. 1998a; Miller et al. 2002b). The relative N and non-N benefits of a legume to the succeeding cereal depend on a number of factors. In order to distinguish the N benefits of various stubble types from non-N benefits, reference crops must be chosen that have comparable non-N benefits, thereby effectively eliminating the non-N benefits to the subsequent crop.

2.7.3 Direct Nitrogen Benefits of Annual Legumes

The N benefit of a legume to the subsequent crop can be divided into direct and indirect N benefits, each having specific sources on N from which they are generated (Stevenson and van Kessel 1995). The direct N benefit comes from N made available through the mineralization of the legume residue, which is a function of the amount of N fixed in the residue and the degree to which the N fixed in the residue is made available to the following crop.

2.7.3.1 Nitrogen Fixation

The major N benefit of legumes in rotations is usually attributed to the release of biologically-fixed N from legume residue (Wright 1990). Legumes do not acquire their total N requirement solely via N-fixation; a portion of their total N needs is satisfied by soil mineral N. Using the ^{15}N natural abundance technique, Androsoff et al. (1995) estimated the percentage of N derived from the atmosphere (%Ndfa) of field pea at

44.5%, with a range of 0 to 92.8%, depending on landscape position, soil NO_3^- levels, and seed yield. Using the same technique, Stevenson et al. (1995) recorded a similar range in field pea at flowering (24 to 94% Ndfa) and harvest (41 to 100% Ndfa), depending principally on soil inorganic N content. When soil N levels are high, legumes exhibit a lower %Ndfa, since a greater proportion of the legume's N requirement can be acquired from the soil.

Legumes may fix a large amount of N, but the percentage of N removed with the seed, also known as the N harvest index, is typically in the range of 60 to 80% (Peoples et al. 1995). McCallum et al (2000) found the amount of N fixed in field pea shoot DM was between 121 to 175 kg ha^{-1}, yet 115 to 151 kg ha^{-1} of N was removed with the seed. Despite total field pea N fixation of 220 to 227 kg ha^{-1} and atmospheric N fixation of 133 to 183 kg ha^{-1} (60 to 81 %Ndfa), Peoples et al. (1995) reported 135 to 162 kg ha^{-1} N was exported with the seed, leaving an N balance of –2 to +21 kg ha^{-1} N. The %Ndfa above gains to soil N were likely to occur from lupin and pea was estimated by Evans et al. (1989) to be 50 and 65%, respectively. In evaluating the N contribution of grain legumes to a subsequent cereal crop, the idea that the production of a grain legume will always result in an improvement of the soil N status is false, since a low %Ndfa reduces the legume N benefit.

2.7.3.2 Nitrogen in Crop Residues

The direct N contribution of a grain legume is strongly related to the amount of DM produced by the legume (Adderley et al. 1998; Armstrong et al. 1994; Beckie and Brandt 1997; Evans et al. 1989; McCallum et al. 2000). Beckie and Brandt (1997) determined the N residual benefit of field pea to a succeeding non-legume crop to be 15 kg N ha^{-1} for every 1000 kg ha^{-1} of seed produced in the Black soil zone. Biederbeck et al. (1996) estimated the average N value of field pea and lentil to be 18.1 and 9.4 kg N ha^{-1} in western Canada, respectively, although the N credit is higher in areas where soil moisture levels are more favorable such as the Black soil zone.

Once legume grain is harvested, the sole direct N benefit of a grain legume is from plant residue N. The amount of N in aboveground pea residue is usually less than 35 kg ha^{-1}, and is estimated to be not more than 25 kg ha^{-1} above the amount found in cereal residue (Wright 1990). Biederbeck et al. (1996) estimated the amount of N in aboveground grain legume residue to be between 5 to 25 kg ha^{-1}. However, in order for legume residue N to be available to the subsequent crop, it must undergo mineralization, a process that depends on a number of factors.

Because annual legume residues have a lower C/N ratio compared to cereal residues (Bremer and van Kessel 1992; Janzen and Kucey 1988; Ladd et al. 1983), mineralization is expected to occur more quickly for legume residue, in turn affecting the amount and timing of residue N availability to the following crop. Estimates of the percentage of legume residue N recovered by a subsequent cereal crop are commonly in the range of 25 to 30% (Beckie et al. 1997; Senaratne and Hardarson 1988). Therefore, compared to plant recovery of fertilizer N, recovery of legume residue N tends to be lower (Bremer and van Kessel 1992; Janzen et al. 1990; Ladd and Amato 1986).

During the first growing season after legume harvest, a significant portion of legume residue N is retained as organic N, particularly in semiarid environments. Ladd et al. (1986) measured the recovery of medic (*Medicago littoralis*) residue N by wheat at

17%; 62% remained as organic N in the soil. Other authors have reported similar findings (Ladd et al. 1981; Ladd et al. 1983; Amato et al. 1984; Muller and Sundman 1988). In comparing the direct N benefit of lentil and wheat residues to a wheat crop in western Canada, Bremer and van Kessel (1992) found 7% of the ^{15}N-labeled wheat and lentil residue was mineralized by the end of the growing season, compared to 37% of ^{15}N-labeled lentil green manure, since the green manure had a much lower C/N ratio. Only 5.5% of the ^{15}N added in the wheat and lentil straw was recovered by the wheat crop, while roughly 40% of the green manure N was potentially plant-available.

In environments where NO_3^- leaching or denitrification is a problem, the potential N release from legume residue may be underestimated. Jensen (1993) found an average of 60% of the N mineralized from mature pea residue was recovered by winter barley and winter rapeseed when the crop was established immediately after incorporation of pea residue, versus 36 and 15% for fall and spring-sown crops, respectively. Therefore, the net direct N benefit of legume residue depends strongly on factors that influence mineralization as well as other soil N processes.

2.7.4 Indirect Nitrogen Benefits

The indirect N benefit of annual legumes in crop rotations is a function of increased plant N uptake of N from N fertilizer, soil organic mater (SOM), and residual N. However, the indirect N benefit is not necessarily independent of the non-N benefit, since improvements in plant health that result from a non-N benefit will increase N uptake (Stevenson and van Kessel 1995). Two major indirect N benefits associated with annual legumes are the conservation of soil N (Beckie et al. 1997; Chalk et al. 1993; McDonald 1989) and increased N uptake from non-legume sources (Fu et al. 1999).

2.7.4.1 Conservation of Soil Nitrogen

When grain legumes are able to fix a considerable portion of their N needs via biological N fixation, the proportion of plant N derived from inorganic soil N is generally reduced. Given the uncertainty surrounding the timing and amount of N made available through the decomposition and mineralization of legume residue, the "N sparing" or "N conserving" effect (Beckie et al. 1997; Chalk et al. 1993; McDonald 1989) of grain legumes can be of considerable contribution to the total N benefit.

After the harvest of a variety of cereal, oilseed, and legume crops, Strong et al. (1986a) monitored NO_3^--N and NH_4^+-N in the top 120 cm of the soil profile. Forty days after harvest, soil inorganic N was higher where legumes were grown (34 to 76 kg ha^{-1}) compared to where oilseeds or cereals were grown (16 to 30 kg ha^{-1}). The net soil mineral N increase 145 d after the first soil sampling was much higher for legume stubble (53 to 85 kg ha^{-1}) than for cereal (21 to 27 kg ha^{-1}) or oilseed (40 kg ha^{-1}) stubble.

In a similar study, Francis et al. (1994) determined soil N removal by barley, rapeseed (*Brassica napus* L.), and lupins was in the range of 104 to 119 kg ha^{-1}, compared to a range of 50 to 74 kg ha^{-1} for field beans, field peas, or lentils. The high N removal by lupin was attributed to higher lupin grain N yield rather than grain yield. The amount of mineral N conserved by lupin or pea was estimated by Evans et al. (1991) to be up to 60 kg ha^{-1} to a depth of only 10 cm. Compared to the total N accumulated in the legume residue (up to 152 kg ha^{-1}), the authors estimated the soil N conserving effect was responsible for 77% of the N benefit to a subsequent wheat crop.

2.7.4.2 Increased Nitrogen Uptake from Non-Legume Sources

The other main indirect N benefit attributed to wheat grown after legumes is the increased uptake of N from SOM and fertilizer N (Stevenson and van Kessel 1995). Where fertilizer N uptake efficiency as measured by the difference method is higher than that measured by using labeled-N, more organic N is being mineralized (and probably immobilized) in fertilized plots (Fu et al. 1999). The difference between the two values is attributed to the priming effect (Cowell and Doyle 1993b; Fu et al. 1999; Jansson and Persson 1982; Tomar and Soper 1987). The simultaneous stimulation of mineralization and immobilization when legume residues are added means that recovery of ^{15}N from residue is often low, even when the residue has a low C/N ratio and is expected to result in net mineralization (Stevenson and van Kessel 1995; Stevenson and van Kessel 1997).

In a study comparing the N contribution of chickpea and wheat residues to a subsequent wheat crop, Fu et al. (1999) hypothesized that since net ^{15}N recovery will be subject to other soil N processes such as immobilization, estimates of the amount of legume residue N mineralized will be low. The added nitrogen interaction, defined as the increase or decrease in mineralization of native soil N following fertilizer application, and was determined to be 1.80 kg N ha^{-1} for chickpea residue, compared to –0.82 kg N ha^{-1} for wheat residue. N recovery by wheat from chickpea residue in footslope positions was also significantly higher compared to N recovery from wheat residue. The lack of differences in shoulder positions was attributed to a lack of moisture, reinforcing the importance of soil moisture on mineralization of N from crop residues.

2.7.5 Relative Contribution of Nitrogen and Non-Nitrogen Benefits

The N and non-N benefits of legumes are most often studied by comparing the productivity of wheat grown after a cereal versus wheat grown after a legume. In a number of these studies, the contribution of the legume in breaking disease cycles has been considerable (Felton et al. 1998; Reeves et al. 1984; Stevenson and van Kessel 1995; Stevenson and van Kessel 1996; Stevenson and van Kessel 1997). Comparing wheat produced on field pea and wheat stubble, Stevenson and van Kessel (1996) attributed 91% of the yield advantage (equivalent to a 129 kg ha^{-1} increase in soil N supplying power) of wheat grown after field pea to reduced leaf disease severity and reduced grassy weed infestations.

In annual cropping sequences in western Canada, a broadleaf crop such as an oilseed or pulse crop often follows a cereal crop in order to break disease cycles. By using two reference crops that are expected to provide similar reductions in pest pressure, the N benefits of legumes can be more effectively evaluated. Using wheat, pea, and canola as reference crops, Stevenson and van Kessel (1998) found wheat grain yield was 14% higher when either canola or pea was used as a reference crop compared to using wheat. Leaf disease severity was reduced 17 to 30% when canola and pea were used as reference crops compared to wheat. The authors attributed the wheat yield increase associated with non-cereal reference crops to be solely a result of the non-N benefit.

Conversely, pea and flax were used by Beckie as the reference crops preceding a wheat crop (Beckie and Brandt 1997; Beckie et al. 1997). By using two non-cereal reference crops, differences in the non-N benefits of the reference crops were effectively limited. The total N benefit was equivalent to the residual N effect, meaning the amount of fertilizer required for wheat grown on flax stubble to produce the same yield as wheat grown on pea stubble was attributable solely to the N contribution of pea to the wheat crop. Reference crops must be chosen carefully in order for research to provide meaningful results with respect to current and accepted crop management practices.

2.8 Controlled-Release Fertilizers

One of the ways fertilizer N recovery can be increased is via the use of fertilizers designed to time N release to match crop uptake (Haderlein et al. 2001; Hauck 1985; Shaviv 2001; Shaviv and Mikkelsen 1993). Controlled-release fertilizers (CRFs) have been designed with this idea in mind. The pattern of N release from CRFs is different from slow-release fertilizers (SRFs) (Haderlein et al 2001; Shaviv 2001). SRFs release a given nutrient more slowly than conventional fertilizers, but the pattern and rate of release are not well controlled (Shaviv 2001). Conversely, the nutrient release pattern of CRFs is well-defined and predictable (Haderlein et al. 2001; Tindall and Detrick 1999).

One type of CRF, namely polymer-coated urea (PCU), is a water-soluble fertilizer coated with a polymer (Haderlein et al. 2001; Tindall and Detrick 1999). When PCU is placed in moist soil, the polymer coating absorbs moisture. The rate at which water is absorbed depends on the thickness and type of polymer. Therefore, the rate of nutrient release is not dependent on soil moisture content per se, and can be both controlled and predicted accurately (Tindall and Detrick 1999).

Global CRF usage is roughly 0.5 million tonnes, or 0.15% of total global fertilizer use (Shaviv 2001). The high cost of CRFs is roughly 2.5 to 8 times that of a corresponding conventional fertilizer (Shaviv and Mikkelsen 1993) and is part of the reason behind their lack of adoption by producers. CRF use is currently targeted to intensively grown, high value crops such as vegetables, citrus crops, and golf course turf (Shaviv 2001), although the fertilizer manufacturer Agrium is developing a low cost controlled-release urea product (CRU) for use in large-scale conventional field crop production (Haderlein et al. 2001).

2.8.1 Use of Controlled-Release Urea in Field Crop Production

Limited research exists on the utility of CRFs in large-scale field crop production. Tindall and Detrick (1999) cited a number of fertilizer trials carried out with the PCU Polyon Ag where yields of winter wheat, corn, and soybeans increased with Polyon Ag when compared to typical producer fertilizer practices. Haderlein et al. (2001) compared the effect of side-banded CRU and urea in spring wheat production and found CRU resulted in significantly higher PC and NUE relative to conventional urea. The authors cited increased N uptake and recovery from CRU later in the growing season as the reason for the differences between fertilizer N sources. In comparing three forms of controlled release N with AN in potato production, Wahab and Hogg (1995) found the variety Russet Burbank produced higher yields when fertilized with controlled release N while Norland potato did not. Cultivar differences with respect to N response were attributed to differences in N requirements later in the growing season; Russet Burbank is a more vigorous late maturing potato that requires N over a longer period.

Crop recovery of PCU is greater compared to conventional fertilizer due in part to a reduction of N losses such as NO_3^- leaching and denitrification (Haderlein et al. 2001; Nyborg et al. 1993 (cited in Haderlein et al. 2001); Shoji et al. 1991). Shoji et al. (1991) also found substantially higher plant recovery of PCU relative to conventional urea in years when precipitation is excessive. Increased PCU N recovery results in potential N loss and reduces negative environmental impacts.

2.9 Protein Content

Wheat PC is defined as the concentration of N in the grain multiplied by 5.7 (Simmonds and O'Brien 1981). Wheat PC ranges from 8 to 20% (Selles and Zentner 1998) and is a function of both genotype and environment, the latter being a combination of the amount of N available to the plant and weather conditions during the growing season (Campbell et al. 1997; Smika and Greb 1973). In the Great Plains of North America, environment has a greater effect on PC compared to genotype (Terman et al. 1969), although under the same environmental conditions, different wheat genotypes within the same class have been shown to respond differently to increasing N availability (Campbell et al. 1990; Clarke et al. 1990; Gauer et al. 1992).

2.9.1 Relationship Between Yield and Protein Content

The inverse relationship between yield and protein has been widely documented (Campbell et al. 1997; Entz and Fowler 1988; Hutcheon and Paul 1966; McNeal et al.

1972; Selles et al. 1997; Terman et al. 1969). The majority of the wheat is composed of carbohydrate, of which the majority is starch. Protein is the second most plentiful component of the grain, although it represents only 7 to 15% of total grain weight (Shewry and Miflin 1985). Therefore, the amount of carbohydrate in the kernel in relation to N dictates grain PC. In a study of a number of spring wheat crosses, McNeal et al. (1972) observed that N uptake and N translocation efficiency varied little between the crosses, meaning grain N yield was similar. However, PC differed considerably among the crosses due to the amount of carbohydrate translocated into the grain. Therefore, factors that limit carbohydrate and DM production during the plant's reproductive phase will result in higher PC.

During the filling period, kernel N and carbohydrate content vary. Under dryland conditions, Campbell et al. (1990) found the concentration of N in the kernel of four spring wheat cultivars increased linearly with time; Bauer et al (1987b) and Sofield et al. (1977) reported similar findings. Under irrigated conditions, however, N concentration in the kernel followed a curvilinear pattern, the rate of increase decreasing after anthesis and reaching a minimum between 28 to 37 d after anthesis. In irrigated plots, the rate of DM accumulation throughout most of the filling period exceeded the rate of N accumulation, in turn depressing kernel N concentration. Near maturity, N concentration increased. Soil N and moisture levels were high during filling, permitting continued N uptake while DM production decreased due to the senescence of plant tissues.

2.9.2 Translocation of Nitrogen and Carbohydrates to the Grain

The quantity of N in the wheat kernel is dependent on two sources, namely N assimilated during vegetative development and N taken up during grain filling (Abrol et al. 1984). N translocated from vegetative material is the principal source of grain N for the kernel (Boatwright and Haas 1961; Campbell et al. 1990; Clarke et al. 1990; Darroch and Fowler 1990; Spiertz and Ellen 1978), although N must first be converted into a translocatable form in order to be transported to the kernel. Most of the N in vegetative tissues exists as protein; in leaf tissue the principal protein is the chloroplast enzyme ribulose-1,5-bisphosphate carboxylase, or Rubisco (Peoples et al. 1980). Protein is hydrolyzed by peptide hydrolases (Waters et al. 1980), and the N is translocated principally as glutamine, asparagine, glutamate, and aspartate (Salisbury and Ross 1992).

Not to be overlooked, translocation of carbohydrates is also an important consideration during grain filling. Carbohydrates are assimilated before anthesis, stored primarily in the stem, and translocated to the grain after anthesis (Palta et al. 1994; Spiertz and Ellen 1978; van Herwaarden et al. 1998). Water-soluble carbohydrate reserves in the stem become a larger fraction of total grain biomass when post-anthesis moisture stress limits DM production (Palta et al. 1994; van Herwaarden et al. 1998).

With increasing N fertility, the relative importance of vegetative material as a source of translocatable N increases. Boatwright and Haas (1961) observed that wheat fertilized with N reached maximum DM and N accumulation at the soft dough stage, while wheat that did not receive N fertilizer reached the same point at maturity. The authors speculated that reduced DM accumulation as a result of N deficiency on unfertilized plots reduced N uptake, and that unfertilized wheat depended more on soil N during grain filling. When wheat was restricted to a soil N level of 0 kg ha^{-1} by Nair et al. (1978), the uppermost three leaf blades contributed 22.7% of total grain N. Conversely, when wheat was grown at a soil N level of 120 kg ha^{-1}, the uppermost three leaf blades contributed 48.5% of total grain N. The amount of N translocated from other plant parts to the grain did not differ considerably between the different soil N regimes, meaning the leaf tissue was the main sink for the extra N prior to the filling period. However, N translocation from roots late in development may also be a significant source of grain N. Campbell et al. (1977b) observed increased N uptake under drought conditions along with a concurrent decline in root DM and N content. Maximizing translocation efficiency from vegetative tissue to grain increases the kernel N quantity, and is especially important when soil N levels are high.

Assuming there is N and water available for plant uptake, N uptake can continue until late in the filling period, even in dryland environments (Campbell et al. 1990; Clarke et al. 1990). Clarke et al. (1990) observed increased N uptake during the soft dough phase of kernel development exceeded N translocation from leaves and stems.

2.9.3 Effect of Fertilizer Nitrogen Application Rate on Protein Content

The effect of fertilizer N application on yield and PC has been widely studied (Bole and Dubetz 1986; Campbell and Davidson 1976; Fowler et al. 1990; Grant et al. 1991; Selles et al. 1997), since N is the most important nutrient that influences PC (Olson and Kurtz 1982). Many researchers have demonstrated the positive relationship between fertilizer N application rate and PC (Bole and Dubetz 1986; Bole and Pittman 1980; Gauer et al. 1992; Gehl et al. 1990; Grant et al. 1991).

Knott (1974) demonstrated that across a range 0 to 168 kg ha^{-1} of applied N, barley grain DM and N yield showed a quadratic response, while PC showed a linear response, meaning PC does not increase at as rapid a rate as grain DM or N yield in response to the first few increments of fertilizer N. The proportionately larger increase in grain DM yield dilutes grain N yield, thereby decreasing PC. This effect, called the "lag" phase, has been reported by many other researchers, particularly when soil N levels are low (Bole and Pittman 1980; Fowler and Brydon 1989; Fowler et al. 1990; Knott 1974).

The second phase of the yield-PC relationship has been called the increase phase (Cowell and Doyle 1993b; Fowler et al. 1990). This phase commences once N is no longer the principal factor affecting grain yield, at which point PC begins to increase. Any environmental factor that increases yield potential will increase the amount of N needed to commence this phase (Fowler et al. 1990). The rate of yield increase decreases and eventually levels off with additional increments of N, while PC continues to increase.

2.9.4 Effect of Soil Moisture on Protein Content

PC is modified by the availability of soil water, since yield is related strongly to moisture availability (Clarke et al. 1990; Entz and Fowler 1988; Grant et al. 1991; Henry et al. 1987). In the event of low moisture availability, the main effect of N is to increase PC, since moisture is below the optimum for maximum grain yield (Hutcheon and Paul 1966; Terman 1979; Terman et al. 1969). As the amount of N fertilizer applied increases with increasing soil moisture, grain yield and N yield increase. PC will not increase in direct proportion to yield, since grain yield generally increases more than PC with increasing moisture supply. Where the supply of water is intermediate, both yield and PC increase with increasing N supply (Hutcheon and Paul 1966; Terman et al. 1969).

Darroch and Fowler (1990) found when residual soil N levels were low to intermediate and moisture conditions were adequate, N fertilization increased grain N yield more so relative to PC. When residual soil N levels were intermediate to high, both grain N yield and PC increased in response to N fertilization. Therefore, the yield response to fertilizer N will not be as great and the PC response may be relatively larger where soil N levels are high prior to fertilizer N application (Darroch and Fowler 1990; Lloveras et al. 2001).

2.9.4.1 Effect of Timing of Moisture Stress on Protein Content

The timing of moisture stress also has a dramatic effect on PC. For winter wheat production in western Canada, Entz and Fowler (1988) determined that environmental stresses between Zadoks stage 21 (main shoot + 1 tiller) and Zadoks stage 65 (mid-anthesis) had the greatest effect on grain yield, DM production, and grain N yield, since this phase corresponded to the plant's most rapid period of growth and demand for water. Grain PC was affected by moisture stress before and after anthesis, and was most strongly correlated with root zone water at anthesis.

When moisture stress is imposed during kernel development, grain PC increases considerably relative to grain yield, since N remobilization to the grain from vegetative tissue is less affected by moisture stress compared to carbohydrate synthesis (Hutcheon and Paul 1966; Panozzo and Eagles 1999). An increased rate of N remobilization has also been suggested as an explanation of higher PC as a result of moisture stress (Palta et al. 1994; Panozzo and Eagles 1999). However, in extremely dry conditions, N remobilization from vegetative tissues may be severely retarded, decreasing N recovery in the grain and lowering translocation efficiency (Spratt and Gasser 1970).

2.9.5 Effect of Temperature on Protein Content

Temperature and moisture stress interact to affect yield and PC. Temperature is inversely related to yield and related directly to PC (Campbell and Davidson 1979). Campbell et al. (1981) observed the highest spring wheat PC under high N fertility and temperature when moisture was applied from near boot stage to maturity. The lowest PC was observed under cool conditions with medium N fertility, where moisture stress was applied from late anthesis until maturity. Soil moisture levels were observed by Sosulski et al. (1962) to have a greater effect on PC at higher temperatures compared to lower temperatures due to an increase in overall plant water stress. High temperatures during kernel development result in reduced starch synthesis relative to protein synthesis, especially when moisture is not limiting, in turn increasing PC.

2.9.6 Effect of Fertilizer Nitrogen Source and Timing on Protein Content

Timing N availability to a wheat crop modifies the relationship between yield and PC. By delaying the availability of N until later in the growing season, N will contribute more to PC relative to grain yield, since the potential for yield increase is more limited (Fowler and Brydon 1989; Fowler et al. 1990; Johnston and Fowler 1991). Therefore, fertilizer type is an important consideration with respect to wheat protein dynamics, since different fertilizer types have different release characteristics.

A number of studies in western Canada have evaluated the relative efficiency of AN versus urea for cereal production (Campbell et al. 1991; Fowler and Brydon 1989; Matus et al. 1996; Johnston and Fowler 1991a; Johnston and Fowler 1991b; Matus et al. 1999). In two of the aforementioned studies, fertilizer source did not influence yield or PC (Campbell et al. 1991; Matus et al. 1996). However, in a later study, higher spring wheat yields were observed with urea when compared to AN by Matus et al. (1999), despite higher levels of ^{15}N-labeled urea remaining in the soil at harvest. The authors suggested differences might have been attributable to NO_3^- loss from AN due to denitrification or leaching.

Fowler and Brydon (1989) compared the effectiveness of broadcasting and banding AN and urea at different times on winter wheat productivity. Broadcast urea resulted in lower grain yield and grain N yield compared to broadcast AN in three trials. N losses were likely due to volatile loss of NH_3, since urea is prone to volatile loss of NH_3 in certain conditions (Nelson 1982). Where spring broadcasting of AN or urea was followed by dry conditions, N availability was decreased, resulting in large increases in PC for both N sources. Compared to broadcasting AN or urea early in the spring, delaying spring broadcasting by three weeks resulted in lower winter wheat DM yields and delayed N uptake (Johnston and Fowler 1991b). In a similar study, Johnston and Fowler (1991a) observed grain N yield and PC response to early spring broadcast urea and banded urea was 89% of the response observed with early spring broadcast AN. Therefore, yield and PC response to conventional types of fertilizer may differ considerably depending on environmental conditions, emphasizing the importance of proper fertilizer placement and timing.

In a comparison of side-banded CRU versus conventional urea, Haderlein et al. (2001) found spring wheat yields were not statistically different. However, CRU produced higher PC and NUE across an N application range of 0 to 100 kg ha^{-1}. The authors suggested the release characteristics of CRU permitted more N to be taken up in later growth stages when N is more likely to be concentrated in the grain. Similar field studies comparing conventional urea with urea amended with nitrification inhibitors have not shown significant differences in yield or PC (Bronson et al. 1991; Goos et al. 1999).

2.9.6.1 Effect of Delayed Fertilizer Nitrogen Application on Protein Content

Since N taken up later in the growing season contributes more to PC than to yield, using split applications of N to increase N availability later in the growing season frequently results in increased PC compared to when N applied solely at seeding (Hogg and Brown 1997; Hucklesby et al. 1971; Morris and Paulsen 1985; Miceli et al. 1992; Selles et al. 1997; Tran and Tremblay 2000; Wuest and Cassman 1992a). The overall recovery of fertilizer N applied closer to anthesis is also frequently higher than when N is applied solely at seeding. In Québec, Tran and Tremblay (2000) observed recovery of ^{15}N-labeled AN applied to spring wheat at the boot stage was 49.8%, compared to 36.2% when ^{15}N-labeled AN was applied at seeding. Under irrigated conditions in California, Wuest and Cassman (1992a) recorded similar results. Recovery of ^{15}N-labeled ammonium sulfate applied at anthesis varied from 55 to 80%, compared to 30 to 55% for ^{15}N-labeled ammonium sulfate applied at seeding. Both experiments, however, were carried out under favorable moisture conditions that permitted N applied later in plant development to be made readily available to the plant.

Under semiarid conditions, the effects of split N applications on PC have been variable. In Colorado, Vaughan et al. (1990) evaluated the effect of fall-applied, spring-applied, and split applied AN on winter wheat yield and PC. Spring-applied AN increased yield and PC to a greater extent compared to fall-applied AN or split applications of AN. In order to achieve the same grain yield and PC as winter wheat that received AN in the spring, 20 and 18% more fall-applied and split-applied N was required, respectively. In southern Saskatchewan, Selles et al. (1997) found topdressing of spring wheat at anthesis that had received N at seeding had no effect on grain yield and marginally increased PC. Topdressing N at the five-leaf stage increased yield and PC. Topdressed N at anthesis applied directly to the soil was less effective than foliar N since timely rains were not received after N application. Furthermore, in some cases, foliar N resulted in substantial leaf burn when applied at the flag leaf stage or anthesis, reducing PC. Therefore, the effectiveness of midseason broadcast and foliar-applied N application under semiarid conditions is heavily dependent on environmental factors, particularly rainfall events to move the fertilizer into the root zone.

2.10 Influence of Protein Content on End-Use Quality

Besides grain grade, PC is traditionally recognized as the most influential factor affecting wheat breadmaking quality (Bushuk et al. 1969; Bushuk and MacRitchie 1989; Finney and Barmore 1948; Schofield 1994; Shewry and Miflin 1985; Shewry et al. 1986; Tipples et al. 1994; Wooding et al. 2000a). The importance of PC to end-use quality relates to its substantial effects on some of the most important technological properties of wheat, namely absorption of water by flour (Ayoub et al. 1994; Kosmolak and Crowle

1980; Tipples et al. 1994), dough rheological properties (Kosmolak and Crowle 1980; Pechanek et al. 1997; Preston and Tipples 1980; Wooding et al. 2000a), and bread loaf volume, or dough gas retention (Bushuk et al. 1969; Bushuk and MacRitchie 1989; Finney and Barmore 1948; Timms et al. 1981).

2.10.1 Effect of Protein Content on Flour Water Absorption

There are two types of water absorption that are relevant to the discussion of the effect of PC on end-use quality, namely Farinograph absorption and baking absorption (Tipples et al. 1994). Farinograph absorption is defined as the amount of water that can be added to a fixed weight of flour to produce dough having a specific consistency when mixed at a specified speed using the Brabender Farinograph (Tipples et al. 1994). The Farinograph is a torque measuring, recording dough mixer that is used to provide an initial estimate of baking absorption. Farinograph absorption depends strongly on PC; as flour PC increases, Farinograph absorption increases (Ayoub et al. 1994; Finney 1945; Kosmolak and Crowle 1980; Tipples et al. 1994).

Optimum baking absorption is the maximum amount of water that can be added to flour and yield dough of a consistency that can be conveniently handled by bakery equipment without the occurrence of problems such as dough stickiness (Finney 1945). Since bread flour is sold on a weight basis, and since bread yield will increase as water absorption increases, flour with a higher PC is more valuable to a baker compared to flour that is capable of absorbing less water.

2.10.2 Effect of Protein Content on the Rheological Properties of Dough

When wheat flour is mixed with water, dough is formed that exhibits characteristic visco-elastic properties (Bushuk and MacRitchie 1989; Hoseney 1988). The unique rheological properties conferred to dough by protein are generally regarded as being responsible for breadmaking quality (Fido et al. 1997; Schofield 1986). No other cereal grain flour exhibits these characteristics (Bushuk and MacRitchie 1989).

Numerous studies have involved the use of the Farinograph to evaluate dough rheology (Ayoub et al. 1994; Bushuk et al. 1969; Parades-López et al. 1985; Pechanek et al. 1997; Tipples et al. 1977; Wooding et al. 2000b). Generally, as flour PC increases, the time required to mix the dough to peak consistency increases. Farinograph stability and mixing tolerance index, which are both measures of tolerance of dough to mixing past peak consistency, also improve as PC increases. However, when PC is excessively high (e.g. 17% on a 13.5% moisture basis), negative effects on mixing characteristics (Tipples et al. 1977) can result. Increasing PC increases dough mixing requirements and positively affects dough strength to a point, but very high PC results in detrimental effects on end-use quality.

Like the Farinograph, the Mixograph is a torque-measuring, recording dough mixer. Compared to the Farinograph, the Mixograph is generally run at constant water absorption and the dough mixing action differs, resulting in very different results for the same flour sample. At constant water absorption, as flour PC increases, the time required to reach peak dough resistance to mixing (MDT) decreases, while peak dough resistance (PDR) increases (Kosmolak and Crowle 1980; Luo et al. 2000; Moss et al. 1981;

Wooding et al. 2000a). Like the Farinograph, stability and resistance to mixing past peak development increase as PC increases (Preston and Tipples 1980).

While the Farinograph and Mixograph measure resistance of dough to mixing, the Extensigraph measures dough extensibility. There are two key parameters that the Extensigraph generates, namely maximum resistance to extension and extensibility, or the degree to which a dough piece is able to stretch without breaking (Bangur et al. 1997). As dough strength increases as a result of increased PC, resistance to dough extension (Moss et al. 1981b) and extensibility (Kettlewell et al. 1998; Moss et al. 1981b; Zhao et al. 1999) increase. When PC is excessively high, resistance decreases markedly, resulting in poor quality dough for breadmaking (Tipples et al 1977). The role of grain sulphur content in influencing dough extensibility is also an important consideration along with PC, since sulfhydryl groups and disulphide bonds play a critical role in the visco-elastic properties of dough (Kettlewell et al. 1998; Zhao et al. 1999).

2.10.3 Effect of Protein Content on Loaf Volume

The ability of dough to retain gas during fermentation is responsible for the volume associated with a loaf of bread, and is attributable to the gluten proteins (Hoseney 1988). Finney and Barmore (1948) demonstrated a strong, positive, linear relationship between loaf volume and PC when evaluating a series of winter and spring wheat varieties over a wide range of flour PC, although the loaf volume potential of different cultivars differed along the same range of PC. Other researchers have also found that increasing PC results in increased loaf volume (Ayoub et al. 1994; Bushuk and MacRitchie 1989; Bushuk et al. 1969; Finney and Barmore 1948; Timms et al. 1981).

2.11 Protein Quality

Where end-use quality differs significantly among samples with similar PC, differences in end-use quality are attributable to differences in protein quality. While PC is simply the percentage of N in the grain multiplied by 5.7 (Simmonds and O'Brien 1981), protein quality is much more complex. Protein quality refers to the composition of distinct fractions of protein in endosperm or flour, each of which contributes uniquely to end-use quality.

2.12 Protein Classification and Nomenclature

Basically, wheat proteins can be classified as gluten (forming) proteins or non-gluten proteins. Non-gluten protein, namely the albumin/globulin fraction, plays a relatively small role in determining end-use quality. Gluten proteins, which are responsible for protein functionality in breadmaking, represent 80 to 90% of total flour protein, and increase as a percentage of total protein as PC increases (Schofield 1994; Stone and Savin 1999). The relative quantity and composition of the two protein fractions that constitute gluten protein, namely gliadin and glutenin, are of the most interest to researchers because of their tremendous influence on quality (Gupta et al. 1992; Hamada et al. 1982; MacRitchie 1992; MacRitchie et al. 1991; Schofield 1986; Schofield 1994; Shewry et al. 1986; Stone and Savin 1999; Wall 1979). Gliadin, which is a very heterogeneous protein fraction, is responsible for the viscous properties of dough during mixing (Fido et al. 1997; Wooding et al. 2000b). Conversely, glutenin is polymeric protein that exhibits a high degree of inter-molecular bonding (Gianibelli et al.

2001), reduces dough extensibility (Wieser and Kieffer 2001) and is the protein fraction responsible for dough strength (Schofield 1986; Wall 1979).

Wheat proteins were first classified into groups based on their sequential solubility in a series of solvents by Osborne in 1907 (Shewry et al. 1986; Wall 1979). Traditionally, these groups have been called albumins (soluble in water), globulins (insoluble in water but soluble in dilute solutions of salts), prolamins (soluble in aqueous alcohol), and glutelins (soluble in dilute acid or alkali). The majority of wheat flour protein is comprised of prolamin and glutelin, which are present in roughly similar amounts in gluten (Shewry et al. 1986; Stone and Savin 1999).

Instead of using extractability criteria to classify wheat proteins, Shewry et al. (1986) proposed that gluten proteins be classified into groups based on amino acid sequence and composition, including the presence or absence of inter- or intramolecular disulphide bonds. S-poor prolamins (ω-gliadins), S-rich prolamins (α-, β-, γ-gliadins, and low molecular weight glutenin subunits), and high molecular weight (HMW) prolamins (HMW glutenin subunits) each contribute uniquely to dough strength and extensibility (Bushuk and MacRitchie 1989; MacRitchie 1992; Schofield 1986; Schofield 1994), and can be separated based on their molecular size. In the following discussion, gliadin sub-fractions are referred to individually (α-, β-, γ-, and ω-gliadins). Glutenin is referred to as either small or large polymers (glutenin molecules), or in terms of in its chemically reduced form as low molecular weight glutenin subunits (LMW-GS) or high molecular weight glutenin subunits (HMW-GS).

2.12.1 Albumin and Globulin Protein

The albumins and globulins represent roughly 15 to 20% of total protein in flour (Shewry et al. 1986; Stone and Savin 1999). These proteins have almost no direct effect on breadmaking protein functionality, though because this fraction contains a number of enzymes, namely amylases and proteases, the albumin/globulin fraction may contribute indirectly to breadmaking quality (Bushuk and MacRitchie 1989). Approximately half of the albumin/globulin fraction is located in the embryo, which is removed during white flour milling (Stone and Savin 1999).

2.12.2 Characterization of Gliadin

The gliadin fraction is very heterogeneous, and is composed of up to 50 different single-chain polypeptides in a given wheat genotype (Schofield 1986). Gliadin molecules associate non-covalently by hydrogen bonding or hydrophobic interactions. Gliadin molecules are generally considered to be non-aggregating, although they may interact with glutenin (Sapirstein and Fu 2000; Shewry et al. 1986). Upon hydration, pure gliadin forms a mass that is easily stretched and does not hold its form well (Wall 1979), and is responsible for dough extensibility rather than elasticity (Schofield 1986; Shewry et al. 1986; Schofield 1994; Stone and Savin 1999; Wall 1979).

Gliadin can be further classified into α-, β-, γ-, and ω-gliadin fractions based on electrophoretic mobility under acidic conditions (Wall 1979; Wrigley and Bietz 1988). The α-, β-, and γ-gliadins have a MW of 30000 to 45000 kDa and have roughly 2-3% cysteine and methionine residues. Mainly because of the presence of an even number of cysteine residues (typically 6 or 8), gliadin molecules participate only in intramolecular bonding (Wall 1979; Shewry et al. 1986). Polypeptides similar to γ–gliadins are incorporated into glutenin via disulphide bonding (Huebner et al. 1997; Lew et al. 1992). However, these polypeptides have an odd number of cysteine residues, meaning they can participate in inter-molecular disulphide bonds. The ω-gliadins have a MW of 40000 to 70000 kDa and lack S-containing amino acids, namely cysteine and methionine (Shewry et al. 1986; Shewry and Tatham 1997).

A few studies have reported the relative of proportion of gliadin fractions in relation to total gliadin content. Wieser et al. (1994) found the proportion of α-+β-, γ-, and ω-gliadins in a wide range of wheat cultivars to be 43.9-59.9, 30.5-45.6, and 6.2-20.0%, respectively. When the French soft wheat cultivar Thésée was exposed to a range of N supply and temperature regimes, Daniel and Triboi (2001) reported the proportions of α-+β-, γ-, and ω-gliadins to be 42-58, 24.5-32, and 10-19%, respectively. The reason for the differences in the reported values is likely due to a combination of differences in methods of extraction, as well as the effects of genotype and environment.

2.12.3 Characterization of Glutenin

Glutenin is polymeric protein composed of many individual subunits, each with a MW between 12000 to 130000 kDa (MacRitchie et al. 1990; Stone and Savin 1999). Glutenin molecules are able to aggregate because of intermolecular disulphide bonding (MacRitchie et al. 1990). Because of the high degree of intermolecular bonding and aggregative behaviour of polymeric glutenin, the MW of an individual glutenin molecule can be as high as several million kDa, making glutenin the largest known protein molecule found in nature (Wrigley 1996). Up to 20 different polypeptides comprise glutenin, making it less heterogeneous than gliadin (Schofield 1986). Upon hydration, pure glutenin forms a tough mass that is elastic and resistant to stretching (Wall 1979). These properties make glutenin responsible for dough strength (Hamada et al. 1982; Shewry et al. 1986; Stone and Savin 1999; Wall 1979; Weegels et al. 1996).

Reducing glutenin by breaking disulphide bonds yields two classes of subunits, namely LMW-GS and HMW-GS (Kasarda 1989). LMW-GS have an average MW of 30000 to 45000 kDa, and an amino acid sequence similar to the α-, β-, and γ-gliadins (S-rich gliadin); the structure of LMW-GS most closely resembles γ-gliadin (Lew et al. 1992). The cysteine residues of LMW-GS participate in either intra- or intermolecular disulphide bonds. Cysteine residues capable of inter-molecular bonding allow for the formation of glutenin polymers (Lew et al. 1992) via formation of disulphide bonds with other LMW-GS or HMW-GS (Shewry and Tatham 1997). Generally, the ratio of LMW-GS to HMW-GS is 2:1 to 3:1 (Kasarda 1989). Gupta et al. (1993) reported sodium dodecyl sulfate (SDS)-soluble glutenin contained 70% LMW-GS and 30% HMW-GS, while SDS-insoluble glutenin contained 60% LMW-GS and 40% HMW-GS.

The MW of HMW-GS have been reported to be 80000 to 120000 kDa, although estimates based on derived amino acid sequences indicate a MW between 60000 to 90000 kDa (Gianibelli et al. 2001). In terms of their amino acid sequence, HMW-GS contain relatively more glycine and less glutamine/glutamic acid than α-, β-, or γ-gliadins. More importantly, HMW-GS contain only 0.5 to 1.5% cysteine, and are therefore classified as being S-poor (Zhao et al. 1999a). The cysteine residues of HMW-GS allow for intermolecular disulphide bonding between LMW-GS or other

HMW-GS, and occur only within 100 residues of each end of the polypeptide chain (Kasarda 1989).

Glutenin molecules can be also classified into sub-groups based on their solubility in SDS (Gupta et al. 1993; Stone and Savin 1999) or other solvents such as acetic acid (Orth and Bushuk 1972) or propanol (Sapirstein and Johnson 2000). The MW of SDS-soluble polymer is lower than the MW of SDS-insoluble polymer due in part to the higher ratio of HMW-GS to LMW-GS in SDS-insoluble glutenin (Gupta et al. 1993; Stone and Savin 1999).

2.13 Effects of Individual Protein Fractions on Dough Rheological Properties

As mentioned previously, gliadin and glutenin have dramatically different effects on the rheological properties of dough. The same can be said of the contribution of individual gliadin and glutenin fractions to dough strength and extensibility.

2.13.1 Effect of Gliadin on Dough Rheological Properties

Gliadin is mainly responsible for the viscous properties of dough during mixing. With respect to the Mixograph, the quantity of gliadin is negatively correlated to dough mixing strength, peak dough resistance, and stability (Fido et al. 1997; MacRitchie 1987; Uthayakumuran et al. 1999; Uthayakumuran et al. 2000; Wooding et al. 2000b). As for studies involving the Extensigraph, many studies have confirmed gliadin increases the extensibility of dough while decreasing maximum resistance (Khatkar et al. 1995; Uthayakumuran et al. 1999; Uthayakumuran et al. 2000; Wooding et al. 2000b).

2.13.1.1 Effect of Individual Gliadin Fractions on Dough Rheological Properties

The effect of individual gliadin fractions on dough strength has also been investigated (Branlard and Dardevet 1985; Fido et al. 1997; Huebner et al. 1997; Scanlon et al. 1990; van Lonkhuijsen et al. 1992). However, because gliadins are encoded by complex gene loci and inherited in blocks, they are closely linked genetically. Therefore, research surrounding the effects of individual gliadins on end-use quality is not as well-defined as it is for glutenin.

Branlard and Dardevet (1985) observed α- and β-gliadins were positively and moderately correlated with swelling (G), as measured with the Alveograph, while weak, negative correlations were observed between individual gliadin fractions (α-, β-, γ-, and ω-gliadins) and the ratio of tenacity (P) to extensibility (L). Fido et al. (1997) evaluated the contribution of individual gliadins to dough strength and demonstrated the addition of purified gliadins to low and high protein flours resulted in decreased dough strength. For the Mixograph, the relative weakening effects were in the order of $\omega\text{-} \approx \alpha\text{-} \approx \beta\text{-} > \gamma$, while the order for the Extensigraph was $\gamma\text{-} > \alpha\text{-} \approx \beta\text{-} \approx \omega$. Given the different contributions of individual gliadin fractions to dough strength, environmental factors that influence the quantity or composition of gliadin are expected to affect end-use quality.

2.13.2 Effect of Glutenin on Dough Rheological Properties

In comparing the relative contribution of gliadin and glutenin to end-use quality, research clearly points to the much greater importance of glutenin (Gupta et al. 1992; Gupta and MacRitchie 1991; Huebner and Wall 1976; MacRitchie 1987; Orth and Bushuk 1972; Sapirstein and Fu 1998; Schofield 1986; Weegels et al. 1996). As flour glutenin content increases, Mixograph dough development time decreases, peak dough resistance increases (Preston and Tipples 1980; Gupta et al. 1992; Wooding et al. 2000b), and dough resistance to over-mixing increases (Preston and Tipples 1980). When flour is evaluated with the Farinograph, dough development time increases as glutenin content increases (Hamada et al. 1982; Preston and Tipples 1980), and dough stability and mixing tolerance index improve (Preston and Tipples 1980).

The effect of glutenin content on dough extensibility has also been evaluated. Using a device similar to the Extensigraph, Uthayakumaran et al. (2000) determined that increased levels of glutenin increased rupture viscosity but decreased rupture strain of a dough, confirming that glutenin contributes to strength properties of dough rather than extensibility. As glutenin content increases, dough maximum resistance and extensibility (Antes and Wieser 2001; Gupta et al. 1992; Gupta et al. 1993; Singh et al. 1990; Southan and MacRitchie 1999) are expected to increase, although a negative relationship between glutenin content and extensibility has also been reported (Wieser and Kieffer 2001).

2.13.2.1 Contribution of HMW-GS and LMW-GS to Dough Rheological Properties

The contribution of HMW-GS to end-use quality is generally considered to be greater than that of the LMW-GS (Gupta and MacRitchie 1991; Hamada et al. 1982; Kasarda 1989; MacRitchie 1991; Weegels et al. 1996). Using sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), the effect of HMW-GS on dough development time was determined by Pechanek et al (1997) and Wooding et al (2000b) to be more pronounced than that of LMW-GS, though increasing the quantity of both LMW-GS and HMW-GS positively influenced dough strength.

Differences of opinion surrounding the overall effect of glutenin on extensibility may be due to the significantly different contribution of HMW-GS versus LMW-GS to glutenin functionality (Fu et al. 1998). The positive effect of HMW-GS on dough extensibility properties has been demonstrated by many researchers (Antes and Wieser 2001; Gupta et al. 1991; Verbruggen et al. 2001; Wieser and Kieffer 2001). Gupta et al. (1991) showed that as a percentage of total protein, increasing the percentage of HMW-GS increased maximum dough resistance to extension much more than when the percentage of LMW-GS increased. In a similar study, Wieser and Kieffer (2001) reported that the addition of twice the amount of LMW-GS was required to get the same degree of maximum resistance to extension achieved with the addition of HMW-GS. Furthermore, the addition of LMW-GS to base flour has been shown to actually decrease maximum resistance and extensibility (Antes and Wieser 2001; Verbruggen et al. 2001). Hamada et al. (1982) postulated that stronger wheats must contain a higher percentage of HMW-GS, since dough mix time and stability increased when gluten was of a higher MW. Clearly, environmental factors that modify the ratio of HMW-GS to LMW-GS will influence dough rheological properties.

2.13.2.2 Effect of Average Polymer Size on Dough Rheological Properties

The size distribution of glutenin polymers is an important consideration with respect to dough functionality (Fu et al. 1998). The positive effect of glutenin on dough strength is attributed in large part to the molecular size of glutenin, since as average polymer size increases, dough strength increases (Gupta et al. 1993; Gupta and MacRitchie 1991; Kasarda 1989; MacRitchie 1987; Orth and Bushuk 1972; Sapirstein and Fu 1998; Schofield 1986; Shewry and Tatham 1997; Singh and MacRitchie 2001; Weegels et al. 1996). However, the contribution of large and small polymers to dough strength differs, which may explain the inconsistencies sometimes observed in the relationship between total glutenin content and dough strength parameters (Gupta et al. 1993; South and MacRitchie 1999). A number of researchers have reported a higher ratio of HMW-GS of LMW-GS in SDS-insoluble glutenin compared to SDS-insoluble glutenin (Southan and MacRitchie 1999; Stone and Savin 1999). As such, the differences in GS composition are thought by some to be the reason behind the stronger contribution of larger glutenin to dough strength.

2.14 Effects of Individual Protein Fractions on Loaf Volume

Finney and Barmore (1948) demonstrated a strong, positive, linear relationship between loaf volume and PC, as well as differences in loaf volume potential of different cultivars along the same range of PC. The latter was postulated to be due in part to differences in protein composition. Given the dramatic differences in the contribution of gliadin and glutenin to dough strength and extensibility, it should come as no surprise that these protein fractions has significantly different effects on breadmaking quality.

2.14.1 Effect of Gliadin on Loaf Volume

Results regarding the effect of gliadin on loaf volume are variable. In a flour reconstitution study, MacRitchie (1987) found that the first 50% of protein extracted (using increasing concentrations of HCl), which corresponded to gliadin, maintained or slightly depressed loaf volume. Other researchers (Johansson et al. 2001; Martin et al.

1992; Pechanek et al. 1997) have found a positive relationship between loaf volume and gliadin content, which is not surprising since as PC (and loaf volume) increases, gliadin content also increases. Other researchers have reported weak relationships between gliadin and loaf volume (Gupta et al. 1992; Hamada et al. 1982; MacRitchie et al. 1991; Martin et al. 1992; Scanlon et al. 1990), while loaf texture was found by Martin et al. (1992) to be strongly correlated with gliadin.

2.14.1.1 Effect of Individual Gliadin Fractions on Loaf Volume

Studies involving the effect of individual gliadin fractions on loaf volume have clarified this controversy. Using wheat varieties with a constant HMW glutenin-A subunit composition, van Lonkhuijsen et al. (1992) determined variation in gliadin composition was responsible for 82% of the variation in loaf volume. Furthermore, the peak most highly correlated with loaf volume, as well as positively correlated, was an γ–gliadin peak. Three other peaks, of which two corresponded to ω-gliadins while the other corresponded to a β–gliadin, were negatively correlated with loaf volume. The positive relationship between gliadins and loaf volume was also reported by Huebner et al. (1997), who also found α-, β-, and ω-gliadins were negatively correlated with loaf volume, while γ–gliadin was positively correlated with loaf volume. However, sine the γ–gliadin fraction did not increase proportionately with loaf volume as compared to α-, β-, and ω-gliadins, the positive influence of γ–gliadin on loaf volume decreased as PC increased. While all of the gliadin fractions tend to weaken dough and confer extensibility, the γ-gliadins appear to weaken dough the least and may have positive effects on loaf volume.

2.14.2 Effect of Glutenin on Loaf Volume

The positive effect of glutenin on loaf volume has also been demonstrated by many researchers (Huang and Khan 1997; Huebner and Wall 1976; MacRitchie et al. 1991; Martin et al. 1992; Pechanek et al. 1997; Preston and Tipples 1980; Sapirstein and Fu 2000; Timms et al. 1981), as has the greater contribution of HMW-GS to loaf volume compared to LMW-GS (Antes and Wieser 2001; Pechanek et al. 1997; Timms et al. 1981; Weegels et al. 1996). HMW-GS was determined by Pechanek et al. (1997) to be much more strongly correlated to loaf volume than LMW-GS, while Martin et al. (1992) found both LMW-GS and HMW-GS were strongly correlated to loaf volume. Addition of HMW-GS to a base flour was demonstrated by Antes and Wieser (2001) to increase loaf volume, while the opposite was true of the addition of LMW-GS. Regardless, a higher proportion of HMW-GS relative to LMW-GS is likely to increase loaf volume (Timms et al. 1981).

Given the importance of HMW-GS to end-use quality, it should be no surprise that as the average molecular size of glutenin increases, loaf volume also increases (Daniel and Triboi 2002; Huang and Khan 1997; Jia et al. 1996b; Weegels et al. 1996). Comparing the effects of the addition of acid-soluble and acid-insoluble glutenins to base flour (relatively comparable to SDS-soluble and SDS-insoluble polymer), Preston and Tipples (1980) demonstrated similar increases in loaf volume with the addition of gluten proteins and acid-soluble glutenin. The addition of acid-insoluble glutenin significantly reduced loaf volume, although the loaf volume decreases were recorded only when the acid-insoluble glutenin was added in excess. These results were in disagreement with those of Orth and Bushuk (1972). Tipples (1980) attributed the decrease in loaf volume to acid-insoluble glutenin that disaggregated during dough mixing rather than the acid-insoluble glutenin fraction as a whole. Zhu and Khan (2001) demonstrated loaf volume was positively correlated to the proportion of insoluble glutenin in flour, while the proportion of insoluble glutenin was negatively correlated to loaf volume.

2.15 Effect of the Ratio of Gliadin to Glutenin on End-Use Quality

Although the importance of the relationship between gliadin and glutenin in determining end-use quality is well established, research surrounding the importance of the ratio of gliadin to glutenin on wheat end-use quality has not yielded consistent results. While some research suggests the ratio of gliadin to glutenin is a key factor in determining dough rheological properties and breadmaking quality (Janssen et al. 1991; Timms et al. 1981; Uthayakumuran et al. 1999; Uthayakumuran et al. 2000), other researchers have found the ratio of gliadin to glutenin has no value as a predictor of end-use quality (Bushuk and MacRitchie 1989; Johansson et al. 2001; Orth and Bushuk 1972; Pechanek et al. 1997). These differences in experimental results may be due to different extraction procedures or other methods of fractionation. Two recent papers by Uthayakumaran et al. (1999, 2000) strengthen the case for use of the gliadin to glutenin ratio as a predictor of end-use quality. For example, increases in the glutenin to gliadin ratio at constant protein content resulted in increased mix time, peak dough resistance, maximum resistance to extension, and loaf volume (Uthayakumaran et al. 1999).

There are a several theories for the interaction between gliadin and glutenin and its impacts on end-use quality. Sapirstein and Fu (2000) suggested that strong mixing wheats have glutenin molecules of larger size compared to weaker wheats. As polymer size increases, specific surface area decreases, reducing the amount of surface area available for interaction with other proteins such as gliadins. Khatkar et al. (1995) proposed that gliadin acts as a plasticizer in interrupting the interaction between glutenin molecules during mixing, in turn increasing extensibility and decreasing resistance to extension. Regardless, the interaction of gliadin and glutenin has been proposed to explain at least part of the role of gliadin in determining end-use quality, as well as the effect of increasing the ratio of gliadin to glutenin.

2.16 Protein Accumulation in the Developing Grain

The accumulation of individual protein fractions in the grain have been evaluated by many researchers using methods that are based solely on extractability and/or SDS-PAGE (Bollini et al. 1981; Castle and Randall 1987; Dell'aquila et al. 1983; Khan and Bushuk 1976; Galterio et al. 1987; Johansson et al. 1994; Kaczkowski et al. 1988; Kaczkowski et al. 1987). However, given the wide variety of extraction techniques employed by different researchers, what one group considers glutenin may be considered gliadin by another group. The use of size-exclusion high-performance liquid chromatography (SE-HPLC) has been suggested as a more accurate tool in assessing the contribution of individual protein fractions to end-use quality (Batey et al. 1991; Dachkevitch and Autran 1989; Pechanek et al. 1997), since protein can be classified according to molecular size as well as extractability. In order to simplify the discussion, the following section focuses on research utilizing SE-HPLC to track the pattern of protein accumulation in the developing grain (Bénétrix et al. 1994; Daniel and Triboi 2001; Daniel and Triboi 2002; Gupta et al. 1996; Huebner et al. 1990; Jamieson et al.

2001; Panozzo et al. 2001; Stone and Nicolas 1996a; Stone and Nicolas 1996b; Stone and Savin 1999; Triboi et al. 1990; Triboi and Leblevenec 1995; Wright et al. 2000; Zhu and Khan 1999), though other research will be referred to periodically.

2.16.1 General Pattern of Protein Accumulation

The accumulation of individual protein fractions is asynchronous and highly ordered, both in terms of initiation and rate of protein synthesis (Daniel and Triboi 2002; Jamieson et al. 2001; Stone and Nicolas 1996a; Stone and Savin 1999). The accumulation of protein fractions in the kernel can be expressed as the percentage of total grain protein or as the quantity of protein in the kernel (Daniel and Triboi 2002; Stone and Nicolas 1996a; Triboi et al. 1990). When expressed on the basis of weight, the accumulation of gliadin and glutenin, like N itself, is linear as a function of thermal time, (Daniel and Triboi 2002; Jamieson et al. 2001; Triboi and Leblevenec 1995).

Depending on environmental conditions, N accumulation in the kernel may proceed for as long as 40 to 50 days after anthesis (DAA) (Gupta et al. 1996; Panozzo and Eagles 2001; Stone and Nicolas 1996a). The order of appearance of the three main protein fractions is 1) albumin/globulin 2) gliadin 3) glutenin, although the initiation of synthesis of each fraction is not nearly as well understood (Gupta et al. 1996; Jamieson et al. 2001; Stone and Nicolas 1996a).

2.16.2 Accumulation of Albumin/Globulin Fraction

During the first 10 DAA, the albumin/globulin fraction is readily detectable (Daniel and Triboi 2002; Jamieson et al. 2001; Panozzo et al. 2001; Stone and Nicolas 1996a; Stone and Savin 1999), and represents over 80% of total protein in the kernel (Panozzo et al. 2001). Accumulation of the albumin/globulin fraction has been reported to continue up to 10 DAA (Jamieson et al. 2001), 19 DAA (Gupta et al. 1996; Stone and Savin 1999) or even 40 DAA (Stone and Nicolas 1996a). However, the rate of synthesis of the albumin/globulin fraction is greatest within the first 10 DAA, and then proceeds at a very slow rate, if at all. At maturity, the albumin/globulin fraction represents between 20 to 30% of total grain protein (Panozzo et al. 2001; Stone and Savin 1999).

2.16.3 Accumulation of Gliadin

The gliadin fraction is detectable within the first 7 to 10 DAA (Dell'aquila et al. 1983; Gupta et al. 1996; Johansson et al. 1994; Panozzo et al 2001; Stone and Nicolas 1996a), and is the first storage protein fraction to accumulate in quantity. The rate of gliadin synthesis is most rapid during mid-development of the wheat kernel. Gupta et al. (1996) determined maximum gliadin synthesis occurred between 22 to 31 DAA, while Stone and Nicolas (1996a) and Panozzo et al. (2001) found maximum gliadin synthesis occurred between 10 to 30 DAA and 7 to 21 DAA, respectively. By the time the rapid phase of gliadin accumulation is complete, gliadin typically represents 30 to 40% of total protein and maintains that level until maturity (Panozzo et al. 2001; Stone and Nicolas 1996a; Stone and Savin 1999).

2.16.3.1 Accumulation of Individual Gliadin Fractions

The accumulation pattern of individual gliadin fractions has also been studied (Bénétrix et al. 1994; Huebner et al. 1990; Kaczkowski et al. 1987; Mecham et al. 1981; Zhu and Khan 1999). Zhu and Khan (1999) detected the presence of α-, β-, γ-, and ω-gliadins 10 DAA, and found the proportion of γ–gliadins increased during the filling period, while the proportion of α– and β-gliadins remained relatively constant, arriving at a stable level 19 to 25 DAA. The synthesis of α-, β-, and γ-gliadins were found to increase considerably between 12 to 18 DAA (first and second sampling periods) by Mecham et al. (1981). Kaczkowski et al. (1987) detected ω–gliadins 10 to 12 DAA, while α-, β-, and γ-gliadins were detected 18 DAA. Differences in extraction procedures may be responsible for the confusion surrounding the accumulation pattern of individual gliadin fractions.

2.16.4 Accumulation of Glutenin

The synthesis of glutenin proceeds at a slower rate than that of gliadin. The glutenin fraction is detectable in small quantities within the first 7 to 10 DAA (Gupta et al. 1996; Huebner et al. 1990; Panozzo et al 2001; Stone and Nicolas 1996a). Glutenin is not present in large quantities until the latter half of the filling period, and is readily detectable around 20 DAA (Gupta et al. 1996; Panozzo et al. 2001; Stone and Nicolas 1996). The increase in glutenin synthesis was found by Panozzo et al (2001) to commence at the same time as the decrease in gliadin synthesis (21 d), while Huebner et al. (1990) determined the rate of glutenin synthesis did not exceed the rate of gliadin synthesis until the fifth week after anthesis. Given these results, the ratio of gliadin to glutenin has been shown to increase during the first half of filling and then decrease considerably, particularly at the end of filling when the steep decline in kernel moisture content occurs (Triboi et al. 1990; Triboi and Leblevenec 1995).

2.16.4.1 Synthesis of LMW and HMW Glutenin Subunits

Complicating the dynamics of glutenin accumulation is the differential accumulation pattern of LMW-GS and HMW-GS (Gupta et al. 1996; Panozzo et al. 2001; Zhu and Khan 1999). Synthesis of HMW-GS and LMW-GS has been reported to occur concurrently, and the quantity of each fraction in the kernel increases over time (Bénétrix et al. 1994; Gupta et al. 1996; Zhu and Khan 1999). Panozzo et al. (2001) demonstrated that synthesis of HMW-GS commenced 7 DAA, or 7 d earlier than synthesis of LMW-GS, and suggested that the initial synthesis of HMW-GS served as a backbone structure for the development of glutenin polymers.

In relative terms, the overall synthesis of LMW-GS is greater than that of HMW-GS during kernel development (Gupta et al. 1996; Panozzo et al. 2001; Zhu and Khan 1999), while on a percentage basis, the increase in the HMW-GS fraction is greater than that of LMW-GS (Gupta et al. 1996). In the first half of glutenin subunit synthesis, the accumulation rate of LMW-GS is greater than that of HMW-GS (Bénétrix et al. 1994; Gupta et al. 1996; Panozzo et al. 2001; Zhu et al. 1999). Panozzo et al. (2001) reported after the synthesis of LMW-GS began (14 DAA), the rate of LMW-GS accumulation in the kernel exceeded that of HMW-GS until 28 DAA, at which point HMW-GS accumulation increased considerably relative to LMW-GS. Given the increase in HMW-GS synthesis late in development, an increase in the ratio of HMW-GS to

LMW-GS glutenin subunits over the course of kernel development has been reported by a number of authors (Gupta et al. 1996; Zhu and Khan 1999).

2.16.4.2 Polymerization of Glutenin

Given that the peak rate for HMW-GS accumulation follows that of LMW-GS, the average size of glutenin polymer increases over the course of grain filling (Bénétrix et al. 1994; Daniel and Triboi 2002; Gupta et al. 1996; Jamieson et al. 2001; Panozzo et al. 2001; Stone and Nicolas 1996a). The polymerization process proceeds upon the onset of glutenin synthesis as HMW-GS and LMW-GS are produced and are subsequently linked via disulphide bonds to form glutenin polymers. Polymerization of glutenin occurs as early as 7 to 10 DAA (Gupta et al. 1996; Zhu and Khan 1999), although a significant increase in polymerization does not occur until late in kernel development (Aussenac and Carceller 2000; Daniel and Triboi 2002; Gupta et al. 1996; Jamieson et al. 2001; Stone and Nicolas 1996a; Triboi and Leblevenec 1995; Zhu and Khan 1999).

Stone and Nicolas (1996a) detected 90% of polymeric protein as SDS-soluble protein (small polymers) 35 DAA, at which point the contribution of SDS-soluble protein to total protein decreased dramatically. Only trace amounts of SDS-insoluble protein (large polymers) were present at 25 DAA, but by physiological maturity (50 DAA), SDS-insoluble polymer represented 60% of total polymer. Aussenac and Carceller (2000) and Hussain and Lukow (1995) also detected the onset of large glutenin polymer accumulation roughly 35 DAA. The increase in HMW-GS synthesis and the increase in the ratio of HMW-GS to LMW-GS later in kernel development is thought to be responsible for the increase in polymer size (Gupta et al. 1996; Stone and Nicolas 1996a; Zhu and Khan 1999).

2.17 Modification of Protein Composition by Environment and Fertilization

Although the deposition of different protein fractions is highly ordered, it is also asynchronous (Jamieson et al. 2001; Panozzo et al. 2001; Stone and Savin 1999). Given the dramatic effect of environment on the duration of the filling period, as well as growth and development in general, factors that affect the rate and quantity of deposition will affect the composition of protein and, ultimately, end-use quality. The following section deals with the effect of environment on the composition and content of gliadin and glutenin, as well as their respective sub-fractions.

2.17.1 Contribution of Genotype and Environment to Protein Quality

Wheat quality is influenced by genotype, environment, and the interaction between genotype and environment (Fowler et al. 1998; Graybosch et al. 1995; Graybosch et al. 1996; Lukow and McVetty 1991; Panozzo et al. 2000; Peterson et al. 1986; Rousset et al. 1985; Zhu and Khan 2001). The degree to which individual protein fractions are influenced by genotype and environment varies. The strong influence of environment on the composition and quantity of gliadin has been demonstrated by a number of researchers (Castle and Randall 1987; Doekes and Wennekes 1982; Huebner and Bietz 1988; Huebner et al. 1997; Marchylo et al. 1990; Pechanek et al. 1997; Triboi et al. 2000; Wieser and Seilmeier 1998). A number of studies suggest gliadin is much more strongly influenced by environment than genotype compared to glutenin (Graybosch et al. 1996; Panozzo and Eagles 2000).

Genetics predetermines the actual composition of HMW glutenin subunits (Lukow et al. 1989; Payne et al. 1987), while the effect of environment is to influence the quantity and composition of glutenin polymer (Kolster et al. 1991; Panozzo and Eagles 2001; Zhu and Khan 2000). Within the glutenin fraction itself, Zhu and Khan (2000) demonstrated SDS-soluble glutenin was influenced more by environmental factors as compared to genotypic factors, while the opposite was true of SDS-insoluble glutenin. While the influence of environment on gliadin is much greater relative to glutenin, both fractions are influenced by environment, both in terms of crop management and weather.

2.17.2 Effect of Increasing Nitrogen Supply on Gliadin Content and Composition

Several studies have demonstrated the positive effect of increased N supply on gliadin content (Daniel and Triboi 2000; Daniel and Triboi 2001; Doekes and Wennekes 1982; Dubetz et al. 1979; Johansson et al. 2001; Pechanek et al. 1997; Stenram et al. 1990; Timms et al. 1981; Triboi and Triboi-Blondel 2001). Since gliadin content and composition at maturity is a function of the rate of accumulation and duration of gliadin synthesis, increased N availability results in increased gliadin content. Since the increase in gliadin content is greater than the increase in glutenin as a result of increased N supply, the ratio of gliadin to glutenin increases as N supply increases (Daniel and Triboi 2000; Daniel and Triboi 2001; Doekes and Wennekes 1982; Dubetz et al. 1979; Pechanek et al. 1997; Stenram et al. 1990; Triboi et al. 2000; Triboi and Triboi-Blondel 2001).

The composition of gliadin also changes as grain N content increases. The quantity of ω-gliadin (Daniel and Triboi 2000; Daniel and Triboi 2001; Timms et al. 1981; Wooding et al. 2000b) and α- and γ-gliadin (Pechanek et al. 1997; Wieser and Seilmeier 1998; Wooding et al. 2000b), have been shown specifically to be affected more than the accumulation other gliadin fractions. In response to increasing N supply, Wieser and Seilmeier (1998) reported the quantity of α- and β- (combined), ω-, and γ-gliadins increased 79, 109-149, and 50%, respectively.

The proportion of ω-gliadin generally increases as N supply increases (Daniel and Triboi 2000; Daniel and Triboi 2001; Wieser and Seilmeier 1998). The proportions of α-gliadin, β-gliadin (Daniel and Triboi 2000; Daniel and Triboi 2001; Pechanek et al. 1997; Timms et al. 1981), and γ-gliadin (Daniel and Triboi 2000; Daniel and Triboi 2001; Huebner et al. 1997; Timms et al. 1981; Wieser and Seilmeier 1998) have all been demonstrated to decrease with increasing supply. Working with hard red winter wheat cultivars, Huebner et al. (1997) and Wieser and Seilmeier (1998) found that γ-gliadin did not rise in direct proportion to other gliadins. Since loaf volume is positively correlated to the proportion of γ-gliadin, the proportionately smaller rise of γ-gliadin compared to α-, β-, and ω-gliadins was responsible for reduced increases in loaf volume observed by Huebner et al. (1997) as PC increased.

2.17.3 Effect of Increasing Nitrogen Supply on Glutenin Content and Composition

Glutenin content increases as N supply increases (Johansson et al. 2001; Pechanek et al. 1997; Peltonen 1992; Peltonen and Virtanen 1994; Timms et al. 1981; Wieser and Seilmeier 1998; Triboi et al. 2000; Zhu et al. 1999). The quantity of LMW-GS and

HMW-GS also increases in response to increased N supply (Johansson et al. 2001; Martin et al. 1992; Pechanek et al. 1997; Wieser and Seilmeier 1998; Timms et al. 1981; Triboi et al. 2000).

N fertilization has also been found to increase the proportion of HMW-GS and decrease the proportion of LMW-GS, in turn increasing the ratio of HMW-GS to LMW-GS (Pechanek et al. 1997; Singh et al. 1990; Weiser and Seilmeier 1998; Wooding et al. 2000b; Zhu et al. 1999). Zhu et al. (1999) reported that the ratio of HMW-GS to LMW-GS increased slightly for SDS-soluble glutenin in two sets of wheat genotypes. An increase in the ratio of HMW-GS to LMW-GS should translate into improved breadmaking quality, since production of HMW-GS increases average MW and contributes more to breadmaking quality and dough strength than LMW-GS (Pechanek et al. 1997; Southan and MacRitchie 1999; Stone and Savin 1999; Timms et al. 1981; Weegels et al. 1996). Other studies have reported an increase in the quantity of LMW-GS relative to HMW-GS, although results have been inconsistent and variable (Peltonen and Virtanen 1994; Triboi et al. 2000; Triboi and Triboi-Blondel 2001).

2.17.4 Effect of Sulphur Fertility on Protein Composition

The effect of sulphur fertility, alone or in combination with N fertility, has pronounced effects on protein composition (Castle and Randall 1987; Fullington et al. 1987; MacRitchie and Gupta 1993; Randall and Wrigley 1986; Shewry and Tatham 1997; Unger 2002; Wrigley et al. 1984; Zhao et al. 1999a; Zhao et al. 1999b). When soil S status is low, increases in the proportion of S-poor protein fractions are observed (HMW-GS and ω-gliadin), while the proportion of S-rich protein fractions decreases, namely α-, β- and γ-gliadin, along with LMW-GS. Increases in the proportion of S-poor proteins are associated with dough that exhibits increased dough strength, increased resistance to extension, and reduced extensibility (Wooding et al. 2000b; Wrigley et al. 1984; Zhao et al. 1999a), as well as reduced breadmaking quality (Kettlewell et al. 1998; Moss et al. 1981; Zhao et al. 1999a; Zhao et al. 1999b).

2.17.5 Effect of Temperature Stress on Gliadin Composition

High temperature stress primarily affects the gliadin protein fraction (Blumenthal et al. 1993; Borghi et al. 1995; Ciaffi et al. 1996; Corbellini et al. 1997; Daniel and Triboi 2000; Daniel and Triboi 2001; Panozzo and Eagles 2000; Panozzo et al. 2001; Stone and Nicolas 1996b). In response to increased temperature, the rate of gliadin synthesis increases. However, the quantity of gliadin in the kernel decreases overall due to a reduction in the length of the filling period (Blumenthal et al. 1993; Borghi et al. 1995; Ciaffi et al. 1996; Daniel and Triboi 2000; Daniel and Triboi 2001; Stone and Nicolas 1996b; Triboi and Leblevenec 1995). Increasing the rate of gliadin synthesis and reducing the duration of both gliadin and glutenin synthesis results in an increase in the ratio of gliadin to glutenin, in turn lowering dough strength and affecting end-use quality (Blumenthal et al. 1993; Daniel and Triboi 2000; Daniel and Triboi 2001).

With respect to individual gliadin fractions, Daniel and Triboi (2001) determined the effect of elevated temperature on gliadin accumulation was greater for α- and β-gliadin relative to γ- or ω-gliadin. The proportion of α-, β- and ω-gliadin increased as temperature increased, while the proportion of γ-gliadin decreased. Ciaffi et al. (1996) observed increases in the proportion of γ- and ω-gliadin as heat stress increased.

2.17.6 Effect of Environment on Glutenin Polymerization

In recent years, the effect of environment on glutenin polymerization has attracted considerable interest, given the importance of polymer size to end-use quality (Gupta et al. 1993; Southan and MacRitchie 1999; Stone and Savin 1999). Along with a reduction in the quantity of glutenin as a result of temperature stress (>35°C) during filling, a number of researchers have also observed a reduction in the proportion of SDS-insoluble polymer relative to SDS-soluble polymer. The reduction in the proportion of SDS-insoluble polymer indicates a reduction in glutenin polymerization (Ciaffi et al. 1996; Corbellini et al. 1997; Stone et al. 1997; Stone and Nicolas 1996b; Triboi and Leblevenec 1995). Negative effects of heat stress on the polymerization of glutenin are most pronounced when heat stress is applied late during the filling period (Corbellini et al. 1997). Since polymerization does not occur on a large scale until roughly 35 DAA (Aussenac and Carceller 2000; Hussain and Lukow 1995; Stone and Nicolas 1996a), heat stress imposed late during filling has a detrimental effect on polymerization. Stresses that result in a reduction of the duration of the filling period will negatively affect the accumulation of individual protein fractions, particularly those that are laid down later during the filling period.

Studies of gliadin and glutenin gene expression by Altenbach et al. (2002) and Perrotta et al. (1998) support the idea that the effect of heat and/or moisture stress is to reduce the duration of the filling period (and the potential for glutenin polymerization) rather than to increase gliadin synthesis. Neither study detected increased gliadin synthesis as a result of heat stress. However, under high temperature regimes, Altenbach et al. (2002) observed expression of gliadin and glutenin genes that occurred slightly earlier compared to wheat that was not stressed by high temperatures, particularly where wheat did not receive post-anthesis N fertilizer. The duration of the expression of gliadin and glutenin genes was also reduced.

Temperature and moisture conditions may also have a positive effect on glutenin polymerization. Randall and Moss (1990) observed that warm temperatures below a threshold level of 30°C during grain filling increased dough strength, while daytime temperatures that exceeded 30°C for even a few days reduced dough strength dramatically. Even where PC did not change as a result of the stress, dough strength was reduced by high temperature stress, suggesting differences in protein quality were responsible for the reduction in dough strength. Comparing dryland and irrigated wheat subjected to heat stress roughly 21 DAA, Panozzo et al. (2001) found wheat from the dryland environment had an identical gliadin to glutenin ratio as irrigated wheat grown nearby, but dryland wheat exhibited significantly higher dough strength than irrigated wheat. The authors attributed the increased dough strength of wheat from the dryland environment to a higher proportion of highly polymeric glutenin.

Environmental factors that lengthen the duration of the filling period will also affect the accumulation of individual protein fractions. The effects of N fertilization and duration of the filling period on the quality of the French soft wheat cultivar Soissons were evaluated by Jia et al. (1996a; 1996b). Compared to plots that received both N fertilizer and fungicide treatment, wheat in plots that were fertilized but that did not receive fungicide application had a higher proportion of SDS-soluble glutenin and a lower proportion of SDS-insoluble glutenin (Jia et al. 1996a). The authors attributed the lower proportion of SDS-insoluble glutenin of the treatment that did not receive fungicide to shortening of the duration of the filling period. Differences in the response of various Alveograph parameters to increasing N supply at a wide variety of locations were attributed to the effect of environment on glutenin polymerization (Jia et al. 1996b), although information regarding the effect of environmental factors on filling period duration were not given. In each study, the response of glutenin polymers to N fertilization depended on environmental conditions, specifically conditions during the filling period.

3.0 THE EFFECT OF CROP ROTATION AND FERTILIZER N SOURCE ON SOIL NITROGEN STATUS AND NITROGEN ACCUMULATION OF CANADA WESTERN RED SPRING WHEAT

3.1 Abstract

Two goals in improving the sustainability of western Canadian cropping systems are maximizing soil N supplying power and improving the synchrony of N availability and crop N uptake. The main goal of this study was to evaluate the effect of pulse crop rotation and controlled-release urea (CRU) on soil N status and N accumulation of Canada Western Red Spring (CWRS) wheat. Spring wheat (*Triticum aestivum* L. cv. AC Barrie) was grown at Carman, MB in 2000 and 2001, and at Brandon, MB, in 2001 on field pea (*Pisum sativum* L.) and flax (*Linum usitatissimum* L.) stubble at three rates (0, 30, and 90 kg N ha^{-1}) of fertilizer N from two N sources, namely ammonium nitrate (AN) and CRU, a polyurethane-coated urea with an N content of 43 per cent. Prior to planting, estimated soil NO_3-N to a depth of 120 cm was significantly higher for field pea stubble than for flax stubble at Carman-00 ($P < 0.0015$) and Brandon-01 ($P < 0.022$). Similar differences were also evident at anthesis at Carman-00. The higher N-supplying power of field pea stubble was attributed to the sparing of soil N, as well as greater post-harvest N mineralization. Previous crop and fertilizer N source had an effect on the pattern of N accumulation. At anthesis, aboveground N yield of wheat grown on field pea stubble (P-W) was significantly higher compared to flax stubble (F-W) at Carman-00 and Brandon-01. Apparent net mineralized N during the growing season and per cent post-anthesis N uptake were higher for F-W compared to P-W at Carman-00 and Brandon-01, contrary to many western Canadian studies that suggest enhanced

mineralization and/or post-anthesis N uptake where wheat is preceded by an annual grain legume. Grain yield and N yield were significantly higher for P-W versus F-W at Carman-00 and Brandon-01 at all three N rates and appeared to be due primarily to increased N availability early in the growing season.

Plant N yield at anthesis was higher with AN compared to CRU at Carman-00 ($P < 0.0147$) and Brandon-01 ($P < 0.0198$) and was attributed to differences in fertilizer N release pattern. Post-anthesis N uptake with CRU was significantly higher than for AN at Brandon-01 ($P < 0.0091$), although differences did not translate into significant differences in grain yield, PC, or N yield. The relatively high soil N status at Carman in 2001 may have masked the effect of N source on plant N availability and uptake.

3.2 Introduction

In recent years, the premium paid by the Canadian Wheat Board for high protein concentration (PC) Canada Western Red Spring wheat (CWRS) (*Triticum aestivum* L.) of acceptable quality has comprised a sizeable proportion of wheat producer returns (Flaten et al. 2000). At the same time, an increasing proportion of grain produced on the Prairies is being collected in large-scale high throughput elevators with the capacity to deliver large volumes of wheat cleaned to export standards of a specific grade and PC to end users. As regional averaging of wheat quality through blending declines (Preston et al. 2002), the wheat industry must learn more about the impact of agronomic practices, including crop rotation and fertilizer technology, on wheat PC and quality. Given the relatively high cost of nitrogen (N) fertilizer, as well as the environmental and economic costs associated with excessive N fertilization, maximizing N use efficiency and the N supplying potential of cropping systems are of considerable interest.

Growing wheat after annual grain legumes such as field pea (*Pisum sativum* L.) has been identified as one means of increasing the N supplying power of soils (Beckie and Brandt 1997; Beckie et al. 1997; Fu et al. 1999; Mooleki et al. 1997; Strong et al. 1986a). Annual grain legumes improve soil N status as a direct consequence of the decomposition and subsequent mineralization of legume residue N (Fu et al. 1999; Jensen 1993; Mooleki et al. 1997), as well as indirectly through the conservation of soil N as a result of biological N fixation (Chalk et al. 1993; Evans et al. 1991; Soon et al. 2001; Strong et al. 1986).

The contribution of the legume direct N benefit (i.e. N made available from the legume residue) to the total N benefit depends on the quantity (Adderley et al. 1998; Beckie and Brandt 1997; McCallum et al. 2000) and quality of legume residue. Grain legume residues tend to have a low carbon to nitrogen ratio, and as such legumes have been demonstrated to enhance N availability to a succeeding crop due to more rapid decomposition and net mineralization (Janzen and Kucey 1988; Schoenau 1995), as well as reduced immobilization of fertilizer N (Fu et al. 1999; Mooleki et al. 1997). In numerous short-term rotation studies conducted in the Northern Plains, the increased N availability from legume residues is attributed primarily to mineralization during the growing season (Badaruddin and Meyer 1994; Beckie et al. 1997; Flaten and Greer 1998; Miller et al. 2002a; Miller et al. 2002b).

One of the best illustrations of the effect of crop rotation on N mineralization during the growing season is the long-term wheat-lentil rotation established at Swift

Current in 1967. Zentner et al. (2001) reported that wheat grown after lentil had higher grain PC than wheat grown after wheat despite each rotation starting out with the same amount of total available N. One perceived benefit of mineralization of residue N during the growing season is improved synchrony of N availability and plant N uptake (Grant et al. 2002; Miller et al. 2002; Zentner 2001). However, besides legume residue quantity and quality, factors such as post-harvest and growing season soil moisture and temperature regime have pronounced effects on the quantity and temporal availability of residue N (Schoenau 1995).

Controlled-release fertilizers (CRFs) may also have the ability to improve the synchrony of N uptake and N availability, increase NUE, and reduce N losses to the environment such as leaching and denitrification (Haderlein et al. 2001; Hauck 1985; Shaviv 2001). Compared to slow-release N fertilizers, CRFs have a more well-defined, predictable pattern of N release. Due in part to its prohibitive cost relative to conventional N fertilizers, most CRF research has been relegated to vegetables, ornamental crops, and turf; little information exists on the effect of CRFs on the production of conventional grain crops such as wheat or corn (Shaviv 2001). Haderlein et al. (2001) evaluated the effect of side-banded controlled-release urea (CRU) and conventional urea on spring wheat and found significantly higher PC and NUE for the CRU treatment as a result of higher N uptake and recovery later in the growing season.

Improving late season N availability is important when considering PC. As N availability is delayed until later in the growing season, it has a greater positive impact on PC relative to dry matter (DM) yield (Grant and Flaten 1998; Haderlein et al. 2001; Johnston and Fowler 1991a; Selles et al. 1997). However, in order to realize the perceived benefits of annual grain legumes or CRU in a succeeding wheat crop, N must be in an available form, plant N uptake must not be limited by a lack of soil moisture, and the N must be effectively translocated to the grain. Even when these conditions are satisfied, plant N uptake may be repressed due to a series of complex source-sink relationships within the plant (Tourraine and Gojon 2001).

The main objective of our study was to evaluate the effect of pulse crop rotation and controlled-release urea on N accumulation and protein quality in CWRS wheat. Specifically, in the part of the study reported in this paper, we wanted to further investigate the observation that annual grain legumes and CRU improve the timing of N availability to match crop demand under conditions typical for the eastern Prairies. In many similar studies, legume-wheat rotations have been compared to cereal-wheat rotations. This method typically results in an overstatement of the legume benefit due to the presence of sizeable legume non-N benefits such as soil moisture conservation (Miller et al. 1998a; Miller et al. 2002b), the interruption of cereal disease cycles (Evans et al. 1991; Reeves et al. 1984; Stevenson and van Kessel 1996), and weed pressure reduction (Stevenson and van Kessel 1996). Therefore, flax (*Linum usitatissimum* L.) was chosen as the non N-fixing reference crop in order to focus on the N benefits of the field pea crop to the succeeding wheat crop.

3.3 Materials and Methods

The experiment was part of a larger rotational study initiated in 1998 comparing the N benefit of four annual grain legumes and flax on the production of spring wheat. Main plot treatments were established in 1999 and 2000 at the Carman Research Station (prior to the wheat at Carman-00 and Carman-01, respectively) on a Denham sandy loam, and in 2000 at the Brandon Research Centre (prior to the wheat at Brandon-01) on a Newdale loam. In the first phase of the rotation, each location contained two main treatments, namely field pea (cv. Grande) and flax (cv. Norlin). Dimensions of the main plots were 10 m x 8 m at Carman and 30 m x 7 m at Brandon. Four replicates were arranged in a randomized complete block design.

In the re-crop phase of the study, spring wheat (cv. AC Barrie) was sown at a rate of 135 kg ha^{-1} with a low-disturbance plot seeder; row spacing was 15 cm and 30 cm at Carman at Brandon, respectively. Five N fertilizer treatments were randomly arranged as sub-plots in each main plot as part of a split plot design, where the main plot was previous crop and the subplot was N fertilizer treatment. N was applied at three rates (0, 30, and 90 kg N ha^{-1}) as commercial grade ammonium nitrate (AN) or CRU. The CRU product was Duration™, a polyurethane-coated urea with an N content of 43%. N fertilizer was banded prior to seeding at right angles to the direction of seeding at Carman, and side-banded at seeding at Brandon. Sub-plot dimensions were 2 m x 8 m at Carman and 6 m x 7 m at Brandon. Commercial grade triple super phosphate was applied near the seedrow at a rate of 25 kg ha^{-1} P_2O_5. Neutron access tubes were installed in the control plots and AN sub-plots to a depth of at least 120 cm as soon as possible after planting.

Borders and alleyways were sown with wheat and left un-mowed until prior to harvest to minimize edge effects. Herbicides were applied at recommended rates during the growing season, while Folicur (tebuconazole) was applied at recommended rates at anthesis in order to limit the severity of Fusarium head blight. Meteorological data were collected on a daily basis using automated weather stations located near the field sites (Table 3.1).

	Site		
	Carman-00	Carman-01	Brandon-01
May			
Precipitation (mm)	55 (53)	53	70 (48)
Average Air Temperature (°C)	11.5 (11.9)	12.8	12.7 (11.0)
June			
Precipitation (mm)	94 (73)	41	168 (67)
Average Air Temperature (°C)	14.6 (17.4)	16.2	15.2 (16.2)
July			
Precipitation (mm)	47 (69)	193	31 (72)
Average Air Temperature (°C)	19 (20.1)	19.8	19.0 (18.7)
August			
Precipitation (mm)	86 (66)	22	53 (69)
Average Air Temperature (°C)	18.7 (18.7)	19.5	18.9 (17.5)

[z] Data in parentheses are 1961-1990 climatic averages (Source: Environment Canada Climate Center, Winnipeg, MB).

Table 3.1. Meteorological data for the experimental sites.[z]

3.3.1 Field and Analytical Techniques

A summary of management practices and other relevant information is presented in Table 3.2. Prior to planting and fertilization of the wheat, soil in main plots was sampled at depths of 0-15 cm, 15-60 cm, and 60-120 cm. Composites of three to five 50 mm diameter soil cores were prepared for each main plot replicate and stored at 5°C until they could be air-dried. A summary of soil characteristics based on the average of the four replicates of each main plot (previous crop) for each site is provided in Table 3.3.

Characteristic	Site		
	Carman-00	Carman-01	Brandon-01
Reference Crop Residue Management	Plot combine with chopper; no incorporation	Plot combine, no chopper; no incorporation	Plot combine, no chopper; residue mowed and disked
Spring Soil Sampling	end of April	7-May	10-May
Seeding Date	14-May	16-May	17-May
First neutron probe reading	30-May	21-Jun	22-Jun
50 per cent Anthesis Date	13-Jul	10-Jul	13-Jul
Last Tissue Sampling Date	17-Aug	14-Aug	17-Aug
Harvest Date	24-Aug	16-Aug	24-Aug
Soil Sampling at Harvest	29-Aug	17-Aug	24-Aug

Table 3.2. Agronomic information for the experimental sites.

Anthesis tissue and soil sampling was initiated when 50% of main stems were in the mid-anthesis stage. At the end of each sub-plot opposite to where neutron access tubes were installed, two adjacent rows 1 or 1.5 m long (depending on location and row spacing) were removed just above the soil surface. Heads were separated from the stem/leaf fraction by removing heads from stems just below the peduncle. Every 7 days thereafter until 35 days after anthesis (DAA), a single row 1 or 1.5 m long was removed at a distance of at least 30 cm from the last row sampled. Dry matter (DM) samples were oven-dried at 70°C for 48 hr as soon as possible after sampling or else frozen immediately. Oven-dried plant samples were weighed to determine DM yield and ground to pass through a 2 mm sieve using a Wiley mill. Samples were analyzed for total N by combustion (LECO Corporation, St. Joseph, MI). Total N yield was calculated by multiplying DM yield by tissue N concentration; N yield of total aboveground plant material was calculated by addition of the N yield of the head and stem/leaf fractions.

		Site and Soil Type					
		Carman-00		Carman-01		Brandon-01	
Characteristic[z]	Depth (cm)	Denham Orthic Black Chernozem sandy loam		Denham Orthic Black Chernozem sandy loam		Newdale Orthic Black Chernozem loam	
		Pea	Flax	Pea	Flax	Pea	Flax
pH	0-15	5.7	5.8	5.9	6.0	7.1	7.3
Organic Matter (%)	0-15	3.1	2.9	5.1	4.7	4.2	4.1
Electrical Conductivity (ds/M)	0-15	0.31	0.27	0.23	0.23	0.89	0.76
Cation Exchange Capacity (meq/100 g)	0-15	14.8	16.2	23.5	23.3	26.0	24.2
Estimated NO_3-N (kg ha^{-1})[y]	0-60	92 (VH)[x]	48 (M)	64 (H)	59 (H)	51 (M)	33 (L)
Estimated NH_4-N (kg ha^{-1})	0-15	30	37	15	17	49	57
Extractable SO_4-S (mg kg^{-1})	0-60	7	7	7	8	16	3
Extractable P (mg kg^{-1})	0-15	39	34	29	27	10	13
Extractable K (mg kg^{-1})	0-15	277	293	198	184	225	216

[z] Particle size analysis for soil texture determination was determined by hydrometer method (Black et al. 1965), organic matter by ignition (McKeague 1976), cation exchange capacity by NH_4OAc at pH 7 (McKeague 1976), 2 N KCl extractable NO_3-N by automated cadmium reduction method (Clesceri et al. 1998), 2 N KCl extractable NH_4-N by automated phenate method (Clesceri et al. 1998), extractable SO_4-S by turbidimetric method (Clesceri et al. 1998), NH_4OAc extractable K by flame photometric method (Clesceri et al. 1998), and benzene-isobutanol-extractable P by stannous chloride method (Clesceri et al. 1998). Soil pH and electrical conductivity were determined in water using a soil to water ratio of 1:2 (McKeague 1976).

[y] Estimated assuming a bulk density of 1.33 g cm^3.

[x] Ratings for wheat production according to the Manitoba Soil Fertility Guide where VL = very low; L = low; M = medium; H = high; VH = very high (Manitoba Agriculture and Food 2001).

Table 3.3. Physical and chemical soil characteristics at the experimental sites.[z,y,x]

At anthesis, soil samples corresponding to 0-10 cm and 10-30 cm depths were collected from a trench dug perpendicular to the direction of the fertilizer bands, thoroughly mixed, and sub-sampled. Trench length was equivalent to twice the distance between fertilizer bands. For deeper samples, a single soil core 50 mm in diameter was taken from the trench corresponding to depths of 30-50 cm, 50-70 cm, 70-90 cm, and 90-110 cm. All coring holes and trenches were filled and packed after sampling. As soon as possible after harvest, two 50 mm diameter soil cores were taken within the harvested area of each sub-plot corresponding to the depths sampled during anthesis. Soil samples were stored at 5°C until further processing was possible.

Once air-dried, soil samples taken at anthesis and maturity were ground (< 2 mm) using a rotating steel roller and sieve and extracted with 2 *M* KCl (using a 5:1 extractant to dry soil equivalent ratio). Soil extracts were analyzed by autoanalyzer (Technicon 1975) for NH_4^+ (NH_4-N) using a phenate colorimetric method and $NO_{3/2}^-$ (NO_3-N) using a cadmium column reduction method (Clesceri et al. 1998). Nitrite-N was assumed to be negligible for NO_3-N determination. NH_4-N and NO_3-N concentration were calculated by multiplying the autoanalyzer result by the dilution factor and the extraction ratio.

The estimated quantity of NH_4-N and NO_3-N (expressed in kg ha^{-1}) was calculated as N concentration*(sample profile depth/15)*2, assuming a bulk density of 1.33 g cm^3. Apparent net mineralized N (NMN, expressed in kg N ha^{-1}) at anthesis and harvest was calculated as (sampling date aboveground plant N yield + soil NO_3-N to 110 cm) – (soil NO_3-N to 120 cm prior to planting + fertilizer N rate). Apparent amount of N recoverable by the wheat crop at anthesis and harvest (kg N ha^{-1}) was calculated as (sampling date aboveground plant N yield + soil NO_3-N to 110 cm). Plant N yield 35 DAA was used for calculation of NMN at harvest.

Soil water status was monitored periodically prior to anthesis, as well as on a weekly basis between anthesis and harvest. Volumetric soil water content was measured at depths of 10-30 cm, 30-50 cm, 50-70 cm, 70-90 cm, and 90-110 cm using a field-calibrated neutron moisture gauge. At the Brandon-01 site, gravimetric water content (GWC) was determined for the 0-10 depth by collecting two 25 mm wide soil cores from each sub-plot. VWC was calculated by multiplying GWC by bulk density, which was assumed to be 1.33 g cm^3. A neutron moisture gauge equipped with a surface shield was used to collect VWC data at the Carman-00 and Carman-01 sites.

Prior to harvest, sub-plots were scored for lodging using a 0-9 scale. Wheat was harvested from a 9-34 m^2 area using a small plot combine, excluding plot edges. Samples were allowed to air-dry, using aeration where necessary. Grain yield was based on cleaned samples. Grain samples were ground to pass through a 2 mm sieve using a Wiley mill; total grain N content was determined by combustion. Grain N yield was determined by multiplying grain N concentration by grain yield, and was adjusted for harvested area and a 14% moisture basis.

3.3.2 Statistical Analysis

Data were analyzed by analysis of variance (ANOVA) for a factorial experiment arranged in a randomized complete block design using the Proc GLM procedure (SAS Institute Inc. 2001). Statistical analysis of all soil NO_3-N data was preceded by natural log transformation in order to ensure homogeneous variances. The effect of previous crop on spring soil NO_3-N was analyzed by ANOVA using the Proc GLM procedure. Pre-determined, non-orthogonal single degree of freedom contrasts were used to evaluate fertilizer N source and stubble*N rate combinations. Effects were considered to be significant at $P < 0.05$. Soil water extraction was evaluated using paired t-tests and was assumed to have occurred for a given depth where at least one pair of soil water sampling dates (successive or non-successive) showed significant depletion of water ($P < 0.05$) prior to or after anthesis. This method assumes no loss in water content due to upward or downward movement of water between soil depths.

3.4 Results and Discussion

3.4.1 Soil Water Status During the Growing Season

The results of paired t-tests indicated that by the end of the growing season, soil water had been extracted to a depth of 90-110 cm at Carman-00 and Carman-01, compared to 70-90 cm at Brandon-01 (Fig. 3.1). Therefore, soil NO_3-N at 90-110 cm at Brandon-01 was not considered to be recoverable by the wheat crop and was omitted when calculating plant recoverable N at anthesis and harvest.

At 35 days after planting, the only instance where previous crop had a significant effect on VWC was at the 30-50 cm at Brandon-01, where VWC for P-W was significantly lower than for F-W. This observation, along with visual evaluations of weed or disease pressure in the wheat crop prior to pesticide application, demonstrated that the effect of non-N benefits was effectively excluded by using flax as the non N-fixing reference crop. Significantly lower VWC was observed post-anthesis at

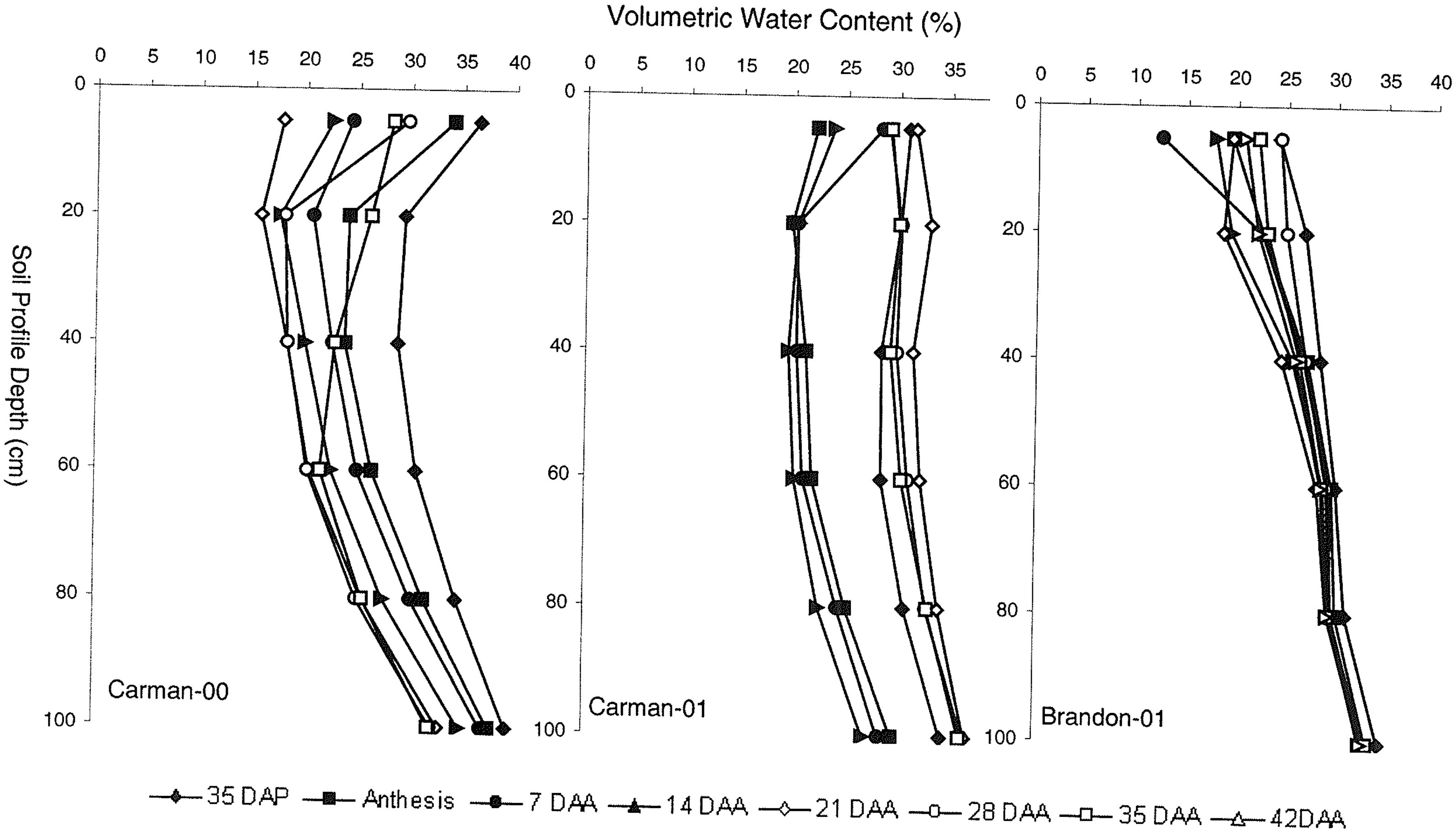


Figure 3.1. Evolution of soil volumetric water content in the soil profile at the Carman-00, Carman-01, and Brandon-01 sites.[z, y]
[z] Based on results of paired t-tests, soil water extraction was considered to have occurred to the 90-110 cm depth increment at Carman-00, and Carman-01, and to the 70-90 cm depth increment at Brandon-01.
[y] DAP = days after planting, DAA = days after anthesis.

Carman-00 for P-W compared to F-W at 10-30 cm, 30-50 cm, and 50-70 cm; differences were attributed to differences in plant water demand as a result of higher DM production.

3.4.2 Soil N Status Prior to Planting

Previous crop did not have a significant effect on soil NH_4-N status prior to planting at any of the experimental sites (data are not presented). At Carman-00 and Brandon-01, soil NO_3-N was higher at all three depth increments where field pea was grown compared to flax, though statistically it was not significantly higher at 15-60 cm at Brandon (Table 3.4). At Carman-01, previous crop had no effect on soil NO_3-N levels; overall NO_3-N levels were very high, particularly at a depth of 60-120 cm. The lack of an effect of previous crop on soil NO_3-N status at Carman-01 may have been due to the initially high soil N-supplying power of the site prior to establishment of the initial phase of the rotation (this area of the research station has a long-term history of perennial forage, including alfalfa). In such a situation, field pea would make greater use of mineral N rather than fix atmospheric N (Androsoff et al. 1995; Stevenson et al. 1995), decreasing the soil mineral N pool and limiting the N benefit of the legume. Therefore, this site year will not be discussed extensively.

Differences in N-supplying power of field pea and flax at the Carman-00 and Brandon-01 sites were most likely due to the N sparing effect of field pea as well as mineralization of N from field pea residue (Chalk et al. 1993; Evans et al. 1991; Strong et al. 1986), although the contributions of each factor to the total N benefit likely differed among the sites. Given the high soil NO_3-N levels at the Carman sites, the proportion of the N benefit attributable to post-harvest mineralization was likely greater, since as described previously, field pea makes more use of mineral N rather than fix atmospheric N in situations where soil mineral N levels are high. At Brandon-01, soil N levels were much lower than at the Carman sites. Therefore, a higher proportion of the N benefit would likely come from soil N sparing.

A significant contribution of N from the legume residue as a result of mineralization of field pea residue during the re-crop phase of the study and prior to anthesis is unlikely, especially in light of the low estimate of net N mineralization during the growing season. However, post-harvest mineralization during the initial phase of the study may have contributed to the N benefit of the grain legume.

	Depth (cm)			
	0-15	15-60	60-120	0-120
Carman-00				
Pea	23	69	28	120
Flax	10	37	18	65
Significance (Pr > F)[y]	0.0027	0.0022	0.0036	0.0015
CV (%)	8.6	4.4	4.4	3.5
	Depth (cm)			
	0-15	15-60	60-120	0-120
Carman-01				
Pea	13	52	70	134
Flax	13	46	91	150
Significance (Pr > F)	0.95	0.50	0.48	0.82
CV (%)	4.4	8.4	8.8	6.3
	Depth (cm)			
	0-15	15-60	60-120	0-120
Brandon-01				
Pea	22	30	30	81
Flax	14	19	16	50
Significance (Pr > F)	0.0357	0.10	0.0099	0.022
CV (%)	8.4	11.7	7.7	6.0

[z] Means are presented as non-transformed data.
[y] Statistical analysis was preceded by log transformation to ensure homogeneity of variance.

Table 3.4. Distribution of estimated NO_3-N (kg ha^{-1}) in the soil profile prior to planting as affected by previous crop.

Given its chemical composition, the N contribution of legume residue to the soil inorganic N pool is often low because the C:N ratio of grain legume residue is between 40:1 to 50:1 (Bremer and van Kessel 1992; Grenier 1992; Soon et al. 2001). Grenier (1992) found the N concentration of lentil residue was 2.5 and 2.1 per cent in the bloom and mid-pod stages, respectively, which translated into C:N ratios of 16:1 and 17:1, respectively, indicating addition of the residue to the soil, resulting in initial net mineralization. At maturity, residue N concentration was 0.9%, and the C:N ratio was 46:1, suggesting initial net immobilization. A more immediate source of N attributable to the legume and available to the subsequent crop is N found in legume roots (Armstrong et al. 1994; Chalk et al. 1993; Senaratne and Hardarson 1988) and rhizodeposits (Jensen 1996; Soon et al. 2001). However, this N source typically comprises no more than 10% of the total N content of legume residue (Senaratne and Hardarson 1988). Jensen (1996) found rhizodeposits contributed 35% of the N mineralized after field pea compared to 12% of the N mineralized after barley; total net N mineralization of field pea and barley stubble was similar upon removal of roots and root fragments from the soil.

If grain legume residue were to directly contribute to soil N, mineralization would have to occur during the period following grain legume harvest in late summer and fall. In addition to residue quantity and quality, soil moisture and temperature also strongly influence mineralization (Schoenau 1995). Thiessen Martens and Entz (2001) found southern Manitoba was best suited for relay and double cropping with winter wheat in western Canada due to the potential for significant late summer and early fall precipitation and thermal energy accumulation. While southern Saskatchewan receives significant thermal energy late in the growing season, precipitation is considerably lower than in southern Manitoba, reducing the potential for mineralization. The potential for late-season N mineralization was high in Brandon and Carman. The apparent early maturation of field pea relative to other major field crops in western Canada, combined with conditions conducive to N mineralization during the period following harvesting, suggests increased potential for N mineralization on field pea stubble.

Therefore, soil NO_3-N under field pea stubble at Carman-00 and Brandon-01 was likely present post-harvest as a result of soil N conservation and N mineralization. As such, the potential for N losses from leaching and denitrification increased, both of which are of considerable concern in southern Manitoba given the potential for wet post-harvest conditions. In western Europe, for example, N leaching following legume production is a serious issue (Lung et al. 1989). Selection of crops that are effectively able to accumulate N during the autumn are essential following production of annual grain legumes, since conserved N and N made available through mineralization of legume is subject to leaching (Jensen 1993; Jung et al. 1989). The combination of high soil N levels and favorable post-harvest soil moisture heat resources make field pea stubble an ideal candidate for relay-cropping or double cropping with a fall cereal such as winter wheat (Thiessen Martens and Entz 2001).

3.4.3 Soil N Status at Anthesis

No consistent previous crop or fertilizer N source effects were observed for estimated soil NH_4-N at anthesis (data not presented). Differences in soil NO_3-N levels observed at planting at Carman-00 remained prominent at anthesis (Fig. 3.2). Estimated soil NO_3-N for P-W was higher at all sampling depths and became more pronounced as sampling depth increased, although NO_3-N was reasonably well distributed through the soil profile. In control plots, P-W had 25 kg ha^{-1} of additional NO_3-N to a depth of 110 cm compared to F-W ($P < 0.0199$). At Brandon-01, total NO_3-N to a depth of 110 cm for P-W was 40 kg ha^{-1} versus 36 kg ha^{-1} for F-W; differences were statistically significant ($P < 0.0433$) and most prominent at depths of 0-10 cm and 10-30 cm. The higher soil NO_3-N concentrations for field pea stubble prior to planting at the Carman-00 and Brandon-01 sites translated into higher wheat N uptake prior to anthesis rather than during grain filling.

3.4.4 Soil N Status at Harvest

No consistent differences were observed for the effect of previous crop or fertilizer N source on estimated soil NH_4-N at harvest. Estimated soil NO_3-N to a depth of 110 cm at Carman-00, Carman-01, and Brandon-01 averaged 40 kg ha^{-1}, 55 kg ha^{-1}, and 18 kg ha^{-1}, respectively. Differences in estimated soil NO_3-N observed at anthesis as affected by previous crop were no longer evident at harvest. Interestingly, there was very little change in soil NO_3-N content between anthesis and harvest at Carman-00. Soil NO_3-N increased substantially in the upper soil profile between anthesis and harvest, while at the same time NO_3-N content declined in the lower soil profile (70-110 cm), indicating NO_3-N extraction at depth and N mineralization in excess of N uptake in the upper soil profile.

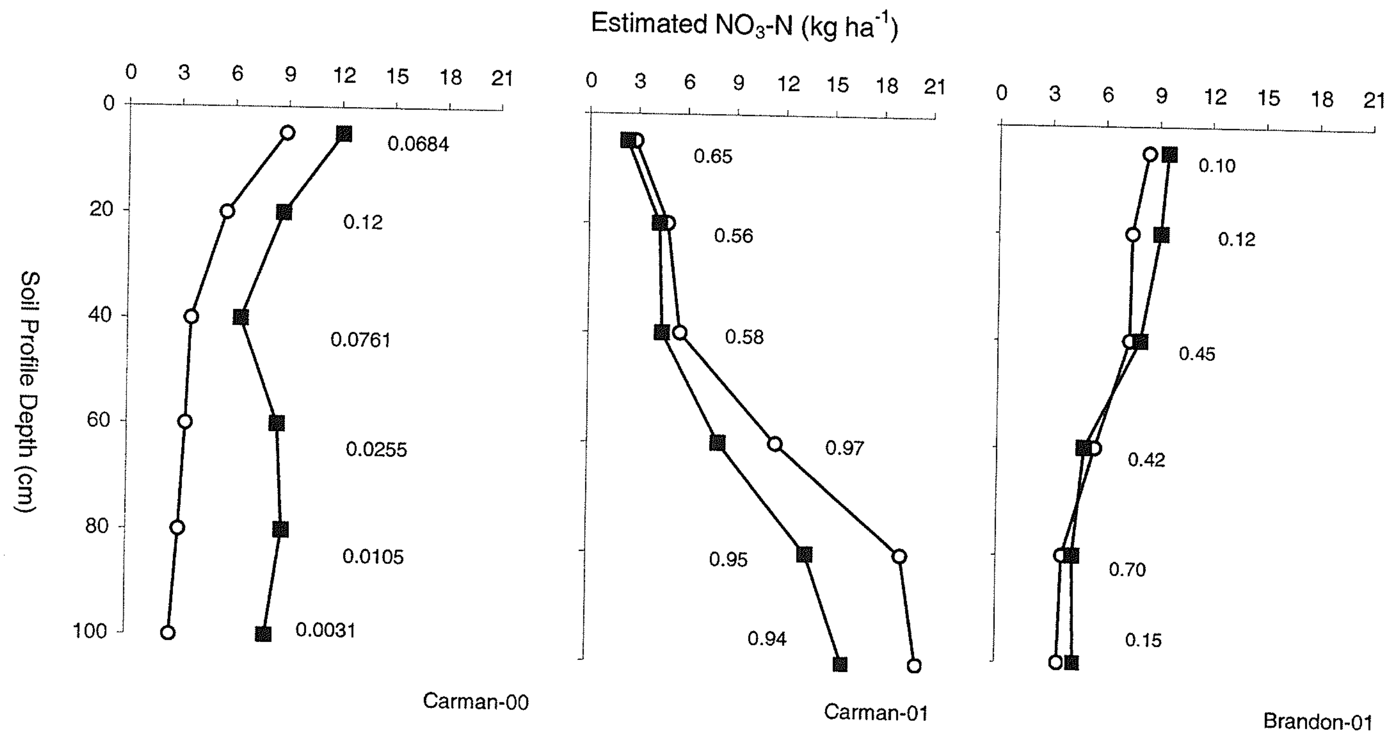


Figure 3.2. Estimated NO_3-N (kg ha^{-1}) in the soil profile at anthesis as affected by previous crop. Open symbols represent flax stubble while closed symbols represent field pea stubble. P-values are presented for each sampling depth.

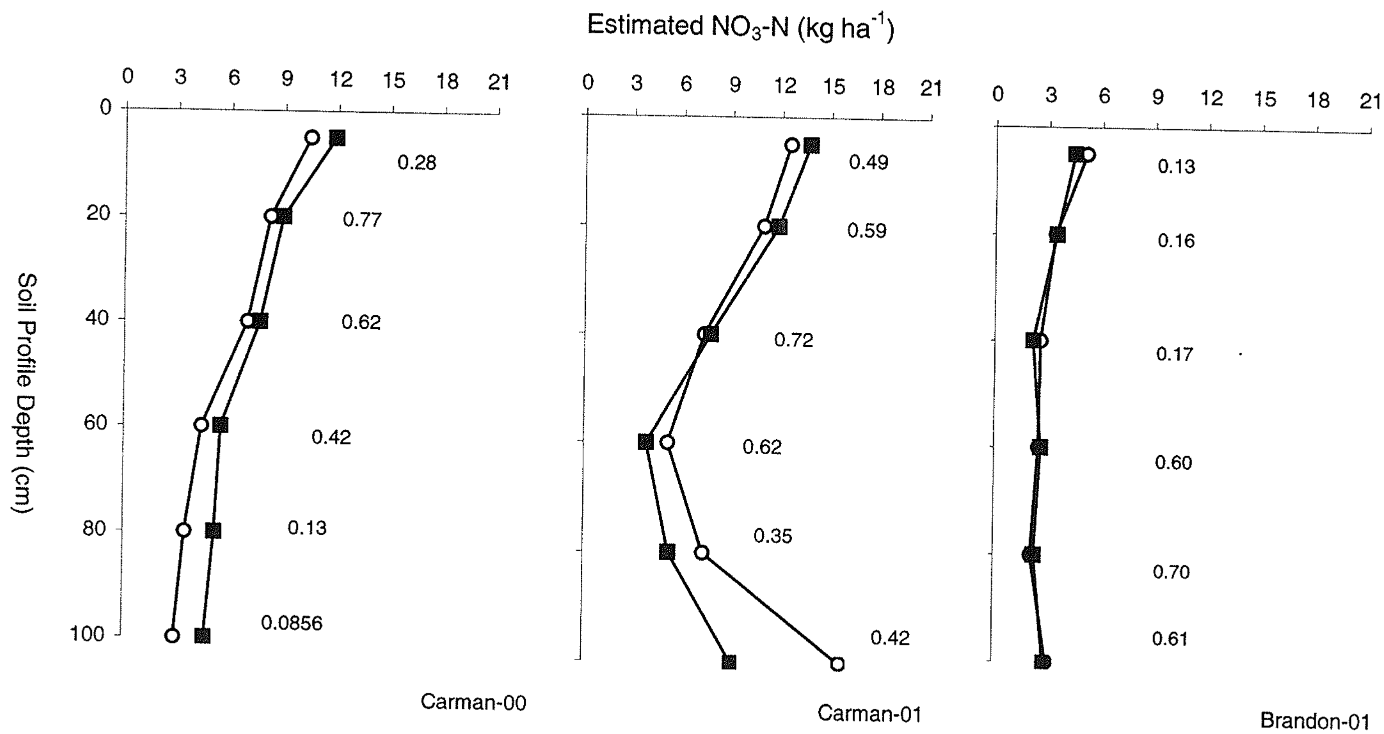


Figure 3.3. Estimated NO_3-N (kg ha^{-1}) in the soil profile at harvest as affected by previous crop. Open symbols represent flax stubble while closed symbols represent field pea stubble. P-values are presented for each sampling depth.

3.4.5 Evolution of Plant Recoverable N During the Growing Season

Plant recoverable N at anthesis (Table 3.5) was significantly higher for P-W at Carman-00 relative to F-W due to a combination of significantly higher soil NO_3-N within the root zone (Fig. 3.2) and N uptake. Higher plant recoverable N for P-W at Brandon-01 at anthesis was attributable almost exclusively to significantly higher plant N uptake. The only instance where previous crop had a significant effect on estimated plant recoverable N at harvest was at Brandon-01, due primarily to higher plant N yield for P-W compared to F-W. The AN treatment exhibited significantly higher plant recoverable N at anthesis compared to the CRU treatment at Brandon-01 and Carman-00 due to differences in plant N accumulation; fertilizer N source had no effect on recoverable N at Carman-01. It is important to note that fertilizer N source had no significant effect on plant recoverable N at harvest at Brandon-01, meaning recoverable N for the CRU treatment increased between anthesis and harvest, implying greater N availability post-anthesis.

3.4.6 Evolution of Apparent Net Mineralized N During the Growing Season

Previous field research done under conditions typical of southern Manitoba suggests most mineralization takes place after anthesis once soil temperature increases considerably (McGill 1969). Mineralization in western Canadian soils may be limited in early spring because of dryness or soil temperatures too cool to stimulate appreciable mineralization (McGill 1969; Schoenau 1995). Jowkin and Schoenau (1995) reported potential N availability increased from late June to early September, corresponding to a rapid increase in soil temperature. The pattern of apparent net mineralized N (NMN)

Treatment		Anthesis			Harvest		
Previous Crop	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01	Carman-00	Carman-01	Brandon-01
Pea		199	193	143	225	244	143
Flax		141	214	116	196	264	124
	0	132	180	96	188	208	105
	30AN[z]	157	179	122	209	228	120
	30CRU[y]	164	194	108	197	254	130
	90AN	208	239	168	241	294	157
	90CRU	189	226	152	219	287	156
ANOVA		Pr > F					
Previous Crop (P)		0.005	0.44	0.0122	0.14	0.26	0.0333
N Applied (kg ha^{-1}) (N)		<0.0001	0.0156	<0.0001	0.0224	0.0004	<0.0001
P*N		0.0166	0.23	0.13	0.38	0.64	0.29
Contrast							
AN versus CRU		0.0628	0.96	0.0223 (+)	0.10	0.48	0.47
Pea vs Flax at 0 N		0.0078 (+)	0.0364 (-)	0.0166 (+)	0.25	0.22	0.11
Pea vs Flax at 30 N		<0.0001 (+)	0.89	0.0021 (+)	0.0242 (+)	0.92	0.0017 (+)
Pea vs Flax at 90 N		<0.0001 (+)	0.52	0.0232 (+)	0.10	0.0783	0.71
CV (%)		7.7	19.4	13.7	14.5	14.9	15.0

[z] Ammonium nitrate fertilizer.

[y] Controlled-release urea fertilizer.

[x] A *P*-value followed by (+) indicates the value of the first treatment of the contrast is significantly greater than the value of the second treatment, while (-) indicates the opposite.

Table 3.5. Plant recoverable N (kg ha^{-1}) at anthesis and harvest at the experimental sites as affected by previous crop and fertilizer N treatment.[z,y,x]

during the growing season at the Carman-00 and Carman-01 sites conforms to the findings of McGill in three situations, namely F-W at Carman-00 as well as F-W and P-W at Carman-01 (Table 3.6). In all three cases, apparent NMN was greater than 60 kg ha^{-1}. In the three situations where apparent NMN was low, the easily mineralized N pool may have been exhausted prior to the start of the growing season.

Compared to Brandon-01, higher harvest NMN for the Carman site in both years suggests considerably higher mineralization potential. Based on the data collected, it is unclear exactly when after anthesis the mineralization flush occurred, particularly for Carman-00. There was little change in the estimated quantity of NO_3-N at 0-30 cm at Carman-00 between anthesis and harvest, and NO_3-N levels increased substantially post-anthesis at 0-30 cm at Carman-01 (Fig. 3.3). This observation suggests the N available as a result of mineralization was not fully exploited by the wheat crop at those sites. Given the drying and subsequent re-wetting of the upper 30 cm late in the growing season (Fig. 3.1), a second flush of mineralization may have occurred and therefore N availability would not have been in synchrony with plant N uptake.

Interestingly, NMN for F-W was substantially higher than for P-W between anthesis and harvest for Carman-00 and Brandon-01, which may help to explain the similarities in the quantity of post-anthesis N uptake for F-W and P-W. The lower apparent NMN of P-W relative to F-W may be due to the combination of N sparing and post-harvest mineralization of field pea residue. For example, mineralization of legume N in the P-W rotation during the post-harvest period would explain why the direct N benefit of the residue was realized at planting rather than later in the growing season.

	Planting to Anthesis	Planting to Harvest	Anthesis to Harvest
Carman-00			
Pea	33 (6)	59 (11)	26 (8)
Flax	27 (5)	82 (8)	55 (8)
Pr > F	0.63	0.36	0.054
	Planting to Anthesis	Planting to Harvest	Anthesis to Harvest
Carman-01			
Pea	11 (9)	66 (6)	55 (10)
Flax	16 (11)	62 (10)	46 (14)
Pr > F	0.23	0.72	0.096
	Planting to Anthesis	Planting to Harvest	Anthesis to Harvest
Brandon-01			
Pea	13 (5)	14 (5)	1 (6)
Flax	18 (5)	26 (6)	8 (6)
Pr > F	0.45	0.0726	0.0355

[z] Standard errors are presented in parentheses.

Table 3.6. Apparent net N mineralized (kg N ha^{-1}) during the growing season as affected by previous crop. [z]

The pattern of apparent NMN during the growing season may be explained by the effect of residue addition on immobilization of inorganic N, fertilizer N or otherwise. The C:N ratio of the field pea residue was probably considerably lower than the C:N ratio of the flax residue. Therefore, during the initial phase of decomposition, flax residues should cause greater initial net immobilization of soil and fertilizer N compared to field pea residues. As a result, less soil and fertilizer N would be tied up in the organic form in the field pea system and would be therefore be made available to the wheat crop early in the growing season. Therefore, NMN later in the growing season would be expected to be higher in the flax system, in agreement with the findings of this study.

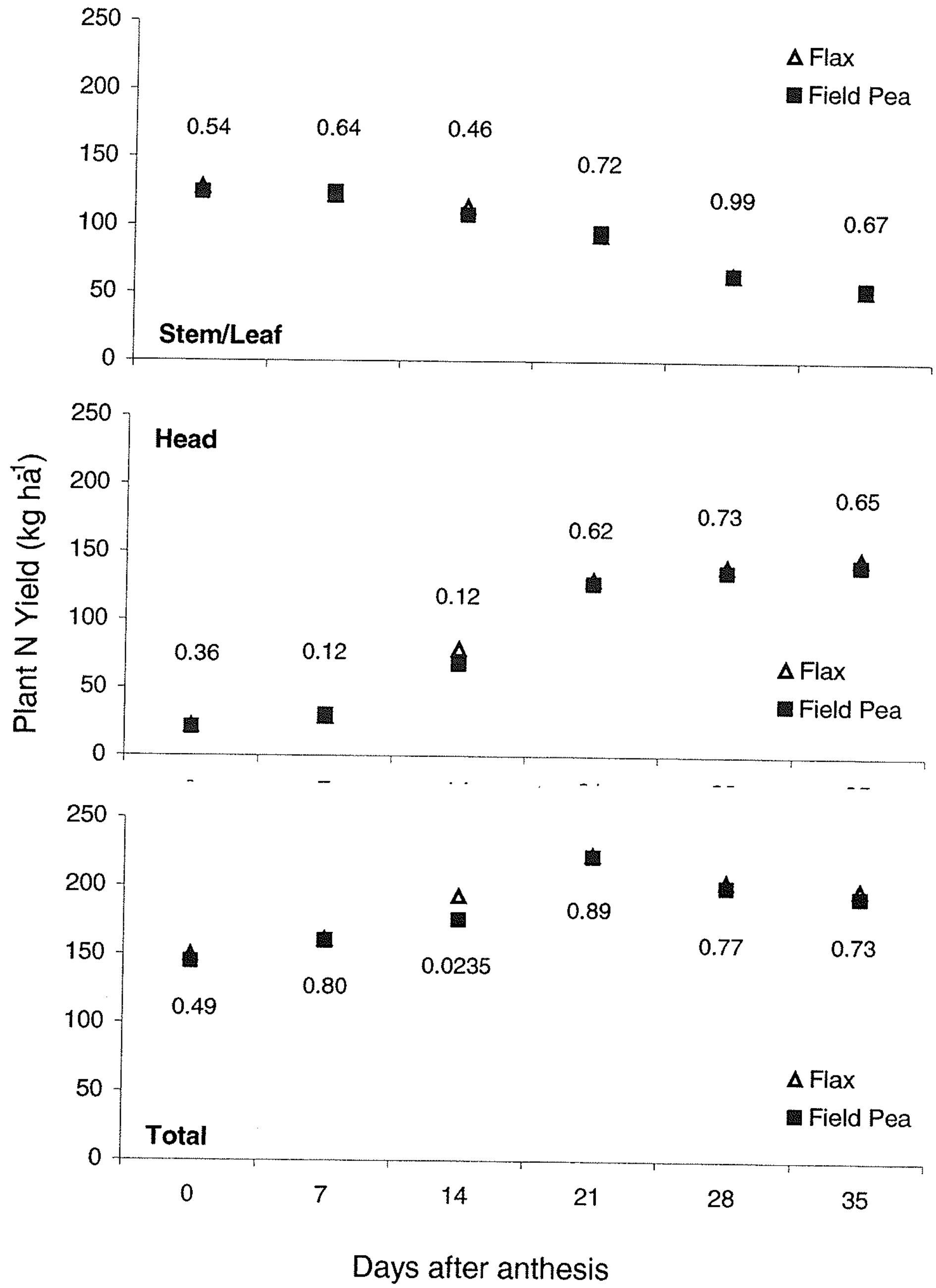
The slow, steady N release pattern of legume residues during the subsequent growing season, as suggested and/or observed by many researchers (Badaruddin and

Meyer 1994; Beckie et al. 1997; Flaten and Greer 1998; Miller et al. 1998b; Miller et al. 2002a) was not observed under the conditions of this study. Our results stress the need for a better understanding of the nature of the N benefit of legumes, including the temporal availability of N with respect to post-harvest environmental conditions and residue quality and quantity. In this study, spring soil testing would have been the most effective means of assessing the N benefit of an annual legume to a succeeding crop rather than allowing an additional N credit for mineralization of field pea residue during the growing season.

3.4.7 Nitrogen Uptake and Partitioning

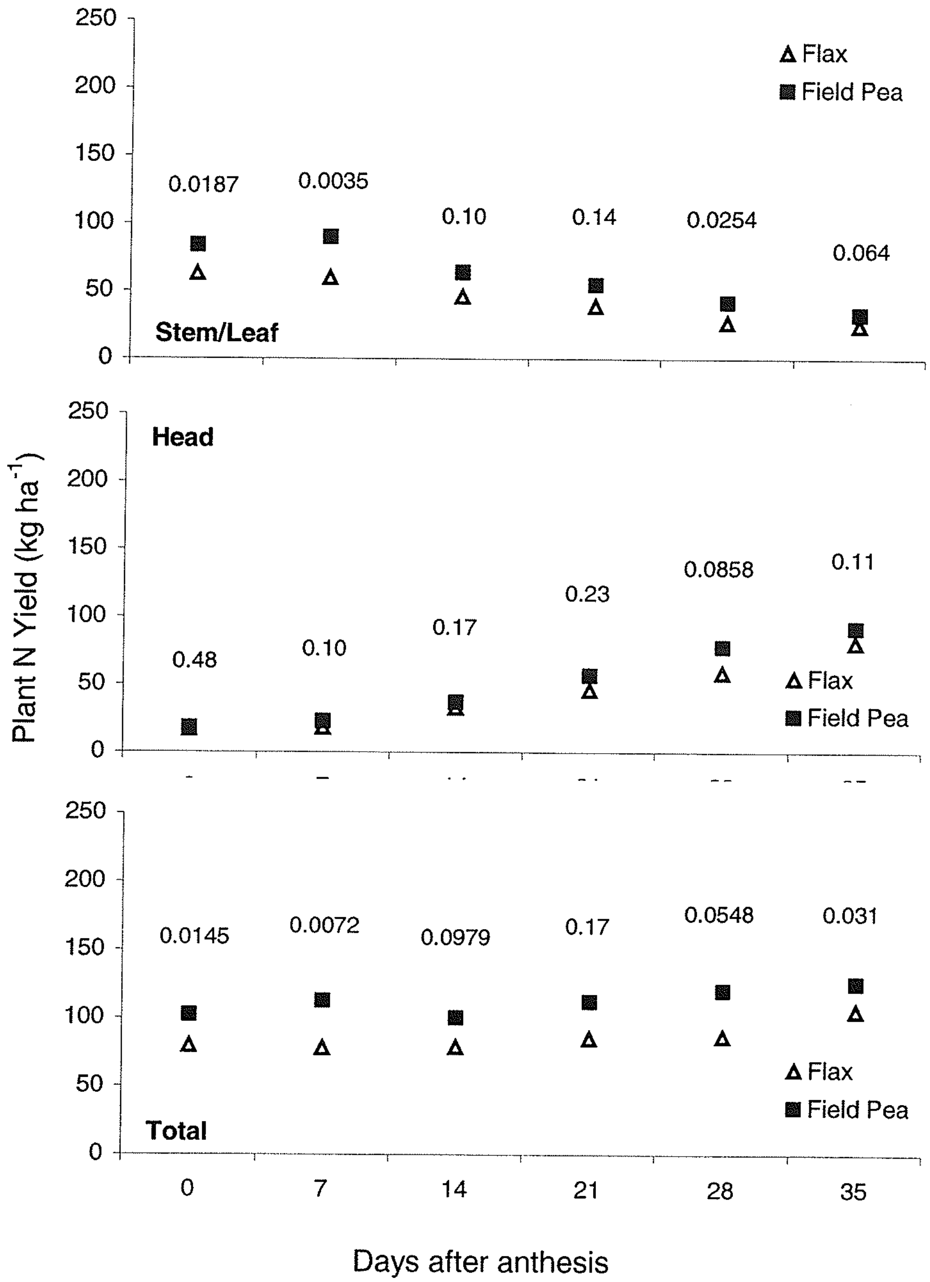
3.4.7.1 General Pattern of N Uptake

The pattern of N yield of the stem/leaf, head, and total aboveground plant fraction as influenced by previous crop is presented in Figures 3.4 to 3.6. Plant N yield at anthesis demonstrated a strong, linear relationship to estimated spring soil NO_3-N to a depth of 120 cm plus fertilizer N rate (data not presented) for Carman-00 (r^2 = 0.67) and Brandon-01 (r^2 = 0.71), while the relationship was weaker at Carman-01 (r^2 = 0.41). Post-anthesis N accumulation as a percentage of plant N yield 35 DAA was 21.9, 24.8, and 20.1% at Carman-00, Carman-01, and Brandon-01, respectively (Table 3.7), similar to results reported in other studies in western Canada (Clarke et al. 1990; Darroch and Fowler 1990). However, given the favorable soil NO_3-N and moisture levels during grain filling, particularly for Carman-01, we expected a somewhat higher proportion of N to be taken up after anthesis. Boatwright and Haas (1961) reported wheat fertilized with N achieved maximum N uptake during the soft dough phase, while unfertilized wheat



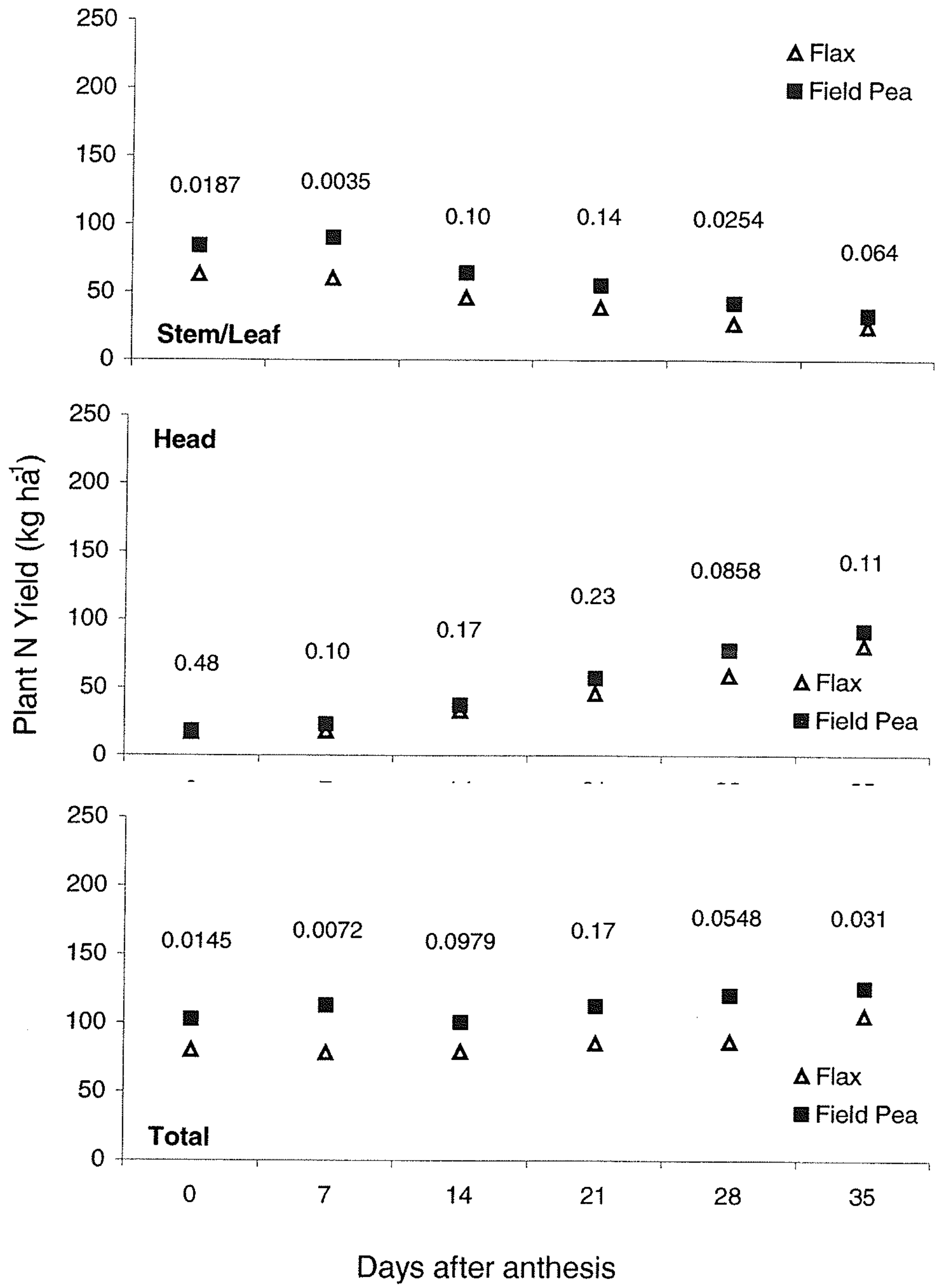
[z] P values are presented for each sampling date. Effects are considered significant at $P < 0.05$.

Figure 3.4. Plant N accumulation of the stem/leaf, head, and total aboveground plant fractions during the growing season at the Carman-00 site as influenced by previous crop.[z]



[z] P values are presented for each sampling date. Effects are considered significant at $P < 0.05$.

Figure 3.5. Plant N accumulation of the stem/leaf, head, and total aboveground plant fractions during the growing season at the Carman-01 site as influenced by previous crop.[z]



[z] P values are presented for each sampling date. Effects are considered significant at $P < 0.05$.

Figure 3.6. Plant N accumulation of the stem/leaf, head, and total aboveground plant fractions during the growing season at the Brandon-01 site as influenced by previous crop.[z]

Treatment		Pre-Anthesis N Uptake (kg ha^{-1})			Post-Anthesis N Uptake (kg ha^{-1})			% N Uptake Post-Anthesis		
Previous Crop	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01	Carman-00	Carman-01	Brandon-01	Carman-00	Carman-01	Brandon-01
Pea		149 (6)	145 (7)	102 (5)	34 (6)	50 (10)	23 (5)	17 (4)	26 (1)	18 (4)
Flax		114 (5)	150 (6)	80 (7)	45 (7)	48 (9)	25 (5)	27 (4)	24 (1)	24 (4)
	0	99 (5)	127 (15)	60 (7)	53 (7)	43 (16)	25 (3)	34 (4)	25 (1)	31 (4)
	30AN[y]	125 (9)	137 (7)	87 (7)	44 (11)	47 (23)	15 (5)	24 (8)	25 (1)	14 (4)
	30CRU[x]	128 (10)	149 (9)	76 (5)	30 (9)	54 (18)	39 (8)	17 (6)	26 (1)	32 (5)
	90AN	166 (10)	161 (7)	122 (5)	33 (8)	50 (10)	14 (12)	16 (4)	23 (1)	7 (7)
	90CRU	139 (6)	161 (5)	110 (8)	37 (15)	51 (15)	27 (5)	18 (8)	24 (1)	20 (5)
ANOVA						Pr > F				
Previous Crop (P)		0.0034	0.49	0.0145	0.24	0.92	0.42	0.0337	0.12	0.0334
N Applied (kg ha^{-1}) (N)		<0.0001	0.0098	<0.0001	0.49	0.95	0.20	0.16	0.99	0.0135
P*N		0.0933	0.19	0.18	0.38	0.91	0.61	0.54	0.55	0.68
Contrast										
AN versus CRU		0.0147 (+)[w]	0.40	0.0198 (+)	0.62	0.65	0.0304 (-)	0.68	0.87	0.0091 (-)
Pea vs Flax at 0 N		0.115	0.0438 (-)	0.0044 (+)	0.71	0.96	0.60	0.99	0.20	0.12
Pea vs Flax at 30 N		<0.0001 (+)	0.60	0.0009 (+)	0.43	0.74	0.33	0.18	0.43	0.92
Pea vs Flax at 90 N		<0.0001 (+)	0.45	0.0382 (+)	0.13	0.56	0.25	0.0813	0.37	0.23

[z] Standard errors are presented in parentheses.
[y] Ammonium nitrate fertilizer.
[x] Controlled-release urea fertilizer.
[w] A *P*-value followed by (+) indicates the value of the first treatment of the contrast is significantly greater than the value of the second treatment, while (-) indicates the opposite.

Table 3.7. Pre-anthesis N uptake, post-anthesis N uptake, and per cent N uptake post-anthesis at the experimental sites as affected by previous crop and fertilizer N treatment.[z,y,x,w]

continued to accumulate N until maturity. Given the quantity of N accumulated by anthesis at Carman-00 and Carman-01, the N needs of the crop were likely satisfied near anthesis and as a result, the crop relied less on post-anthesis N uptake to satisfy overall plant N demand.

The general pattern of N accumulation varied across the three environments studied due to differences in soil N-supplying power and environmental conditions during the growing season. While total plant N yield at Carman-00 and Brandon-01 increased throughout the sampling period, maximum plant N yield at Carman-01 occurred 21 days DAA. Despite ample soil moisture and NO_3-N, overall plant N yield at Carman-01 declined 27 kg N ha^{-1} between 21 and 35 DAA, and may be attributable to volatile loss of NH_3 (Harper et al. 1987) or loss of stem/leaf DM due in part to lodging.

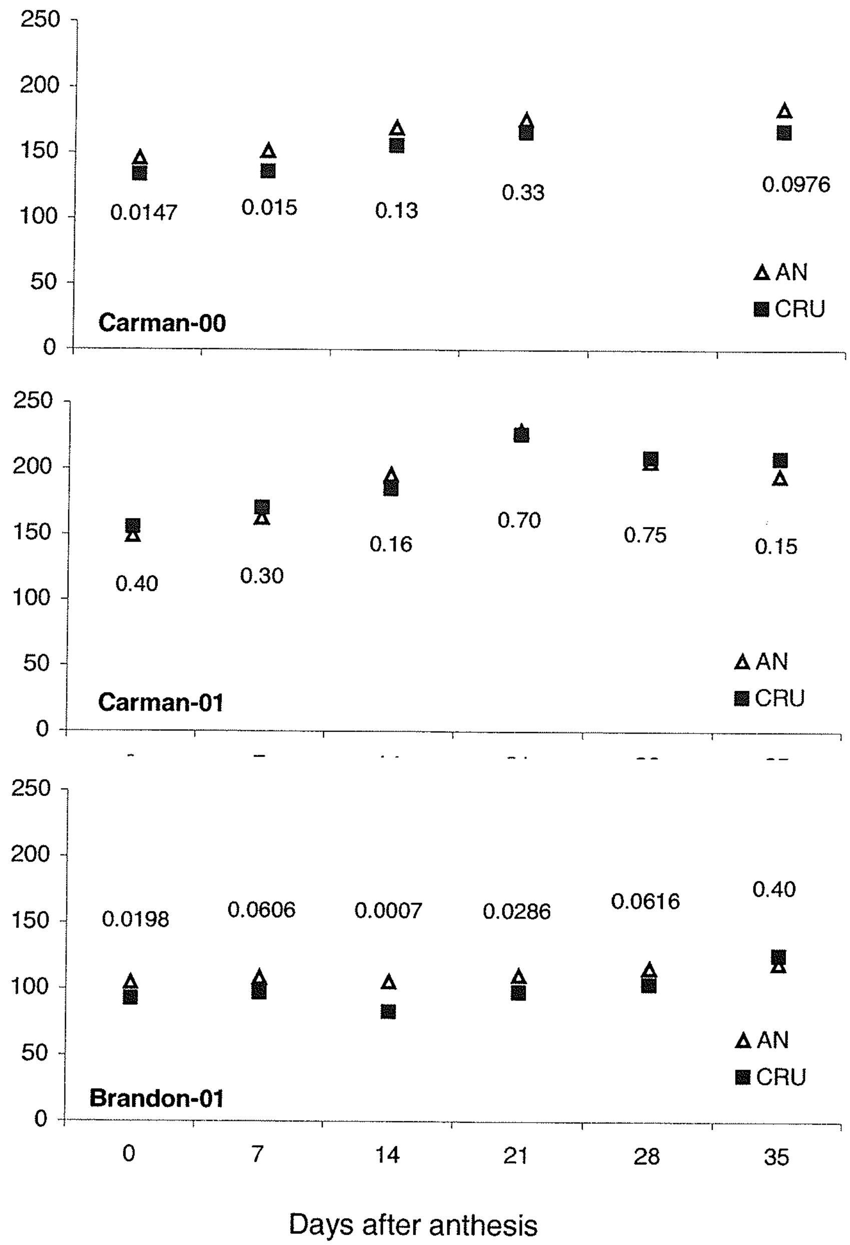
3.4.7.2 Effect of Previous Crop on N Accumulation Pattern

Total N accumulation at anthesis for P-W was significantly higher than for F-W at Carman-00 and Brandon-01; effects were consistent across the three N rates evaluated. As expected, given the lack of an effect of previous crop on soil N supply, previous crop had no effect on N accumulation at Carman-01. At Carman-00 and Brandon-01, differences in N accumulation between P-W and F-W were maintained throughout the sampling period (Fig. 3.4 to 3.6). Significant differences in N yield of the stem/leaf fraction were maintained from anthesis until 35 DAA at Carman ($P < 0.0675$) and 14 DAA at Brandon ($P < 0.10$), while differences in N yield of the head fraction became greater as the filling period progressed, though statistically not significant.

By 35 DAA, P-W and F-W at Carman-00 accumulated 183 kg N ha^{-1} and 159 kg N ha^{-1}, respectively, compared to 125 kg N ha^{-1} and 105 kg N ha^{-1}, respectively, at Brandon-01 (Table 3.7). While the quantity of post-anthesis N uptake was similar for P-W and F-W at all sites, the proportion of N accumulated post-anthesis was significantly higher for F-W versus P-W at Carman-00 and Brandon-01, contrary to expectations. At both sites, the N benefit of field pea was realized by the wheat prior to anthesis, when N has a greater impact on the production of DM and yield rather than PC (Grant and Flaten 1998; Selles et al. 1997). In fact, the increased N supply provided by field pea during vegetative growth at Carman-00 and Brandon-01 proved detrimental to the wheat crop due to a higher incidence of lodging, particularly for Carman-00 (data not presented). The results of the NMN calculations also support the idea of greater post-anthesis N uptake for F-W compared to P-W as a proportion of total N uptake.

3.4.7.3 Effect of Fertilizer N Source on N Accumulation Pattern

Total N accumulation at anthesis for the AN treatment was significantly higher than for the CRU treatment at Carman-00 and Brandon-01 (Fig. 3.7). Differences between N sources were more pronounced at Carman-00 at a rate of 90 kg N ha^{-1} compared to 30 kg N ha^{-1}, while differences were consistent at both N rates at Brandon-01. These results conform to expectations based on the N release pattern of the two N sources. Since 50% of the N in AN is present as highly mobile NO_3-N, AN is rapidly available to plants, making it a popular N source for topdressing in western Canada (Harapiak et al. 1987). Conversely, based on immersion in water at 23°C, the N



[z] P values are presented for each sampling date. Effects are considered significant at $P < 0.05$.

[y] AN = ammonium nitrate, CRU = controlled-release urea

Figure 3.7. Total aboveground plant N during the growing season as affected by fertilizer N source at the Carman-00, Carman-01, and Brandon-01 sites, respectively.[z,y]

release from the CRU product requires 30 to 60 d to reach 80% (Agrium 2000), or 40 to 50 d to reach 100% (Haderlein et al. 2001).

Given the favorable moisture conditions at the three Manitoba sites during the vegetative phase of development, it is reasonable to expect the majority of the N was made available to the wheat crop from CRU prior to anthesis (30 to 40 d after planting). The estimated quantity of NO_3-N at anthesis at a depth of 0-10 cm was higher but not significantly different for the CRU treatment compared to the AN treatment at Carman-01 and Brandon-01 (data not presented). There was also no significant difference between AN and CRU at the Carman-01 site, despite higher N uptake at anthesis for the AN treatment. Lodging scores were higher but not significantly different for AN compared to CRU at Carman-00 (data not presented), also demonstrating subtle differences between the pattern of N availability of the two N sources.

CRU was designed to increase N efficiency by releasing timely amounts of N to match crop uptake (Haderlein et al. 2001; Shaviv 2001). Therefore, the quantity of N uptake of the CRU treatment post-anthesis was expected to exceed that of AN, particularly since soil moisture levels were deemed adequate for crop uptake of NO_3-N. The results from Brandon-01 are in agreement with these expectations, since post-anthesis N uptake as a percentage of total plant N uptake at 35 DAA for the CRU treatment (26.3%) was significantly higher than the AN treatment (12.4%) (Table 3.7). However, at Carman-00 and Carman-01, post-anthesis N uptake was similar for the AN and CRU treatments. A direct comparison of these results with those of Haderlein et al. (2001) is not valid since Haderlein et al. compared CRU to conventional urea, not AN.

The Brandon site was the best suited to evaluate the effect of fertilizer N source on wheat N accumulation, since treatment effects were less likely to be masked by high concentrations of soil N, as encountered at the Carman sites. Given these findings, CRU research deserves further study, particularly on sites that are more reflective of the low concentrations of N that the typical producer could expect.

3.4.8 Harvest Measurements

A summary of harvest data is provided in Table 3.8. Grant and Flaten (1998) suggested spring wheat yield was considered to be limited by a lack of N where PC was less than 13.5% on a 14% moisture basis. Based on this criterion alone, N was not obviously limiting yield at any of the sites. However, grain with a PC greater than 13.5% does not always indicate yield was not limited by a lack of N at some time during the growing season. As expected, there was a pronounced yield response at Brandon-01 due to its relatively low concentration of soil N prior to fertilization. However, wheat from the treatment with the lowest PC (wheat grown on flax and fertilized with 30 kg ha^{-1} as AN) exceeded this critical threshold. P-W produced higher grain yield than F-W at Carman-00 and Brandon-01. At Carman-00, the greatest difference in grain yield between P-W and F-W was in control plots, the differences becoming smaller as fertilizer N rate increased; differences were consistent across all three fertilizer N rates at Brandon-01. As expected, due to high concentrations of soil N, there was almost no difference in PC between the 0 and 90 kg N ha^{-1} fertilizer rates for Carman-01, indicating a poor response to applied N.

Treatment		Grain Yield (kg ha^{-1})			Grain Protein Content (%)			Grain N Yield (kg N ha^{-1})		
Previous Crop	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01	Carman-00	Carman-01	Brandon-01	Carman-00	Carman-01	Brandon-01
Pea		3746	3663	2584	16.7	17.4	15.2	110	114	69
Flax		3381	3724	2061	15.2	17.6	14.4	90	113	52
	0	3479	3719	1795	14.7	17.3	13.9	91	113	44
	30AN[z]	3563	3680	2168	15.7	17.5	14.0	98	113	54
	30CRU[y]	3670	3664	2305	15.4	17.5	14.1	100	113	57
	90AN	3426	3735	2678	17.0	17.6	15.9	102	115	75
	90CRU	3679	3668	2668	16.9	17.7	15.8	109	114	74
ANOVA						Pr > F				
Previous Crop (P)		0.0026	0.50	0.039	0.0305	0.30	0.17	0.0012	0.84	0.0382
N Applied (kg ha^{-1}) (N)		0.46	0.91	<0.0001	<0.0001	0.51	<0.0001	0.0057	0.93	<0.0001
P*N		0.0821	0.83	0.24	0.16	0.49	0.05	0.0552	1.00	0.49
Contrast										
AN versus CRU		0.13	0.52	0.45	0.45	0.73	0.88	0.14	0.7	0.44
Pea vs Flax at 0 N		0.0005 (+)[w]	0.77	0.001 (+)	0.0041 (+)	0.17	0.49	<0.0001 (+)	0.95	0.0061 (+)
Pea vs Flax at 30 N		0.10	0.15	0.0003 (+)	<0.0001 (+)	0.14	0.0039 (+)	<0.0001 (+)	0.76	<0.0001 (+)
Pea vs Flax at 90 N		0.19	0.93	0.0065 (+)	0.0198 (+)	0.55	0.0067 (+)	0.0055 (+)	0.58	0.0004 (+)
CV (%)		9.2	4.9	10.0	4.2	2.6	3.8	8.5	5.9	10.4

[z] Ammonium nitrate fertilizer.
[y] Controlled-release urea fertilizer.
[x] A *P*-value followed by (+) indicates the value of the first treatment of the contrast is significantly greater than the value of the second treatment, while (-) indicates the opposite.

Table 3.8. Grain yield, protein content (14% moisture basis), and N yield (DM basis) at the experimental sites as affected by previous crop and fertilizer N treatment.[z,y,x]

P-W had significantly higher grain PC than F-W at all three levels of applied N at Carman-00 (data not presented). At Brandon-01, PC was significantly higher for P-W than for F-W at the 30 kg N ha^{-1} and 90 kg N ha^{-1} N rates. Higher PC was observed for F-W compared to P-W in the control treatment as a result of the dilution effect of yield on grain PC (Fowler et al. 1990). Grain N yield was significantly higher for P-W than F-W at Carman-00 and Brandon-01, and differences were consistent across all three fertilizer N rates. Average grain N yield at Carman-00 was 110 kg N ha^{-1} and 90 kg ha^{-1} for P-W and F-W, respectively, compared to 113 kg N ha^{-1} and 114 kg N ha^{-1} at Carman-01 and 69 kg N ha^{-1} and 52 kg N ha^{-1} at Brandon-01. While the grain N yields for P-W and F-W are similar to the results reported by Miller et al. (2002b), N yield at the Carman sites is considerably higher than at Brandon-01 reflecting the high N supply at the Carman site relative to the Brandon site.

Despite evidence of differences in post-anthesis N accumulation between AN and CRU treatments, particularly at Brandon-01, N source did not have a significant effect on grain PC, or grain N yield, at any of the sites. Our results are in contrast to those of Haderlein et al. (2001), who observed higher grain PC in CRU treatments compared to conventional urea. However, Haderlein et al. did not compare CRU to AN as in our experiment. Also, given the high background soil N levels at the Carman sites, the effect of N source may have been masked, particularly with respect to post-anthesis N availability as a result of the high NMN values reported in this study.

3.5 Conclusions

Previous crop and fertilizer N source affected the timing and quantity of N available to a subsequent wheat crop at sites where grain yield responded to applied fertilizer N, namely Carman-00 and Brandon-01. Field pea stubble supplied more NO_3-N to a depth of 120 cm than flax stubble at both of these sites. These differences in available N persisted until anthesis at Carman-00 but did not at Brandon-01, where the N benefit of field pea had been fully utilized by the crop at this stage. N yield at anthesis of wheat grown on field pea stubble was significantly higher compared to flax stubble at the N responsive sites and the differences in N yield were effectively maintained until maturity. However, post-anthesis N uptake as a percentage of total N uptake 35 DAA was significantly higher where wheat was grown on flax stubble compared to pea stubble, in contrast to the findings of similar studies carried out in western Canada. Grain yield and grain N yield were significantly higher for wheat grown on pea stubble versus wheat grown on flax stubble at the N responsive sites and appeared to be due primarily to differences in N availability early in the growing season.

Compared to the effect of previous crop, N source had considerably less impact on the pattern and quantity of N uptake by wheat. As expected, plant N yield at anthesis was higher for the AN treatment compared to the CRU treatment at both Carman-00 and Brandon-01. At the Brandon-01 site, where soil NO_3-N levels were low in comparison to the Carman sites, post-anthesis N uptake for the CRU treatment was significantly higher than for AN, although these differences did not translate into significant differences in grain yield, PC, or grain N yield. The relatively high soil N status at Carman in both years may have masked the effect of N source on plant N dynamics and merits further study.

The results of this study suggest that previous crop had a pronounced impact on both the quantity and temporal pattern of N release, and that annual grain legumes provide a considerable N benefit to a succeeding wheat crop. However the temporal availability of N reported in other studies in western Canada, namely the slow, steady release of N from grain legume residue during the subsequent growing season, was not observed. To the contrary, apparent post-anthesis NMN was significantly higher for wheat grown on flax stubble compared to field pea stubble.

The significantly higher soil NO_3-N levels present at planting on field pea stubble indicate there was considerably greater post-harvest N availability on field pea stubble compared to flax stubble. The temporal pattern of N availability exhibited by field pea stubble in this study suggests that under Manitoba conditions, proper N fertility evaluation prior to the establishment of succeeding crops, as well post-harvest N management practices such as the use of N catch crops or the establishment of winter cereals, may improve N recovery from field pea stubble and reduce the risk of N losses such as denitrification and NO_3-N leaching.

4.0 THE EFFECT OF CROP ROTATION AND FERTILIZER N SOURCE ON THE BREADMAKING QUALITY OF CANADA WESTERN RED SPRING WHEAT

4.1 Abstract

The effect of previous crop and fertilizer N source on the end-use quality of CWRS wheat was determined in a series of small plot experiments carried out at Carman, MB, Brandon, MB, and Swift Current, SK. In the first phase of the rotation, field pea (*Pisum sativum* L.) and flax (*Linum usitatissimum* L.) were established at Manitoba sites; durum wheat (*Triticum durum* Desf.) was substituted for flax at Swift Current. In the re-crop phase, spring wheat (*Triticum aestivum* L. cv. AC Barrie) was planted. Fertilizer N was applied at three rates (0, 30, and 90 kg N ha^{-1}) and two N sources (ammonium nitrate and a polyurethane-coated controlled-release urea called Duration™) at the Manitoba sites. Urea was applied at Swift Current at three rates (34, 50, and 78 kg N ha^{-1}) based on soil test recommendations for dry, average, and wet growing conditions, respectively. End-use quality was assessed with the Mixograph, dough micro-extension tests, Farinograph, and the Canadian Short Process bake test. Wheat grown after field pea had significantly higher flour protein content (FPC) at four of five sites compared to wheat grown after flax/durum; fertilizer N source had no effect on FPC. Based on pooled data (n = 110) with a similar range of FPC for field pea and flax/durum stubble, there was a significant interaction between previous crop and FPC ($P < 0.05$) for some quality parameters. Wheat grown on field pea stubble had significantly shorter Mixograph dough development time at FPC < 14%, lower work input-to peak and a lower dough strength index than wheat grown on flax/durum stubble. Wheat grown on field pea

stubble also tended to be more extensible than wheat grown on flax/durum stubble. No strong interactions were observed for micro-extension test parameters, Farinograph water absorption, or loaf volume. Coefficients of determination (r^2) for selected quality attributes and FPC increased in many instances by excluding the Swift Current-01 dataset, most likely as a result of the effect of growing season conditions on protein composition. Besides the effect previous has on overall soil N supply and FPC, this study also demonstrates that at the same FPC, previous crop alters flour technological quality, theoretically as a result of the influence previous crop has on the temporal availability of N during the growing season. This study also stresses the strong effect of growing season conditions and environment on end-use quality, since at the same FPC, site years exhibited dramatically different dough strength and functionality.

4.2 Introduction

An increasing proportion of wheat produced on the Prairies is being collected in large-scale high throughput primary elevators (HTPs) with the capacity to deliver large volumes of wheat cleaned to export standards of a specific grade and PC to flour mills across North America. Combined with a trend towards contract production and marketing, identity-preserved grain handling, and specification-based sales, the regional averaging of wheat quality through blending is expected to decline (Preston et al. 2002). Current changes in the grain industry have the potential to increase the influence of regional agronomic practices and growing season conditions on end-use quality.

Crop rotation and fertilizer N source are known to influence the timing and amount of N available to the plant. A number of western Canadian studies have reported wheat grown on annual grain legume stubble exhibits higher N uptake and grain PC compared to wheat grown on non-legume stubble (Beckie et al. 1997; Fu et al. 1999; Mooleki et al. 1997; Strong et al. 1986b; Wright et al. 1990). In a previous study (Chapter 3) we demonstrated that while wheat grown on field pea stubble accumulated significantly more total N than wheat grown on flax stubble, wheat grown on flax stubble accumulated a greater percentage of total N after anthesis. Fertilizer N source was also shown to influence N uptake, but not to as great an extent as previous crop.

The ability to influence the timing and amount of plant N uptake may influence protein composition. Gliadin and glutenin have dramatically different effects on wheat end-use quality (Gupta et al. 1992; Hamada et al. 1982; MacRitchie 1992; MacRitchie et al. 1991; Schofield 1986; Shewry et al. 1986; Wall 1979). Interestingly, gliadin and glutenin also accumulate in the kernel in a highly ordered, asynchronous manner (Jamieson et al. 2001; Stone and Savin 1999). Gliadin is rapidly synthesized in the early stages of the filling period, while glutenin is not synthesized in considerable quantity until the mid-filling period and glutenin polymerization occurs very late during kernel development. Many studies have demonstrated that N fertilization alters bread wheat quality by directly influencing the rate and duration of N accumulation in the kernel, and/or altering protein composition (Pechanek et al. 1997; Peltonen and Virtanen 1994; Timms et al. 1981; Wieser and Seilmeier 1998; Wooding et al. 2000b; Triboi et al. 2000; Zhu et al. 1999). Given the asynchronous nature of the accumulation of individual protein fractions in the grain, it is plausible that modifying the pattern of N accumulation in the kernel has the potential to alter protein composition. The objective of this study was to determine whether altering N accumulation pattern at similar protein content had an effect on dough rheological properties, flour water absorption, and loaf volume.

4.3 Materials and Methods

The cultural practices of Experiments 1 and 2 were described in detail in a previous paper (Chapter 3 and Appendix I, respectively). In Experiment 1, field pea (*Pisum sativum* L. cv. Grande) and flax (*Linum usitatissimum* cv. Norlin) were established at the Carman Research Station in 1999 and 2000 (prior to the wheat at Carman-00 and Carman-01, respectively), as well as at the Brandon Research Centre in 2000 (prior to the wheat at Brandon-01) in four replicates arranged in a randomized complete block design. In the re-crop phase of the study, spring wheat (cv. AC Barrie) was sown across each main plot. Five N fertilizer treatments were randomly arranged as sub-plots in each main plot as part of a split plot design, namely a control (0 kg N ha^{-1}) and 30 kg N ha^{-1} and 90 kg N ha^{-1} as either commercial grade ammonium nitrate (AN) or controlled-release urea (CRU).

In Experiment 2, field pea (cv. Alfetta) and durum wheat (*Triticum durum* Desf. cv. Kyle) were established in 1999 and 2000 at the Semiarid Prairie Agricultural Research Centre (prior to the wheat at Swift Current-00 and Swift Current-01, respectively) in three replicates arranged in a strip block design. Field pea plots received sulphur (S) fertilizer at the same rate as phosphorus application, which was based on soil test recommendations. In the re-crop phase of the study, N fertilizer treatments were randomly arranged in each block and consisted of three rates of N applied as commercial grade urea based on soil test recommendations for dry, average, and wet growing seasons

(34, 50, and 78 kg N ha^{-1}, respectively). Blocks were subsequently sown with spring wheat (cv. AC Barrie).

4.3.1 Grain Analysis

Grain was harvested using a small plot combine and was allowed to dry. Dockage was removed using a Clipper air-screen cleaner (Blount/Ferrell-Ross, Bluffton, IN); grain was subsequently aspirated to remove light, shriveled, and broken kernels as well as any remaining foreign material. Grain yield was determined on clean samples and adjusted to 14% moisture basis. Sub-samples from each plot were ground with a Wiley mill to pass through a 2 mm sieve and analyzed for total N and S by combustion analysis (LECO Corporation, St. Joseph, MI). Grain grade (including percentage FDK) was determined based on Canadian Grain Commission (CGC) standards. Thousand kernel weight was calculated by multiplying the weight of 200 kernels*5 and adjusting the result to 13.5% moisture basis (CGC 1992). Deoxynivalenol concentration (DON) was determined based on the method of Sinha and Savard (1996).

4.3.2 Milling

Grain samples (1 kg) were tempered for 24 hr to 16.5% moisture content and milled to straight grade flour of approximately 14% moisture basis using a Buhler experimental mill. Flour yield (FY) was calculated as (amount of flour recovered from the mill/amount of grain milled)*100. Flour N and S content, flour protein content (FPC, expressed as %N*5.7), and DON concentration were determined. Flour N:S ratio was calculated based on N and S concentrations as determined by combustion.

4.3.3 Mixograph

Dough was prepared and mixing behaviour was evaluated using a 10 g computerized Mixograph (National Manufacturing, Lincoln, NE). Dough was mixed at constant absorption (62% distilled water) at 25°C for 8 min and monitored for dough development and breakdown. The test was performed in duplicate and data were acquired using Mixsmart software version 3.8 (Walker and Walker 1995). The following parameters were measured: mixing time to peak development (MDT), work input to MDT (WIP), bandwidth at MDT (PBW), dough resistance at MDT (PDR), dough breakdown resistance (BR), and strength index (SI). Please see Appendix J. 2. for a detailed description of the Mixograph method.

4.3.4 Micro-extension Test

Dough extensibility was evaluated according to the method of Smewing (1995) using a TA.XT2*i* texture analyzer fitted with a Kieffer rig (Texture Technologies, Inc., Scarsdale, NY; Stable Microsystems, SMS, Surrey, UK). Dough was prepared with salt using the Mixograph, formed into strips using a Teflon block apparatus, and allowed to rest prior to evaluation of extensibility. The test was done in duplicate (and triplicate if necessary) using 4-6 dough strips per replicate. The parameters measured were maximum dough resistance (Rmax), dough extensibility at Rmax, extensigram area (E Area), and dough extensibility at rupture (E). The dough visco-elastic ratio was calculated as Rmax/E. Please see Appendix J. 3. for a detailed description of the micro-extension test.

4.3.5 Farinograph Absorption and Baking

Optimal flour water absorption (FAB) was determined with a Brabender Farinograph (Brabender Instruments, Inc., South Hackensack, NJ) using Approved Method 54-21 (AACC 2000). Baking was performed in duplicate using the Canadian Short Process procedure (Preston et al. 1982) based on 100 g of flour. This test is performed under conditions of high-speed mixing and short fermentation and is typical of the baking formulation and methods employed by many Canadian commercial bakeries (CGC 1992). Loaf volume (LV) was determined using a rapeseed displacement apparatus. Please see Appendix J. 4. for a detailed description of the Canadian Short Process baking procedure.

4.3.6 Statistical Analysis

Analysis of variance (ANOVA), correlation, and regression analysis was carried out using procedures of the SAS Institute, Inc. (2001). Experiment 1 was analyzed by ANOVA as a factorial experiment arranged in a randomized complete block design, while Experiment 2 was analyzed as a completely randomized design. Non-orthogonal, single degree of freedom contrasts were used to test the effects of fertilizer N source, N rate, and previous crop and N rate interaction, depending on experimental design. Effects were considered significant at $P < 0.05$.

Bartlett's test was used to evaluate homogeneity of variance among site years prior to correlation and regression analysis (Steel et al. 1997). Pearson correlation coefficients were determined for a pooled dataset (n = 110) restricted to a common range of FPC of the two previous crop types (field pea or flax/durum). Coefficients of determination (r^2) were determined for the restricted dataset (based on n = 57 for wheat grown on field pea stubble and n = 53 for wheat grown on flax/durum stubble) and were considered significant at $P < 0.05$. The Proc GLM procedure was used to evaluate linear relationships (no quadratic relationships were observed) between selected quality attributes and FPC. Previous crop was considered to have a significant effect on a given end-use quality parameter where the probability value of the interaction term (previous crop*FPC) of Type III sums of squares was less than 0.05. Type III sums of squares allows multiple regression lines to have different slopes and intercepts (G. H. Crow, personal communication). The interaction between fertilizer N source and selected quality attributes was also evaluated in a similar manner. Data from the Carman-00 and Brandon-00 sites were pooled, and samples that fell out of the common range of FPC of AN and CRU were excluded from further analysis (n = 31 for both AN and CRU). Fertilizer N source was considered to have a significant effect on a given end-use quality parameter where the probability value of the interaction term (N source*FPC) of Type III sums of squares was less than 0.05.

4.4 Results and Discussion

Conditions overall were favorable for growth and development for all site years except Swift Current-01, where a lack of precipitation during the growing season (Table 4.1), coupled with poor soil moisture reserves prior to planting, resulted in low grain yields and restricted N uptake (Appendix D and Appendix G). Urea granules were found stranded in dry soil until anthesis, indicating a lack of fertilizer N availability. Heavy rainfall events and high soil N fertility at the Manitoba sites caused lodging problems, particularly at Carman, where growth was especially lush (Chapter 3).

	Site				
	Carman-00	Swift Current-00	Carman-01	Brandon-01	Swift Current-01
May					
Precipitation (mm)	55 (53)	65 (46)	53.0	70 (48)	23.0
Average Air Temperature (°C)	11.5 (11.9)	10.9 (10.8)	12.8	12.7 (11.0)	12.2
June					
Precipitation (mm)	94 (73)	54 (67)	41.0	168 (67)	32.0
Average Air Temperature (°C)	14.6 (17.4)	13.8 (15.6)	16.2	15.2 (16.2)	15.0
July					
Precipitation (mm)	47 (69)	127 (49)	193.0	31 (72)	63.0
Average Air Temperature (°C)	19 (20.1)	19.1 (18.3)	19.8	19.0 (18.7)	19.7
August					
Precipitation (mm)	86 (66)	13 (38)	22.0	53 (69)	3.0
Average Air Temperature (°C)	18.7 (18.7)	18.5 (17.6)	19.5	18.9 (17.5)	20.9

[a] Data in parentheses are 1961-1990 climatic averages (Environment Canada Climate Center, Winnipeg, MB)

Table 4.1. Meteorological data for the experimental sites.[a]

While wheat samples from Swift Current-00 and Swift Current-01 all graded No. 1 CWRS (Table 4.2), green kernels were noticeable in some Swift Current-01 samples. Samples were hand picked prior to milling to remove noticeably green kernels from all samples. The green kernels present in samples from the Swift Current-01 site are likely a product of kernel physiological immaturity (Preston et al. 1991), and as such likely have elevated levels of starch damage. The majority of the samples from the Carman-00 and Brandon-01 sites graded No. 2 or No. 3 CWRS due to Fusarium head blight damage. Samples from the Carman-01 site graded No. 1 or No. 2 CWRS for the most part and were downgraded for the same reason. While Fusarium damage can result in adverse effects on milling and end-use quality (Dexter and Nowicki 2001), samples that had graded lower than No. 2 CWRS were also included in subsequent analysis as it

Parameter[a]	Location									
	Carman-00		Swift Current-00		Carman-01		Brandon-01		Swift Current-01	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Grade[b]	2.58	0.50	1.00	0.00	1.88	0.40	2.59	0.50	1.23	0.00
TWT	30.8	1.5	31.4	4.0	30.6	1.5	34.8	1.6	30.8	1.1
TKWT	74.9	1.3	n.d.[c]	n.d.	74.9	1.3	79.4	0.6	79.3	0.5
DON	0.36	0.07	n.d.	n.d.	0.32	0.11	0.96	0.17	n.d.	n.d.
FDK	1.23	0.38	0.01	0.03	0.59	0.28	1.18	0.43	0.02	0.02
FPC	14.6	1.3	11.6	1.5	16.4	0.4	14.3	1.2	15.1	1.3
Flour N:S Ratio	17.5	0.4	16.8	0.9	19.4	0.3	17.6	0.5	17.1	0.8
MDT	3.41	0.42	4.00	0.81	3.47	0.26	3.21	0.39	2.76	0.32
PDR	55.2	4.6	45.6	6.5	58.6	2.2	52.6	3.8	53.6	2.5
WIP	136.9	9.3	136.5	12.5	148.6	8.8	125.5	9.9	109.8	10.1
PBW	34.0	2.0	26.1	3.4	36.0	1.6	33.0	2.2	25.4	1.4
BR	6.01	1.06	4.84	1.61	5.20	0.74	5.62	1.46	9.27	1.20
SI	115.5	13.0	102.2	11.2	124.8	11.0	106.2	14.6	70.2	8.6
Rmax	34.2	2.8	28.8	2.3	36.4	1.9	32.8	3.7	25.3	2.7
E at Rmax	89.1	8.8	27.4	3.5	30.1	1.3	27.6	2.4	95.0	7.0
E Area	595	64	474	57	628	40	535	53	477	52
E	95.6	9.1	90.4	9.9	98.3	5.4	90.5	8.0	103.3	7.3
Rmax/E	0.39	0.05	0.36	0.06	0.40	0.03	0.40	0.07	0.27	0.04
FAB	63.3	1.6	60.7	1.5	62.0	0.7	62.1	2.2	62.2	1.4
LV	1188	60	969	77	1199	42	1148	58	1271	70

[a] TWT = test weight, TKWT = thousand kernel weight, DON = deoxynivalenol concentration, FDK = % Fusarium-damaged kernels, FPC = flour protein content, MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak bandwidth, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FAB = Farinograph water absorption, LV = loaf volume.

[b] Where #1CWRS = 1, #2 CWRS = 2, #3 CWRS = 3, CW Feed = 4.

[c] Data were not collected.

Table 4.3. Selected quality attributes of the experimental sites.[a,b,c]

did not compromise the main objectives of the study. Furthermore, average thousand kernel weight was well within the average range of 28 to 33 g for CWRS wheat (CGC 1992) at all sites. Given the variability in growing conditions and soil fertility among the sites, grain sulphur status was also measured, since flour with a ratio of N to S in excess of 17 to 1 produces dough that is stronger and less extensible (Moss et al. 1981). However, the average N:S ratio was relatively consistent across all site years (16.4-17.6), and was therefore not considered an issue within the objectives of this study.

4.4.1 Effect of Agronomic Practices on Flour Protein Content

Previous crop had a strong effect on FPC at two of the three Manitoba sites (Table 4.3). The nature of and the rationale for the effect of previous crop and fertilizer N source on grain PC was reported previously (Chapter 3). Results for the effect of previous crop on FPC at the Manitoba sites are reported in Table 4.4. Differences in FPC as a result of previous crop occurred as a result of higher nitrate nitrogen (NO_3-N) levels at planting for field pea stubble compared to flax/durum stubble (Table 4.4). The higher NO_3-N levels on field pea stubble were due to the conservation of soil N by field pea as a result of atmospheric N fixation, as well as N mineralization during the period following harvesting field pea harvest. Wheat grown with AN exhibited enhanced pre-anthesis N uptake at Carman-00 and Brandon-01, while post-anthesis N uptake of CRU plots at Brandon-01 exceeded N uptake of AN plots at Brandon-01 alone (Chapter 3).

Treatment		Flour Protein Content (%)		
Previous Crop	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	12.6	16.3	13.5
Flax	30AN[a]	13.6	16.2	13.1
Flax	30CRU[b]	13.1	16.2	13.1
Flax	90AN	15.0	16.6	14.6
Flax	90CRU	14.8	16.6	15.3
Field Pea	0	14.6	16.1	13.5
Field Pea	30AN	15.4	16.6	14.1
Field Pea	30CRU	15.1	16.4	14.1
Field Pea	90AN	15.9	16.5	16.1
Field Pea	90CRU	16.2	16.8	16.0
ANOVA			Pr > F	
Previous Crop (P)		0.0369	0.55	0.13
N Applied (kg ha^{-1}) (N)		<0.0001	0.11	<0.0001
P*N		0.15	0.61	0.0895
Contrast				
AN versus CRU		0.33	0.82	0.42
0 N vs 30 N		0.0058	0.38	0.67
30 N vs 90 N		<0.0001	0.0539	<0.0001
Pea vs Flax at 0 N		0.0004	0.58	0.85
Pea vs Flax at 30 N		<0.0001	0.17	0.0036
Pea vs Flax at 90 N		0.0032	0.94	0.0026
CV (%)		3.6	2.4	3.5

[a] Ammonium nitrate fertilizer.

[b] Controlled-release urea fertilizer.

Table 4.3. Flour protein content (14% moisture basis) at the Manitoba experimental sites as affected by previous crop and fertilizer N treatment.

Parameter	Site				
	Carman-00	Swift Current-00	Carman-01	Brandon-01	Swift Current-01
Seeding Date	14-May	17-May	16-May	17-May	8-May
50% Anthesis Date	13-Jul	------	10-Jul	13-Jul	17-Jul
Harvest Date	24-Aug	12-Sep	16-Aug	24-Aug	22-Aug
Soil Name	Denham	Haverhill	Denham	Newdale	Haverhill
Soil Classification	Orthic Black Chernozem	Orthic Brown Chernozem	Orthic Black Chernozem	Orthic Black Chernozem	Orthic Brown Chernozem
Soil Texture	sandy loam	loam	sandy loam	loam	loam
Soil NO_3-N to 120 cm (kg ha^{-1})[a]					
Field Pea Stubble	120a	------	134a	81a	30a
Flax/Durum Stubble	65b	------	150a	50b	26a

[a] Means followed by a different letter within each site are significantly different ($P < 0.05$) based on LSD test.

Table 4.4. Agronomic information for the experimental sites.[a]

At Swift Current, wheat grown on field pea stubble (P-W) had significantly higher FPC compared to wheat grown on durum stubble in 2000 and 2001 (Table 4.5). There was also a strong interaction between fertilizer N rate and previous crop in 2001. P-W had significantly higher FPC at N rates of 34 and 50 kg N ha^{-1}, while previous crop had no effect on FPC at a rate of 78 kg N ha^{-1}. Although no detailed agronomic data was collected at Swift Current in 2000, the FPC data suggest higher N supply on field pea stubble was responsible for the previous crop effect. Given significantly above average grain yields in 2000, along with typically much lower average soil N fertility relative to the Manitoba sites, the low FPC values recorded on durum stubble are not surprising.

As for Swift Current-01, soil NO_3-N levels at planting cannot be used to explain the higher FPC for wheat grown on field pea stubble (Appendix E). Interestingly, soil NO_3-N to a depth of 110 cm was significantly higher for pea stubble at anthesis rather than at planting. Enhanced N availability at anthesis on field stubble compared to durum stubble suggests the potential for enhanced post-anthesis N uptake for wheat grown on field pea stubble. However, given the dry conditions at the site, no such effect was observed. Fertilizer N rate had a strong effect on FPC at Swift Current-00, while fertilizer N rate did not have a significant effect on FPC at Swift Current-01.

Treatment		Flour Protein Content (%)	
Previous Crop	N Applied ($kg\ ha^{-1}$)	2000	2001
Durum	34	9.6	13.7
Durum	50	10.8	13.9
Durum	78	12.1	15.8
Field Pea	34	11.2	15.6
Field Pea	50	12.3	16.2
Field Pea	78	13.9	15.2
ANOVA		Pr > F	
Previous Crop (P)		0.0006	0.0182
N Applied ($kg\ ha^{-1}$) (N)		0.0003	0.30
P*N		0.95	0.0328
Contrast			
34 N vs 50 N		0.88	0.69
50 N vs 78 N		0.75	0.0159
Pea vs Durum at 34 N		0.0214	0.027
Pea vs Durum at 50 N		0.032	0.0093
Pea vs Durum at 78 N		0.0137	0.40
CV (%)		6.6	6.1

Table 4.5. Flour protein content (14% moisture basis) at the Swift Current experimental sites as affected by previous crop and fertilizer N rate.

4.4.2 Relationships between Quality Attributes

Given the strong effect of previous crop on FPC, it was not possible to evaluate previous crop effects across a similar range of FPC for individual site years. Therefore, data were pooled from four of five site years. The Carman-01 dataset, where all FPC values were high, was excluded as per the results of Bartlett's test of homogeneity of variance in order to reduce heterogeneity of variance among site years. The relationship between FPC, dough strength, and baking quality (Table 4.6) is generally consistent with previous reports (Lukow and Preston 1998; Wooding et al. 2000b; Zhu and Khan 2001). FPC was strongly ($r > 0.80$) (and positively) correlated with PDR, FAB, and LV, suggesting these parameters were influenced less by factors other than FPC. FAB is consistently reported to be strongly and positively related to FPC (Finney 1945; Kosmolak and Crowle 1980; Tipples et al. 1994).

The strong relationship between FPC and LV is well-established (Bushuk et al. 1969; Finney and Barmore 1948) and should be expected to be particularly strong when utilizing the CSP bake test. Short fermentation times and a rich formula (particularly the use of shortening) tend to mask some of the environmental or treatment effects that might be more pronounced with a bake test that does not employ optimized dough mix times (H. D. Sapirstein, personal communication). FPC was moderately ($0.4 < r < 0.8$) and negatively correlated with MDT, and positively correlated with dough extensibility and E area. Weak correlations were observed between FPC and WIP, SI, and Rmax/E.

Mixograph parameters were generally moderately correlated with one another. MDT was negatively correlated to PDR, indicating that at constant absorption and increasing FPC, MDT decreases as PDR increases. MDT would also be expected to decrease given the strong inverse relationship observed between FAB and MDT. MDT was also negatively correlated with BR, and strongly correlated with WIP and SI. As PBW was poorly correlated with FPC, so too was PBW generally poorly correlated with other Mixograph parameters except for WIP.

	Flour Properties			Mixograph						Micro-extension					Baking	
	Flour PC	Flour S	Flour N:S	MDT	PDR	WIP	PBW	BR	SI	Rmax	E at Rmax	E Area	E at Rupture	Rmax/E	FAB	LV
Flour Properties																
Flour PC	----															
Flour S	0.93***	----														
Flour N:S	0.56***	0.23^{ns}	----													
Mixograph																
MDT	-0.73***	-0.76***	-0.24^{ns}	----												
PDR	0.91***	0.84***	0.52***	-0.64***	----											
WIP	-0.36**	-0.44***	0.02^{ns}	0.85***	-0.18^{ns}	----										
PBW	0.17^{ns}	0.03^{ns}	0.36**	0.16^{ns}	0.28*	0.42***	----									
BR	0.66***	-0.72***	0.15^{ns}	-0.67***	-0.55***	-0.53***	-0.48***	----								
SI	-0.38***	-0.48***	0.07^{ns}	0.79***	-0.27*	0.84***	0.73***	-0.73***	----							
Micro-extension																
Rmax	0.06^{ns}	-0.10^{ns}	0.36***	0.32**	0.16^{ns}	0.53***	0.73***	-0.48***	0.66***	----						
E at Rmax	0.63***	0.66***	0.17^{ns}	-0.58***	0.63***	-0.37***	-0.15^{ns}	0.65***	-0.49***	-0.31**	----					
E Area	0.41***	0.28*	0.44***	0.00^{ns}	0.52***	0.32**	0.62***	-0.10^{ns}	0.37***	0.83***	0.26*	----				
E	0.59***	0.64***	0.13^{ns}	-0.59***	0.57***	-0.42***	-0.21^{ns}	0.66***	-0.53***	-0.38***	0.98***	0.18^{ns}	----			
Rmax/E	-0.29*	-0.41***	0.16^{ns}	0.53***	-0.23ns	0.56***	0.57***	-0.65***	0.71***	0.85***	-0.75***	0.43***	-0.78***	----		
Baking																
FAB	0.76***	0.66***	0.55***	-0.60***	0.83***	-0.26*	0.22^{ns}	0.40***	-0.28*	0.12^{ns}	0.50***	0.43***	0.51***	-0.22^{ns}	----	
LV	0.83***	0.83***	0.33**	-0.68***	0.72***	-0.42***	-0.01^{ns}	0.68***	-0.44***	-0.09^{ns}	0.68***	0.21^{ns}	0.47***	-0.31**	0.55***	----

[a] ns, *, **, *** not significant. significant at P <0.01, 0.001, and 0.0001, respectively.

Table 4. 6. Coefficients of correlation (r) for selected quality attributes for the pooled dataset (n = 110).[a]

Although comparison of data from the micro-extension test and the standard Extensigraph is complicated by factors such as differences in dough mass, dough geometry (ratio of cross-section to length of dough stretched), and hook speed (Suchy et al. 2000), the output generated by each apparatus is comparable (Smewing 1995). Micro-extension test parameters were moderately correlated with one another. Rmax was strongly and positively correlated with E area as well as Rmax/E, while E was poorly correlated to E area. As expected, Rmax was inversely related to E, although the relationship was weak; Rmax is a measurement of dough strength while E is representative of dough viscosity and extensibility.

Mixograph and micro-extension test parameters were moderately correlated. MDT, WIP, and SI were negatively correlated with dough extensibility and positively correlated with Rmax, reflecting the fact that the Mixograph parameters and Rmax are indicative of dough strength (Uthayakumuran et al. 2000; Wooding et al. 2000b). LV was positively and moderately correlated with BR, PDR, E, and FAB, and negatively correlated with MDT, WIP, and SI. The relationship between FAB and dough rheological measurements followed the same pattern, given the strong relationship between FPC and FAB.

4.4.3 Effect of Previous Crop and Fertilizer Nitrogen Source on End-Use Quality Across a Similar Range of Flour Protein Content

Results of analysis on the restricted dataset suggested that besides its effect on protein concentration, previous crop had an effect on end-use quality in some instances (Table 4.7). With respect to Mixograph parameters, previous crop had a significant effect on MDT and WIP and also appeared to affect SI (Figure 4.1). Below a FPC of 14%, wheat grown on flax/durum stubble had higher MDT compared to wheat grown on field pea stubble; regression lines converged at FPC greater than 15%. Despite a strong relationship between FPC and Mixograph parameters WIP and SI, coefficients of determination were low relative to the relationship between FPC and MDT. Wheat grown on flax/durum stubble tended to have higher WIP and SI compared to P-W (Figures 4.2 and 4.3, respectively); regression lines converged at FPC greater than 15%. The lack of a treatment effect at FPC greater than 15% is in agreement with the observations of other researchers that at higher FPC, dough mixing quality decreases as a result of the weakening effects of an increased ratio of gliadin to glutenin (Janssen et al. 1991; Timms et al. 1981; Uthayakumuran et al. 1999; Uthayakumuran et al. 2000). However, protein composition analysis is required to further validate this hypothesis.

The results of the regression analysis are consistent with correlation analysis that demonstrated these three Mixograph parameters were positively and moderately correlated with one another, as well as the observation that all three parameters are measurements of dough strength. The poor coefficients of determination reflect the strong influence of site year on WIP and SI as compared to MDT.

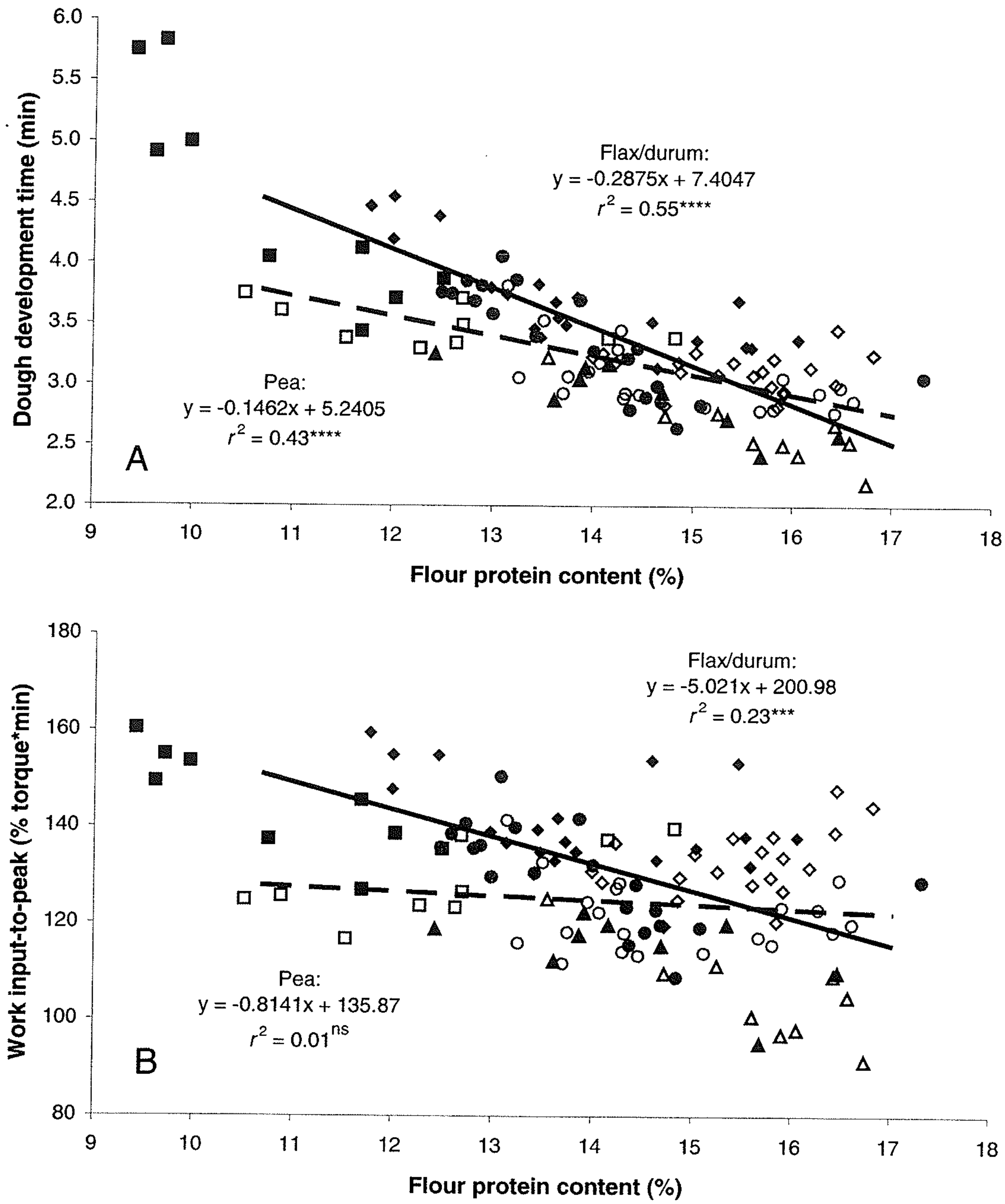
Analysis of the micro-extension test did not yield any significant interaction between previous crop and FPC, although P-W produced dough that was more extensible at FPC less than 14% (Figure 4.4). This result is consistent with the Mixograph observations, since dough extensibility was inversely related to MDT. Not surprisingly, given the results of the correlation analysis, there was also no significant interaction between previous crop and FPC for either FAB or LV (Figure 4.5 and 4.6, respectively).

Parameter	Pooled Dataset		Pooled Dataset excl. Swift Current-01	
	FPC (r^2)	Prev. Crop*FPC (Pr > F)	FPC (r^2)	Prev. Crop*FPC (Pr > F)
MDT	0.53****	0.0009***	0.62****	0.0004***
PDR	0.82****	0.34^{ns}	0.89****	0.46^{ns}
WIP	0.13***	0.0145*	0.25***	0.0017**
PBW	0.03^{ns}	0.94^{ns}	0.32****	0.53^{ns}
BR	0.43****	0.48^{ns}	0.53****	0.0655^{ns}
SI	0.14****	0.0889^{ns}	0.29****	0.0531^{ns}
Rmax	0.00^{ns}	0.68^{ns}	0.14***	0.63^{ns}
E at Rmax	0.40****	0.12^{ns}	0.41****	0.17^{ns}
E Area	0.17****	0.86^{ns}	0.38****	0.91^{ns}
E	0.35****	0.16^{ns}	0.35****	0.18^{ns}
Rmax/E	0.08**	0.29^{ns}	0.08**	0.28^{ns}
FAB	0.57****	0.72^{ns}	0.65****	0.56^{ns}
LV	0.68****	0.62^{ns}	0.72****	0.62^{ns}

[a] ns, *, **, ***, **** not significant, significant at P<0.05, 0.01, 0.001, and 0.0001, respectively.

Table 4.7. Coefficients of determination (r^2) of the pooled dataset for flour protein content (FPC) and selected quality attributes, as well as degree of significance for the interaction between previous crop and FPC for the pooled dataset (n = 110) and the pooled dataset excluding Swift Current-01 data (n = 92).[a]

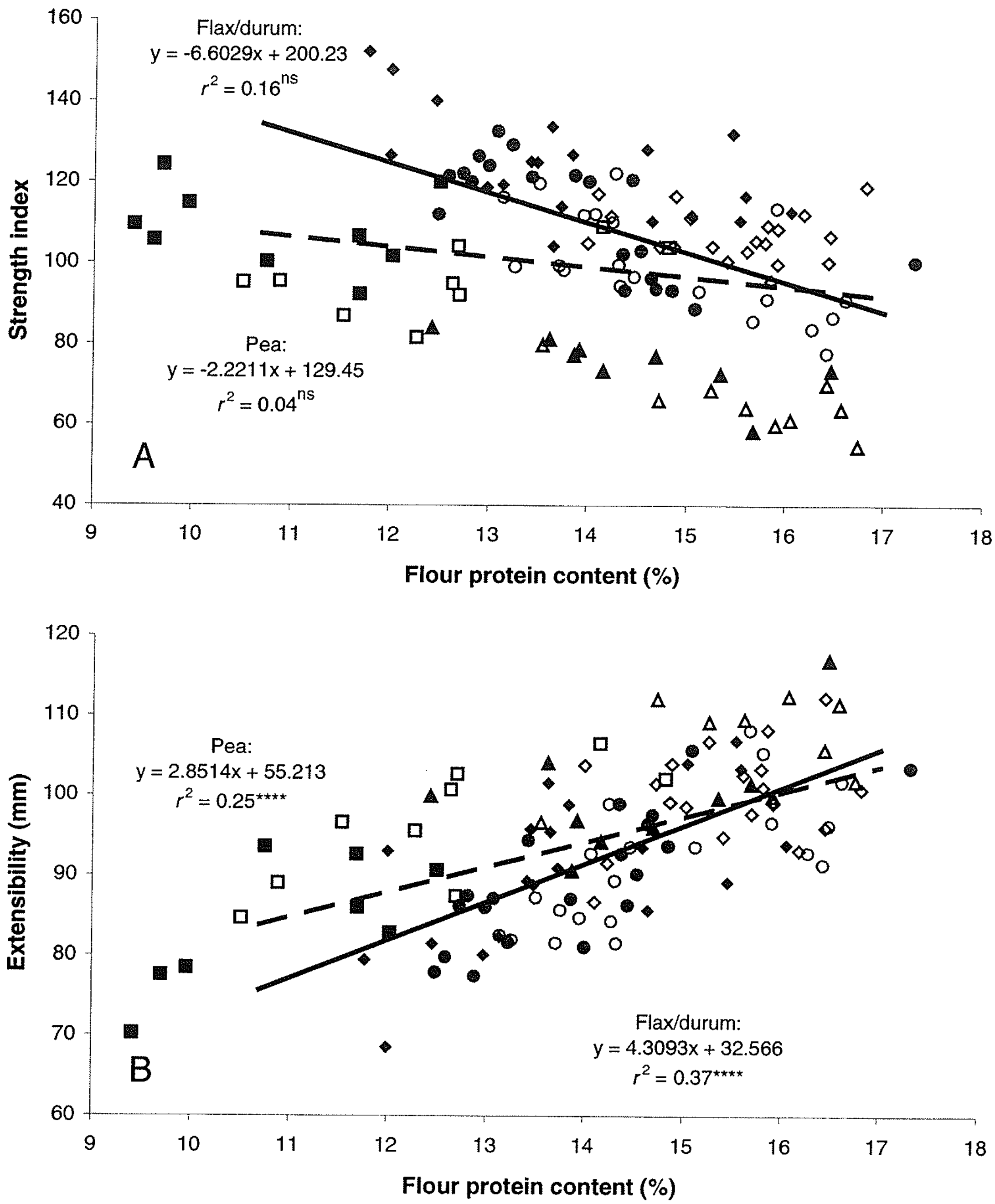
At first glance these results appear to contradict the results of the analysis of the Mixograph data. However, one must keep in mind that, as mentioned previously, the CSP bake test utilizes a rich formula and is carried out under conditions of optimum dough mixing and short fermentation. A bake test with a fixed dough mixing time, leaner formula, and/or long fermentation period might yield different results. As such, the influence of previous crop on baking properties such as LV would not be as of great a concern in Canadian bakeries as compared to U.S. bakeries that utilize procedures very different than the CSP bake test.



a

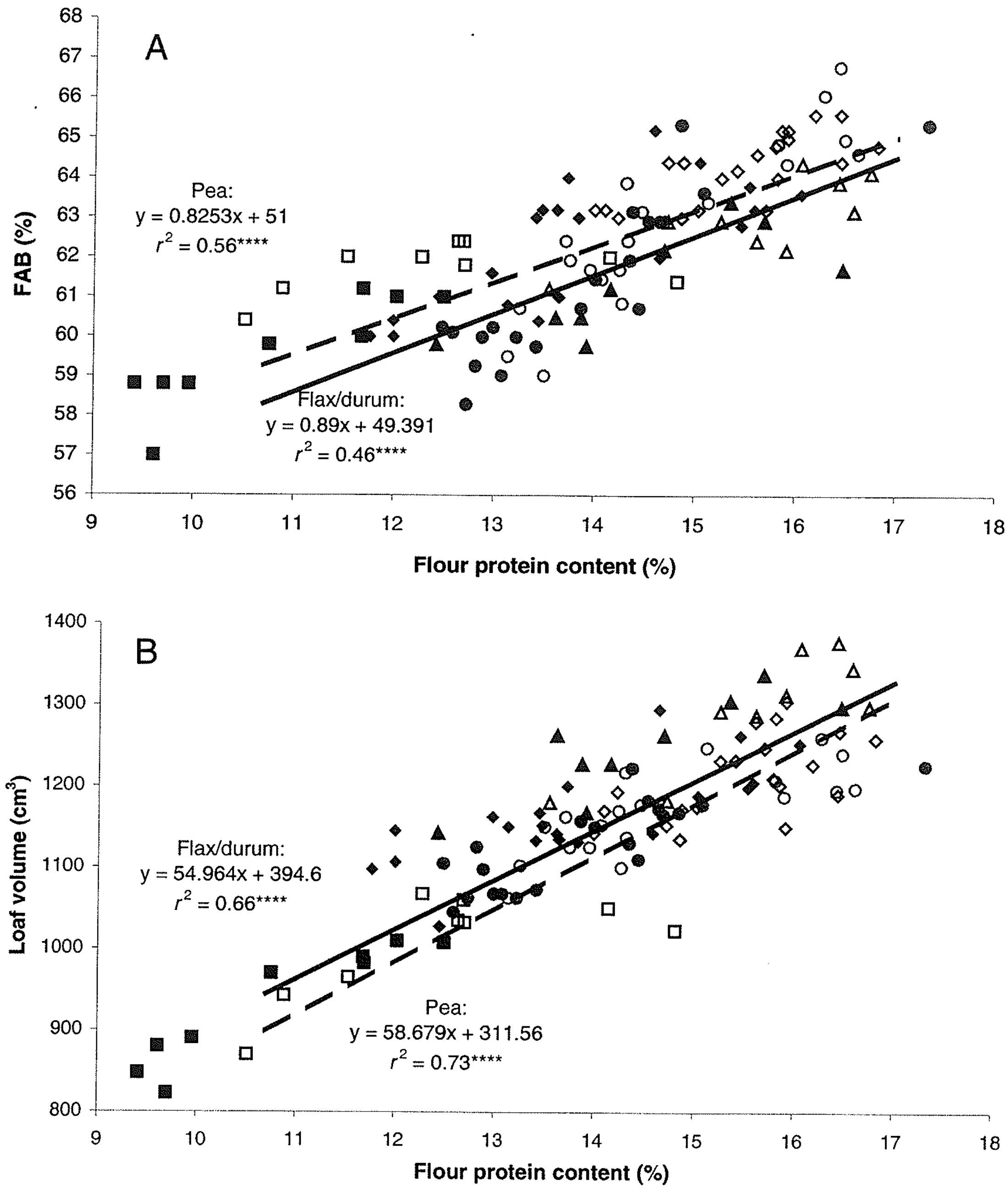
***, ns = significant at $P < 0.001$ and not significant, respectively.

Figure 4. 1. Effect of previous crop on Mixograph dough development time (A) and work input-to-peak (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



[a] ns, **** = not significant and significant at $P < 0.0001$, respectively.

Figure 4. 2. Effect of previous crop on dough strength index (A) and dough extensibility (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (●), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



a

**** = significant at $P < 0.0001$.

Figure 4. 3. Effect of previous crop on Farinograph water absorption (A) and loaf volume (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (●), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]

One possible explanation for the contrasting effects of previous crop on dough strength may be attributable to the pattern of protein accumulation in the kernel. However, no other research has been published in this area of study other than to say legumes in rotation increase FPC as a result of enhanced soil N supply (Branlard et al. 1985). From studies of protein synthesis during kernel development, we know that the rate of glutenin synthesis exceeds the rate of gliadin synthesis 21 to 28 days after anthesis (DAA) ((Gupta et al. 1996; Panozzo et al. 2001). From that point onwards, there is a substantial decrease in the gliadin to glutenin ratio (Triboi et al. 1990). Synthesis of relatively large glutenin molecules occurs only in the late stages of kernel development (Daniel and Triboi 2002; Gupta et al. 1996; Stone and Nicolas 1996a; Zhu and Khan 1999); Stone and Nicolas (1996a) detected small polymer until 25 DAA, at which point synthesis of large polymer was initiated.

When plant N uptake after anthesis as a proportion of total plant N uptake is high, less N is present in the plant at anthesis. N accumulation in the kernel is therefore more dependent on post-anthesis N accumulation. If N accumulation is delayed until later in the filling period, it is reasonable to suggest that N taken up by the plant might be more effectively channeled into glutenin synthesis rather than gliadin synthesis, since glutenin increases markedly in the second half of the filling period relative to gliadin.

Given two flour samples with similar FPC but different N accumulation patterns, one might expect increased dough strength and decreased extensibility from the flour sample from wheat that exhibited delayed N accumulation. Based on the theory presented above, wheat grown on field pea stubble would be expected to yield weaker, more extensible dough. The N uptake pattern of wheat grown on field pea stubble can be described as "front-loaded." A lower proportion of total N uptake occurs after anthesis, meaning in theory there is a higher proportion of N available during synthesis of gliadin. The N uptake pattern of wheat grown on flax stubble is more balanced, and a higher proportion of the N is taken up after anthesis. Therefore, a lower proportion of N would be channeled into the earlier part of protein synthesis, and would be more available during the later stages of kernel development, namely glutenin synthesis. As a result, wheat grown on flax stubble would be expected to have stronger, less extensible dough. This study suggests that this theory has merit. However, differences in N accumulation pattern attributable to previous crop were insufficient to yield definitive answers (Chapter 3; Appendix D). The hypothesis presented in this paper will be evaluated further in a subsequent research paper by evaluating flour protein composition using an extraction procedure based on the differential solubility of flour protein fractions in 50% 1-propanol (Chapter 5).

The implication of the previous crop*FPC interactions reported in this paper is that besides altering FPC by influencing soil N supply, altering the pattern of wheat N uptake as a result of different agronomic practices has the potential to result in different end-use quality characteristics among two flour samples having the same FPC, thereby reducing consistency. While the interaction between previous crop and FPC was significant in a number of instances, the overall impact on quality consistency is limited. Since wheat is binned according to grade and grain PC at primary grain elevators, wheat samples from multiple producers are blended together, resulting in reduced homogeneity.

An observation of particular interest regarding quality consistency is that when Swift Current-01 data were excluded from regression analysis, the strength of the relationship between FPC and most of the parameters evaluated increased, sometimes considerably (Table 4.7). For example, the r^2 for the relationship between FPC and PBW increased from 0.02 ($P < 0.0753$) to 0.26 ($P < 0.0001$), while the r^2 for the relationship between FPC and E area increased from 0.17 to 0.38 (both $P < 0.0001$). There was also a substantial increase in the interactive effect for BR when the Swift Current-01 samples were eliminated from the dataset, but it was still not significant. Swift Current-01 samples were stickier and more extensible than samples from the Manitoba sites, despite the fact that all sites had a similar range of FPC and all Swift Current-01 samples graded as No. 1 CWRS. Swift Current-01 samples took longer to reach peak dough development time, had reduced PBW, and broke down more rapidly after MDT was reached. The FAB of Swift Current-01 samples was generally 1-2% lower than the FAB of comparable Carman-00 samples. Interestingly, despite poor dough mixing properties and lower FAB than comparable samples from Carman-01, loaf volume of Swift Current-01 samples was noticeably higher than comparable Carman-01 samples. This observation reinforces the idea that the rich formula, optimum dough mixing, and short fermentation time of the CSP bake test tend to compensate for sub-par dough strength properties.

The Mixograph and micro-extension test results of the Swift Current-01 dataset are in agreement with other studies that have demonstrated the adverse effect of drought stress during the grain filling period on dough strength (Panozzo et al. 2001; Stone and Nicolas 1996b). By effectively reducing the duration of the filling period, the extent of glutenin polymerization is reduced, thereby decreasing dough strength and increasing extensibility. However, given the observation that Swift Current-01 kernels had visibly green kernels, elevated levels of starch damage or amylase may be responsible for the weak dough properties of the samples (Preston et al. 1991). The extraction method mentioned previously will help to determine whether altered protein composition of the Swift Current-01 samples is responsible for the poor dough mixing properties. Compared to the effect of previous crop, and whether it is starch of protein effects that are responsible for the site year effects observed, it is clearly much more difficult to eliminate the effects of environment on quality at a given delivery point by blending, since conditions such as drought stress would most certainly be prevalent throughout most of the area surrounding the high throughput elevator. As the importance of "direct-hit" shipments (Preston et al. 2002) by rail increases, the consistency of shipments among HTPs will become a much greater concern, particularly given western Canada's reputation for quality consistency.

Based on the results of the analysis of previous crop effects on end-use quality, one might expect that at the Brandon-01 site, wheat grown with CRU might be similar in its effect to flax/durum stubble on end-use quality. However, there was no consistent effect of N source on end-use quality (Table 4.8). The sixteen samples generated per N source at the two Manitoba sites may be an insufficient number of samples to provide a dataset robust enough to test the hypothesis. Furthermore, exclusive selection of N-deficient sites would improve the precision of evaluation of fertilizer N source on N accumulation pattern and end-use quality.

Parameter	FPC (r^2)	Prev. Crop*FPC Pr > F
MDT	0.39****	0.93^{ns}
PDR	0.86****	0.25^{ns}
WIP	0.03^{ns}	0.95^{ns}
PBW	0.02^{ns}	0.90^{ns}
BR	0.05^{ns}	0.92^{ns}
SI	0.30****	0.97^{ns}
Rmax	0.01^{ns}	0.87^{ns}
E at Rmax	0.10*	0.80^{ns}
E Area	0.19***	0.57^{ns}
E	0.47****	0.11^{ns}
Rmax/E	0.17**	0.69^{ns}
FAB	0.70****	0.55^{ns}
LV	0.60****	0.31^{ns}

[a] ns, *, **, ***, **** not significant, significant at P<0.05, 0.01, 0.001, and 0.0001, respectively.

Table 4.8. Coefficients of determination (r^2) for pooled data from the Carman-00 and Brandon-01 sites for flour protein content (FPC) and selected quality attributes, as well as degree of significance for the interaction between fertilizer N source and FPC.[a]

4.5 Conclusions

In a previous study (Chapter 3) we demonstrated previous crop and fertilizer N source affected the quantity and timing of N uptake by CWRS wheat, and that wheat grown on flax stubble tended to accumulate a higher percentage of N after anthesis compared to wheat grown on field pea stubble. Based on the theory that the timing of plant N uptake may influence protein composition, analysis was carried out to determine whether end-use quality differed across a similar range of FPC as a result of previous crop or fertilizer N source and could be attributed to differences in protein composition. The main effect of field pea stubble was to increase soil N supply, resulting in significantly higher FPC at three of five sites (Carman-00, Swift Current-00, and Swift

Current-01), and higher FPC ($P < 0.13$) at an additional site (Brandon-01). The effect of fertilizer N source was inconsistent.

Correlation analysis identified a number of strong relationships between FPC and quality attributes as well as among quality attributes. Across a similar range of FPC, samples of wheat grown on pea stubble resulted in dough with shorter MDT, lower WIP, and a trend towards lower SI at FPC < 14% compared to samples of wheat grown on flax/durum stubble. Previous crop had no significant effect on micro-extension test parameters or FAB, although P-W tended to be more extensible at FPC < 14%.

The interaction between previous crop and FPC may, in theory, due to N accumulation pattern and its effect on protein synthesis. Where wheat is more dependent on post-anthesis N accumulation, N taken up by the plant might be more effectively channeled into glutenin synthesis rather than gliadin synthesis, thereby resulting in less extensible and stronger dough. Conversely, where a higher proportion of N is accumulated prior to anthesis, there is a higher proportion of N available during synthesis of gliadin, thereby favoring gliadin accumulation and reducing dough strength.

Exclusion of the Swift Current-01 dataset from the pooled regression analysis dataset significantly improved the relationship between FPC and a number of quality attributes. Swift Current-01 were visibly more extensible and stickier, took longer to reach peak dough development time, had reduced PBW, and broke down more rapidly after MDT was reached than samples with comparable FPC from other site years. The adverse effect of drought stress during the grain filling period on dough strength due to reduced glutenin polymerization or some other alteration of protein composition may be responsible for the poor dough mixing properties of the Swift Current-01 samples.

Despite hand removal of green kernels from the samples, the weak dough properties may be attributable to altered starch properties as a result drought stress and its effects on physiological immaturity. Regardless of the reason, and unlike the effect of previous crop, environmental conditions cannot be compensated for by blending at HTPs, stressing the need for a better understanding of the effect of environment on protein quality. The treatment and site year effects observed in this study will be evaluated in a subsequent research paper using a protein extraction procedure based on the differential solubility of flour protein fractions in 50% 1-propanol (Chapter 5).

The previous crop*FPC interactions observed for Mixograph MDT, WIP, and SI did not translate into discernable differences in LV, nor did the weak dough properties of Swift Current-01 samples result in reduced LV. The CSP bake test, which is similar to the procedure used by most commercial Canadian bakeries, tends to mask differences in dough strength due to its optimized dough mix time and short fermentation time. However, utilizing a baking procedure with a longer fermentation time or fixed mixing time might yield dramatically different results. This study reinforces that FPC is not the only indicator of wheat breadmaking quality, challenging the notion that %N multiplied by 5.7 is the only yardstick by which wheat protein is valued by end-users.

5.0 THE EFFECT OF NITROGEN MANAGEMENT PRACTICES ON THE PROTEIN COMPOSITION AND TECHNOLOGICAL QUALITY OF CANADA WESTERN RED SPRING WHEAT

5.1 Abstract

A protein extraction method based on the differential solubility of flour protein in 50% 1-propanol was used to evaluate the protein composition of CWRS wheat in a series of small plot experiments carried out at Carman, MB, Brandon, MB, and Swift Current, SK. In the first phase of the rotation, field pea (*Pisum sativum* L.) and flax (*Linum usitatissimum* L.) were established at Manitoba sites; durum wheat (*Triticum durum* Desf.) was substituted for flax at Swift Current. In the re-crop phase, spring wheat (*Triticum aestivum* L. cv. AC Barrie) was planted. Fertilizer N was applied at three rates (0, 30, and 90 kg N ha^{-1}) and two N sources (ammonium nitrate and a polyurethane-coated controlled-release urea called Duration™) at the Manitoba sites. Urea was applied at Swift Current at three rates (34, 50, and 78 kg N ha^{-1}) based on soil test recommendations for dry, average, and wet growing conditions, respectively. The quantity of soluble protein (SP), insoluble glutenin (IG) and total insoluble protein (IP) increased as flour protein content (FPC) increased. Overall, the proportion of each fraction remained relatively stable as N supply and FPC increased, although unexplainable differences in protein composition among site years were observed. Correlation analysis revealed FPC was a poorer predictor of technological quality in many instances than the protein fraction (expressed as total quantity or as a proportion of FPC) or the ratio of SP to IG. IG and the SP:IG ratio were generally more strongly correlated with measures of dough strength than SP, while the opposite was true of

measures of dough viscosity. When the interaction among protein fractions was evaluated, no significant interactions were observed. Protein composition could also not be used to explain the significant differences in technological quality at the same FPC observed among site years. A more sophisticated method of protein composition evaluation such as size exclusion high performance liquid chromatography (SE-HPLC) might provide better insight into the differences in technological quality observed at the same FPC as influenced by previous crop. The balance of protein sub-fractions may be responsible for the differences in end-use quality observed and attributed to previous crop, and requires further analysis.

5.2 Introduction

Crop management practices such as N fertilization and crop rotation have a strong influence on the protein content of bread wheat (*Triticum aestivum* L.). A number of studies have evaluated the effect of N fertilization on protein composition (Johansson et al. 2001; Pechanek et al. 1997; Triboi et al. 2000; Triboi and Triboi-Blondel 2001; Wieser and Seilmeier 1998; Wooding et al. 2000b). As flour protein content (FPC) increases, so too does the quantity of glutenin and gliadin. However, contrasting results have been reported as to the effect of increasing protein content on the relative proportions of individual protein fractions.

The effect of previous crop on protein content and wheat technological quality has only been investigated to date with respect to its influence on total N supply. For example, Branlard et al. (1985) demonstrated that wheat grown after lucerne (*Medicago sativa* L.) accumulated a greater quantity of gliadin and glutenin compared to wheat grown after wheat. In a previous study (Chapter 3), we demonstrated that in addition to altering total N supply, previous crop affected the N accumulation pattern of wheat. Wheat grown after a non-legume accumulated a significantly higher proportion of total plant N after anthesis compared to wheat grown after field pea (*Pisum sativum* L.). Furthermore, across a similar range of FPC, previous crop had an effect on technological quality as assessed with the Mixograph (Chapter 4). Wheat grown on field pea stubble had shorter dough development time (MDT), lower work input-to-peak (WIP), a lower dough strength index (SI), and tended to be more extensible compared to wheat grown on flax/durum stubble.

The ability to influence the timing and amount of plant N uptake may influence protein composition as well as PC. Gliadin and glutenin have dramatically different effects on wheat end-use quality (Gupta et al. 1992; Hamada et al. 1982; MacRitchie 1992; Schofield 1986; Shewry et al. 1986; Wall 1979) and also accumulate in the kernel in an asynchronous manner (Jamieson et al. 2001; Stone and Savin 1999). Gliadin is rapidly synthesized in the early stages of the filling period, while glutenin is not synthesized in considerable quantity until the mid-filling period and glutenin polymerization occurs very late during kernel development. The main objective of this study was to evaluate the effect of N fertilization on the protein composition of Canada Western Red Spring (CWRS) wheat. Given results reported previously, a secondary objective of this study was to determine whether differences in protein composition were responsible for the differences in technological quality as a result of previous crop and differences in growing season conditions among site years.

5.3 Materials and Methods

The cultural practices of Experiments 1 and 2 were described in greater detail in a previous paper (Chapter 3 and Appendix I, respectively). In Experiment 1, field pea (*Pisum sativum* L. cv. Grande) and flax (*Linum usitatissimum* L. cv. Norlin) were established at the Carman Research Station in 1999 and 2000 (prior to wheat for Carman-00 and Carman-01, respectively), as well as at the Brandon Research Centre in 2000 (prior to wheat for Brandon-01) in four replicates arranged in a randomized complete block design. In the re-crop phase of the study, spring wheat (cv. AC Barrie) was sown across each main plot at three rates of N (0, 30, and 90 kg N ha^{-1}) as commercial grade ammonium nitrate (34-0-0) or as a controlled-release urea product called Duration™.

In Experiment 2, field pea (cv. Alfetta) and durum wheat (*Triticum durum* Desf. cv. Kyle) were established in 1999 and 2000 at the Semiarid Prairie Agricultural Research Centre (prior to wheat for Swift Current-00 and Swift Current-01, respectively) in three replicates arranged in a strip block design. Field pea plots received sulphur (S) and phosphorus fertilizer based on soil test recommendations. In the re-crop phase of the study, N fertilizer treatments were randomly arranged in each block and consisted of three rates of N applied as commercial grade urea based on soil test recommendations for dry, average, and wet growing seasons (34, 50, and 78 kg N ha^{-1}, respectively). Blocks were subsequently sown with spring wheat (cv. AC Barrie).

5.3.1 Quality Testing

Grain quality analyses were described in detail previously (Chapter 4 and Appendix J). Protein composition was assessed in duplicate (and triplicate where necessary) using the extraction procedure of Sapirstein and Johnson (2000). The extraction procedure employed is based on the solubility of FPC subjected to various concentrations of 50% 1-propanol. Given the high FPC of a number of samples, the method was modified to utilize 50 mg of flour rather than 100 mg of flour. This alteration resulted in an increase in extraction efficiency and a small increase in the quantity of soluble protein and insoluble glutenin, as well as a reduction in the quantity of residue protein.

Four protein fractions were measured in total. Soluble protein was composed of monomeric protein (albumin, globulin, and gliadin) and soluble low molecular weight (LMW) glutenin (SP), while insoluble glutenin (IG) was composed of high molecular weight (HMW) glutenin. Residue protein (RP), which was determined by difference (FPC-SP-IG), is comprised of HMW glutenin and non-gluten protein, of which the latter constitutes a large proportion (Sapirstein and Fu 1998). Total insoluble protein (IP) was also determined by difference (i.e. FPC-SP). The relative proportions of each of the four fractions were calculated (percentage of FPC), as well as the ratios of SP to IG and SP to IP. Please see Appendix J. 1. for a detailed description of the protein extraction method.

The extraction procedure employed does not allow for direct comparisons of protein composition with other similar studies utilizing different extractants other than 1-propanol. Comparison of results among various protein composition studies is made difficult by the fact that what one researcher considers gliadin may be considered glutenin by another, depending on the extraction procedure employed. A few studies have been published on protein composition where 1-propanol is used as the extractant. Sapirstein and Fu (1998), using 70% 1-propanol to precipitate the soluble glutenin of the SP fraction, reported that soluble glutenin and IG fractions of the CWRS cultivar Katepwa were 12.6% and 19.9% of FPC, respectively. Monomeric protein (gliadin and albumin/globulin) and RP comprised 50.2% and 17.2% of FPC, respectively. Across a diverse range of seven Canadian cultivars of diverse breadmaking quality, there was little variation in the proportion of monomeric protein (48-52%) and residue protein (14-18%), while there was considerable variation in the proportion of soluble glutenin (10-20%) and insoluble glutenin (12-28%).

5.3.2 Statistical Analysis

Analysis of variance (ANOVA), correlation, and regression analysis was carried out using procedures of the SAS Institute, Inc. (2001). Experiment 1 was analyzed as a factorial experiment arranged in a randomized complete block design, while Experiment 2 was analyzed as a completely randomized design. Non-orthogonal, single degree of freedom contrasts were used to test the effects of fertilizer N source, N rate and previous crop*N rate combinations, depending on experimental design. Effects were considered significant at $P < 0.05$.

Pearson correlation coefficients were determined for a pooled dataset (n = 110) and restricted to the common range of FPC of the two previous crop types (field pea or flax/durum). The Proc GLM procedure was used to evaluate linear relationships between selected quality attributes and FPC, as well as between selected quality attributes and protein composition parameters. Previous crop was considered to have a significant effect on a given end-use quality parameter where the probability value of the interaction term (previous crop*protein composition) of Type III sums of squares was less than 0.05. Type III sums of squares allows multiple regression lines to have different slopes and intercepts (G. H. Crow, personal communication).

5.4 Results and Discussion

5.4.1 Effect of Agronomic Practices on the Quantity of Individual Protein Fractions

The effect of previous crop and fertilizer N treatment on FPC was reported previously (Chapter 4). Increasing soil N supply, either as a result of previous crop and/or N fertilization, resulted in an increase in the quantity of individual protein fractions, particularly SP (Tables 5.1 to 5.5). N fertilization tended to exert a stronger and more consistent influence on the quantity of each protein fraction relative to previous crop. Previous crop appeared to have a greater effect on protein accumulation than N fertilization at the Swift Current-01 site, most likely as a result of the effect of dry soil conditions on N fertilizer availability. Swift Current-00 was by far the most responsive to N fertilization, given its low soil N status prior to planting (reported in Chapter 4). At the Carman-01 site, the soil N concentrations prior to planting were similarly high for both types of previous crop, and as such, N fertilization exerted much less influence on the accumulation of protein compared to the other four sites.

Growing wheat on field pea stubble (P-W) resulted in significantly higher quantities of SP and IG compared to growing wheat on durum stubble at the Swift Current-01 site alone; the quantity of IG was significantly higher for P-W compared to

Treatment		Protein Quantity[a]				Proportion of FPC				Ratios	
Previous Crop	N Applied (kg ha^{-1})	SP	IG	RP	IP	% SP	% IG	% RP	% IP	SP:IG	SP:IP
Flax		9.33	3.12	1.37	4.48	67.5	22.5	10.0	32.5	3.00	2.11
Pea		10.52	3.57	1.35	4.92	68.2	23.1	8.8	31.8	2.95	2.16
	0	9.12	3.12	1.37	4.49	66.9	22.9	10.2	33.1	2.93	2.04
	30AN[b]	9.84	3.29	1.37	4.66	67.9	22.7	9.4	32.1	2.99	2.15
	30CRU[c]	9.63	3.21	1.25	4.45	68.3	22.7	8.9	31.7	3.01	2.18
	90AN	10.51	3.61	1.33	4.94	68.0	23.3	8.6	32.0	2.91	2.15
	90CRU	10.54	3.47	1.48	4.96	68.0	22.4	9.6	32.0	3.04	2.16
ANOVA		Pr > F									
Previous Crop (P)		0.13	0.10	0.97	0.0645	0.75	0.44	0.66	0.75	0.42	0.80
N Applied (kg ha^{-1}) (N)		<0.0001	<0.0001	0.92	0.12	0.85	0.28	0.88	0.85	0.0808	0.86
P*N		0.18	0.0844	0.79	0.77	0.65	0.48	0.62	0.65	0.54	0.65
Contrast											
AN vs CRU		0.61	0.073	0.93	0.50	0.84	0.14	0.82	0.84	0.05	0.86
0 N vs 30 N		0.005	0.0752	0.77	0.75	0.31	0.69	0.48	0.31	0.10	0.29
30 N vs 90 N		<0.0001	<0.0001	0.58	0.0274	0.92	0.67	0.97	0.92	0.52	0.90
Pea vs Flax at 0 N		0.0028	0.0014	0.32	0.53	0.16	0.0839	0.12	0.16	0.70	0.18
Pea vs Flax at 30 N		0.0015	0.0002	0.68	0.0099	0.91	0.30	0.86	0.91	0.15	0.92
Pea vs Flax at 90 N		0.0479	0.0315	0.86	0.17	0.92	0.72	0.87	0.92	0.64	0.98
CV (%)		4.6	4.9	36.8	10.0	4.0	3.7	35.3	4.1	3.4	12.7

[a] SP = soluble protein; IG = insoluble glutenin; RP = residue protein; IP = insoluble protein.

[b] Ammonium nitrate fertilizer.

[c] Controlled-release urea fertilizer.

Table 5.1. Effect of previous crop and N fertilizer treatment on protein composition at the Carman-00 site.[a,b,c]

Treatment		Protein Quantity[a]				Proportion of FPC				Ratios	
Previous Crop	N Applied ($kg\ ha^{-1}$)	SP	IG	RP	IP	% SP	% IG	% RP	% IP	SP:IG	SP:IP
Durum		7.28	2.28	1.25	3.53	67.3	21.0	11.7	32.7	3.20	2.07
Pea		8.34	2.50	1.62	4.12	66.9	20.1	13.0	33.1	3.34	2.03
	34	6.88	2.09	1.43	3.52	66.2	20.2	13.7	33.8	3.28	1.96
	50	7.78	2.35	1.42	3.77	67.4	20.4	12.2	32.6	3.30	2.08
	78	8.78	2.73	1.46	4.19	67.7	21.1	11.2	32.3	3.22	2.11
ANOVA		Pr > F									
Previous Crop (P)		0.0008	0.0263	0.0921	0.0103	0.76	0.15	0.42	0.76	0.0944	0.67
N Applied ($kg\ ha^{-1}$) (N)		0.0001	0.0003	0.98	0.0462	0.51	0.51	0.47	0.51	0.64	0.49
P*N		0.94	0.98	0.99	0.98	0.99	0.99	0.98	0.99	0.99	0.98
Contrast											
34 N vs 50 N		0.0092	0.0338	0.97	0.31	0.40	0.90	0.48	0.40	0.82	0.37
50 N vs 78 N		0.0052	0.0049	0.86	0.11	0.78	0.98	0.60	0.78	0.37	0.83
Pea vs Durum at 34 N		0.0145	0.13	0.30	0.0909	0.55	0.74	0.33	0.55	0.36	0.93
Pea vs Durum at 50 N		0.028	0.18	0.27	0.0923	0.42	0.43	0.44	0.42	0.27	0.72
Pea vs Durum at 78 N		0.0366	0.20	0.36	0.14	0.94	0.27	0.19	0.94	0.32	0.77
CV (%)		6.5	7.9	29.7	10.8	3.5	6.6	27.7	7.2	4.7	10.4

[a] SP = soluble protein; IG = insoluble glutenin; RP = residue protein; IP = insoluble protein.

Table 5.2. Effect of previous crop and N fertilizer treatment on protein composition at the Swift Current-00 site.[a]

Treatment		Protein Quantity[a]				Proportion of FPC				Ratios	
Previous Crop	N Applied (kg ha^{-1})	SP	IG	RP	IP	% SP	% IG	% RP	% IP	SP:IG	SP:IP
Flax		10.33	3.28	2.76	6.04	63.1	20.0	16.9	36.9	3.15	1.71
Pea		10.46	3.30	2.69	5.99	63.6	20.1	16.3	36.4	3.17	1.75
	0	10.35	3.25	2.57	5.82	64.0	20.1	15.9	36.0	3.18	1.78
	30AN[b]	10.35	3.28	2.74	6.02	63.2	20.0	16.7	36.8	3.16	1.72
	30CRU[c]	10.37	3.30	2.62	5.92	63.7	20.3	16.1	36.3	3.14	1.75
	90AN	10.46	3.27	2.79	6.06	63.3	19.8	16.9	36.7	3.20	1.73
	90CRU	10.43	3.34	2.90	6.25	62.6	20.0	17.4	36.4	3.12	1.67
ANOVA						Pr > F					
Previous Crop (P)		0.32	0.51	0.50	0.26	0.27	0.95	0.33	0.27	0.70	0.31
N Applied (kg ha^{-1}) (N)		0.82	0.52	0.0575	0.0309	0.0806	0.19	0.0883	0.0806	0.44	0.32
P*N		0.52	0.29	0.0853	0.12	0.0482	0.21	0.0687	0.0482	0.60	0.0203
Contrast											
AN vs CRU		0.93	0.19	0.46	0.58	0.64	0.31	0.42	0.64	0.22	0.58
0 N vs 30 N		0.96	0.42	0.20	0.16	0.20	0.24	0.19	0.20	0.41	0.16
30N vs 90N		0.29	0.74	0.11	0.20	0.17	0.35	0.20	0.17	0.57	0.20
Pea vs Flax at 0 N		0.51	0.35	0.12	0.13	0.0652	0.28	0.0923	0.0652	0.72	0.0574
Pea vs Flax at 30 N		0.10	0.96	0.68	0.63	0.66	0.42	0.91	0.66	0.25	0.63
Pea vs Flax at 90 N		0.69	0.83	0.75	0.77	0.59	0.86	0.68	0.59	0.87	0.54
CV (%)		2.3	3.0	10.7	4.2	1.6	3.9	9.5	2.7	3.0	4.3

[a] SP = soluble protein; IG = insoluble glutenin; RP = residue protein; IP = insoluble protein.

[b] Ammonium nitrate fertilizer.

[c] Controlled-release urea fertilizer.

Table 5.3. Effect of previous crop and N fertilizer treatment on protein composition at the Carman-01 site.[a,b,c]

Treatment		Protein Quantity[a]				Proportion of FPC				Ratios	
Previous Crop	N Applied (kg ha^{-1})	SP	IG	RP	IP	% SP	% IG	% RP	% IP	SP:IG	SP:IP
Flax		8.69	2.56	2.67	5.22	62.5	18.4	19.1	37.5	3.40	1.68
Pea		9.15	2.62	2.99	5.61	61.9	17.8	20.3	38.1	3.48	1.64
	0	8.29	2.54	2.67	5.21	61.4	18.8	19.8	38.6	3.27	1.60
	30AN[b]	8.46	2.44	2.69	5.13	62.2	18.0	19.8	37.8	3.46	1.66
	30CRU[c]	8.42	2.49	2.69	5.18	62.0	18.3	19.7	38.0	3.39	1.64
	90AN	9.63	2.76	2.97	5.73	62.8	18.0	19.2	37.2	3.49	1.70
	90CRU	9.80	2.72	3.12	5.85	62.7	17.4	19.9	37.3	3.60	1.69
ANOVA						Pr > F					
Previous Crop (P)		0.20	0.45	0.045	0.0799	0.25	0.06	0.11	0.25	0.0933	0.31
N Applied (kg ha^{-1}) (N)		<0.0001	<0.0001	0.0193	0.0002	0.39	0.0039	0.95	0.39	0.0006	0.32
P*N		0.094	0.58	0.0147	0.0174	0.0187	0.73	0.0201	0.0187	0.66	0.0203
Contrast											
AN vs CRU		0.64	0.93	0.47	0.76	0.71	0.55	0.62	0.71	0.72	0.66
0 N vs 30 N		0.33	0.16	0.92	0.68	0.30	0.0232	0.96	0.30	0.0112	0.28
30N vs 90N		<0.0001	<0.0001	0.0031	<0.0001	0.26	0.0685	0.77	0.26	0.0159	0.23
Pea vs Flax at 0 N		0.64	0.58	0.19	0.34	0.0652	0.24	0.10	0.16	0.96	0.18
Pea vs Flax at 30 N		0.0183	0.15	0.0284	0.013	0.66	0.0699	0.18	0.43	0.19	0.50
Pea vs Flax at 90 N		0.006	0.18	0.0596	0.0292	0.59	0.0699	0.41	0.87	0.0812	0.89
CV (%)		4.0	4.5	10.9	6.0	2.5	3.6	9.2	4.1	3.8	6.7

[a] SP = soluble protein; IG = insoluble glutenin; RP = residue protein; IP = insoluble protein.

[b] Ammonium nitrate fertilizer.

[c] Controlled-release urea fertilizer.

Table 5.4. Effect of previous crop and N fertilizer treatment on protein composition at the Brandon-01 site.[a,b,c]

Treatment		Protein Quantity[a]				Proportion of FPC				Ratios	
Previous Crop	N Applied (kg ha^{-1})	SP	IG	RP	IP	% SP	% IG	% RP	% IP	SP:IG	SP:IP
Durum		9.43	2.66	2.37	5.03	65.3	18.4	16.3	34.7	3.55	1.90
Pea		9.93	2.76	2.95	5.72	63.5	17.7	18.8	36.5	3.59	1.75
	34	9.36	2.61	2.66	5.27	64.1	17.9	18.0	35.9	3.58	1.80
	50	9.76	2.74	2.54	5.28	65.1	18.3	16.7	34.9	3.56	1.88
	78	9.93	2.78	2.79	5.58	64.1	18.0	18.0	35.9	3.57	1.79
ANOVA		Pr > F									
Previous Crop (P)		0.0829	0.23	0.0572	0.0367	0.18	0.0765	0.12	0.18	0.45	0.16
N Applied (kg ha^{-1}) (N)		0.24	0.25	0.76	0.64	0.77	0.71	0.71	0.77	0.95	0.72
P*N		0.11	0.088	0.21	0.0856	0.42	0.79	0.47	0.42	0.80	0.42
Contrast											
34 N vs 50 N		0.23	0.22	0.73	0.97	0.54	0.46	0.48	0.54	0.75	0.53
50 N vs 78 N		0.62	0.70	0.43	0.43	0.53	0.51	0.49	0.53	0.9	0.47
Pea vs Durum at 34 N		0.0689	0.14	0.14	0.0767	0.1	0.31	0.08	0.10	0.73	0.35
Pea vs Durum at 50 N		0.0622	0.0911	0.0376	0.018	0.76	0.13	0.69	0.76	0.97	0.10
Pea vs Durum at 78 N		0.45	0.23	0.80	0.56	0.71	0.52	0.60	0.71	0.35	0.88
CV (%)		5.8	6.4	22.0	11.5	4.1	4.4	18.4	7.3	3.3	11.4

[a] SP = soluble protein; IG = insoluble glutenin; RP = residue protein; IP = insoluble protein.

Table 5.5. Effect of previous crop and N fertilizer treatment on protein composition at the Swift Current-01 site.[a]

wheat grown on durum stubble at both Swift Current sites. Compared to wheat grown on flax stubble, P-W at Carman-00 and Brandon-01 had higher though not statistically different SP and IG, although the *P*-value approached 0.05 in both instances. The only instances where previous crop had a strong effect on the proportion of individual protein fractions was at Brandon-01 and Swift Current-01, where P-W had a lower proportion of IG than F-W; the *P*-value approached 0.05 in both instances.

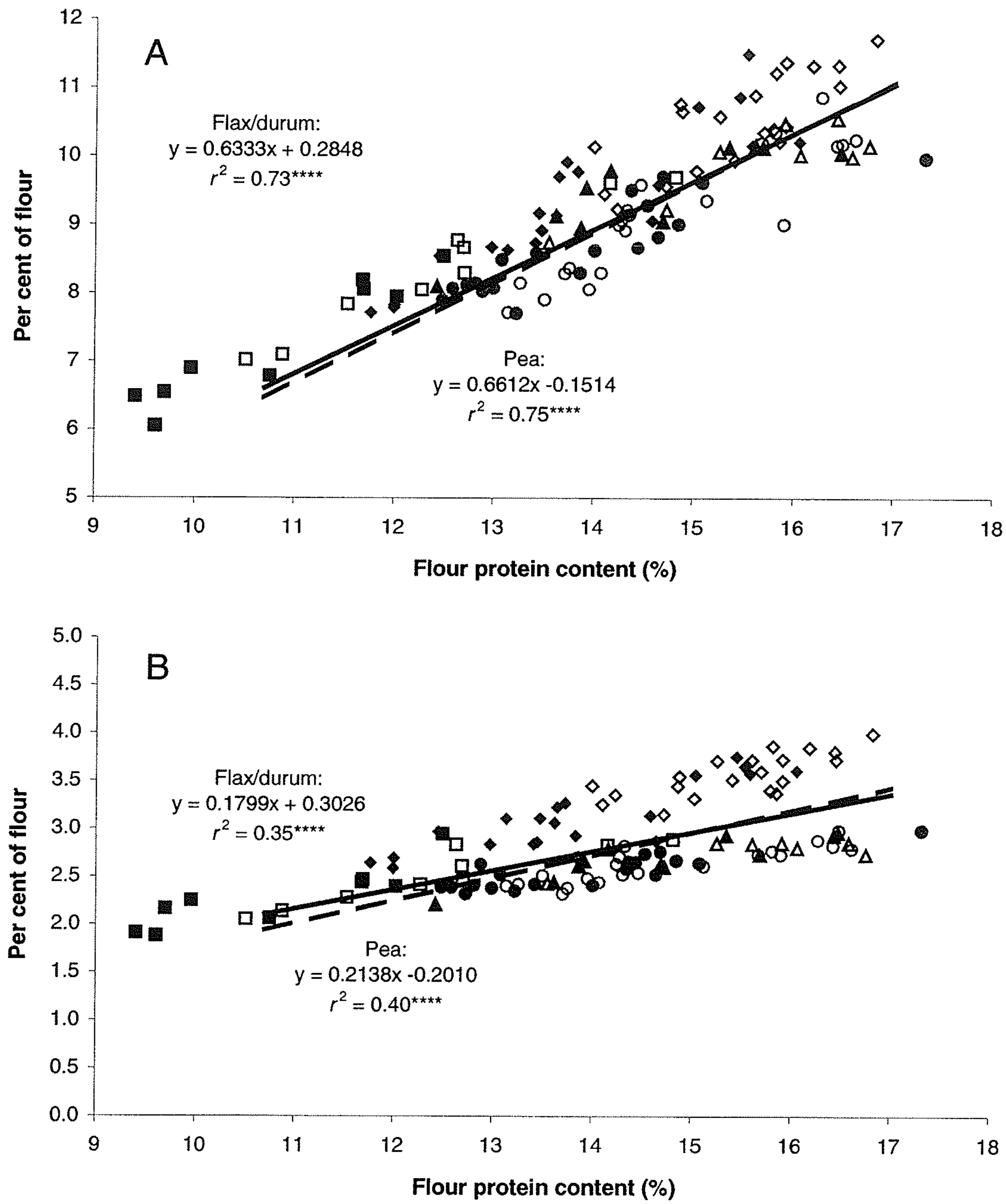
N fertilizer treatment had a significant effect on the quantity of SP and IG at Carman-00, Swift Current-00, and Brandon-01. Compared to control plots, plots receiving 90 kg N ha^{-1} at Carman-00 accumulated 15% and 13% greater SP and IG, respectively, while the quantity of IP increased 10%. At Brandon-01, compared to control plots, the application of 90 kg N ha^{-1} increased the quantity of SP, IG, RP, and IP 17, 8, 14, and 11%, respectively. The increase in the SP fractions was proportionately greater than the increase in the quantity of IG as FPC increased in response to increasing N fertility. Increasing the N application rate from 34 to 78 kg N ha^{-1} at Swift Current-00 increased the quantity of SP and IG by 28% and 30%, respectively. There was very little change in RP, while the quantity of IP increased 19%. At Swift Current-01, the quantity of the four fractions increased 5-7% as N application rate increased.

Fertilizer N source had no effect on FPC at any of the Manitoba sites (Chapter 4). As such, no differences in the quantity of individual protein fractions were expected. However, the CRU treatment at the Carman-00 site resulted in a slightly higher but statistically insignificant quantity of IG compared to the AN treatment as well as a slightly lower quantity of IG; the resultant SP:IG ratio for the CRU treatment was significantly lower than the SP:IG ratio of the AN treatment (Table 5.1). The effect of N source may be explained in part by the observation that wheat fertilized with AN accumulated a significantly higher quantity of N by anthesis at the Carman-00 site compared to plots receiving CRU (data not presented). By harvest, wheat receiving AN accumulated a slightly higher but not significantly amount of N compared to plots receiving CRU.

5.4.2 Relationships Among Flour Protein Content and Protein Composition Parameters

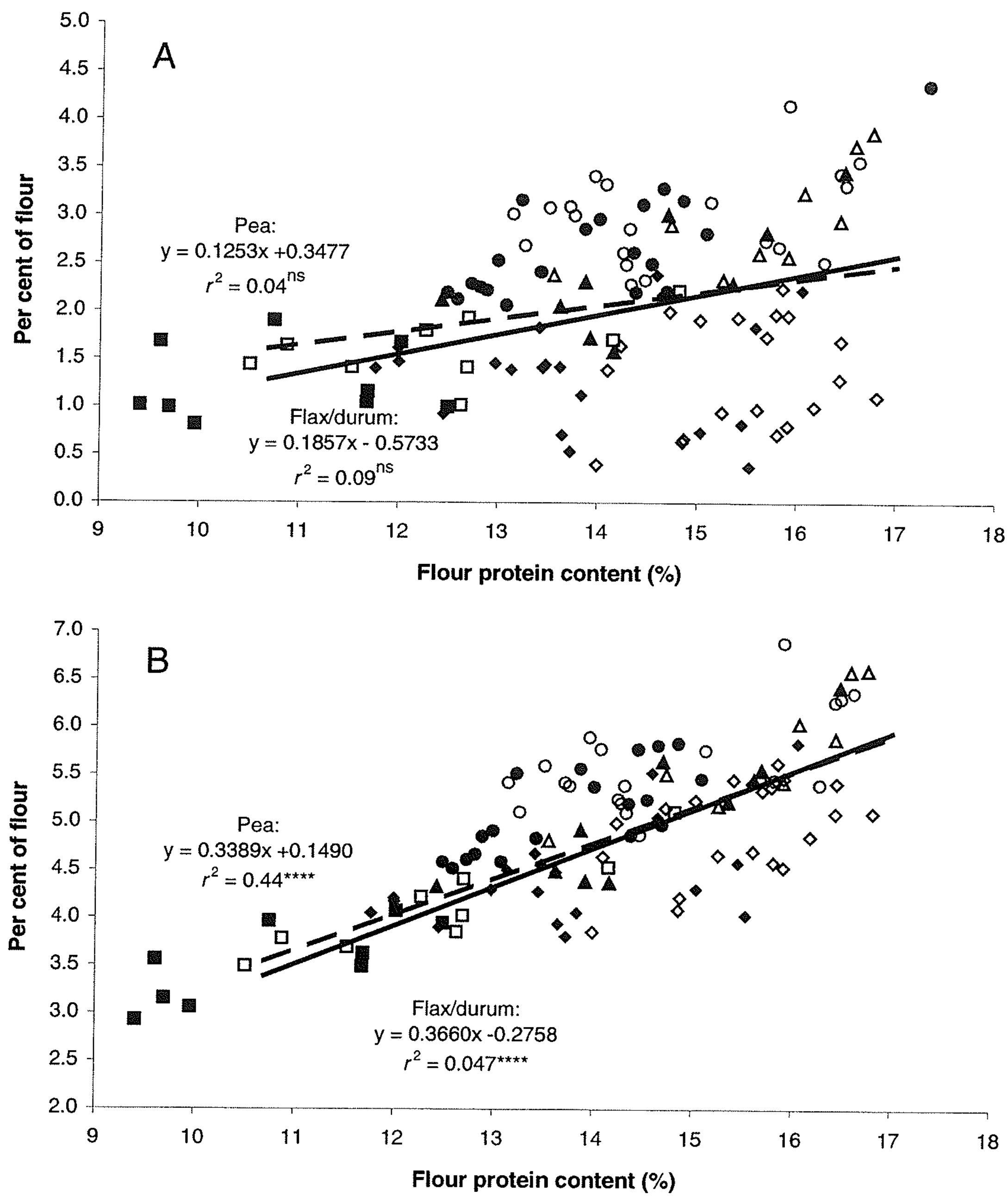
Plots of the quantity and proportion of the four protein fractions quantified (as well as the SP:IG and SP:IP ratios) versus FPC are presented in Figures 5.1 to 5.4 for the Carman-00, Swift Current-00, Brandon-01, and Swift Current-01 sites. Overall, the quantity of each of the four protein fractions tended to increase as FPC increased. SP was strongly ($r > 0.8$) correlated to FPC. IG and IP were moderately correlated ($0.4 < r < 0.8$) to FPC, while RP was poorly correlated to FPC (Table 5.6). Compared to the SP, IG, and IP fractions, the CV of the RP fraction tended to be considerably higher (Tables 5.1 to 5.5), reflecting the sensitivity of the quantity of RP to its dependence on the quantification of SP and IG fractions (i.e. RP is calculated and not extracted).

FPC was poorly correlated with %SP, %IG, %RP, and %IP. Stronger relationships were observed among the quantity and proportion of individual protein fractions. Whereas FPC was poorly correlated to SP:IG, %IG showed a strong, negative correlation to SP:IG. IG was moderately and negatively correlated with SP:IG while residue protein, expressed either in total quantity or as a proportion of FPC was positively correlated to SP:IG.



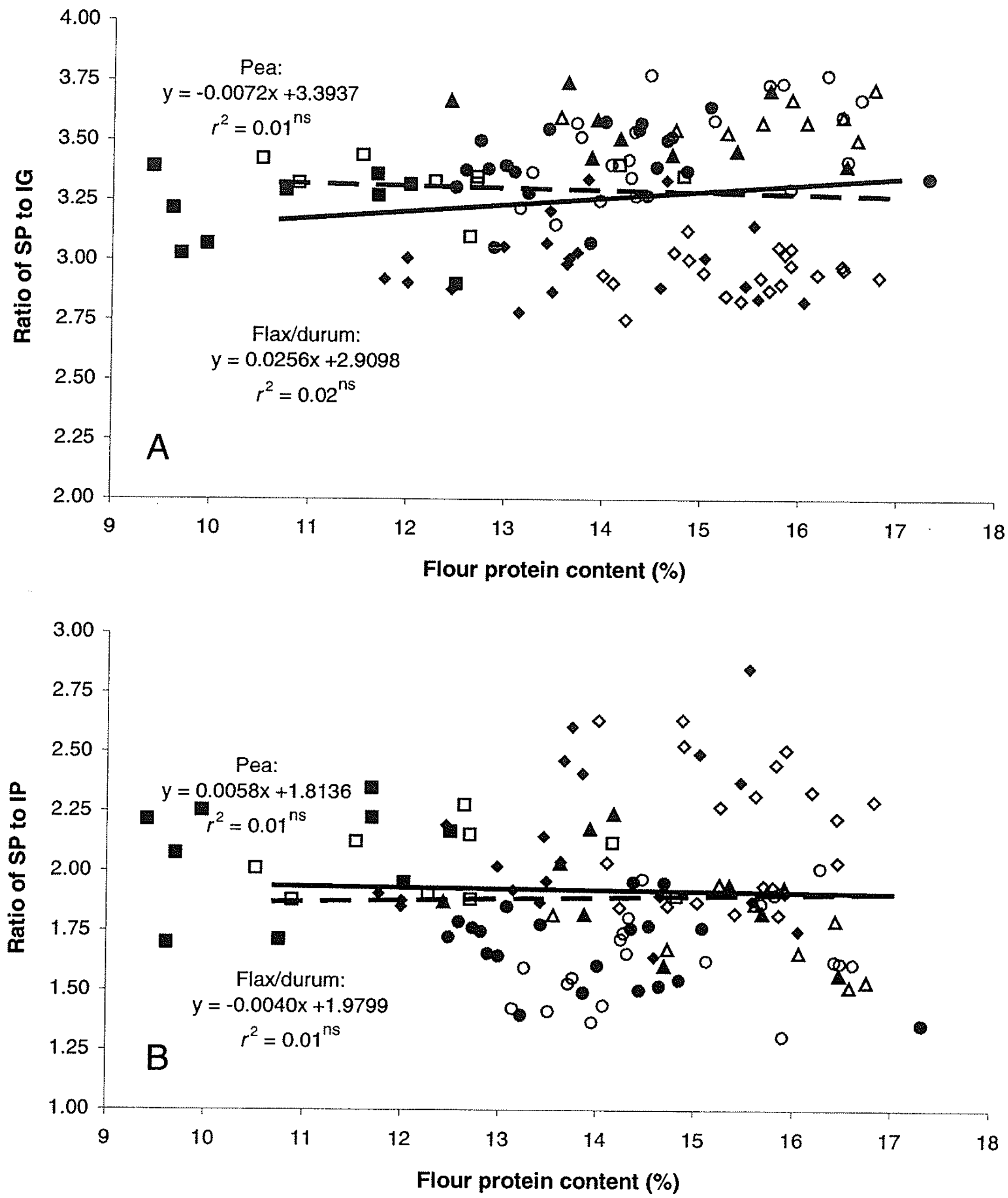
[a] **** = significant at $P < 0.0001$.

Figure 5. 1. Effect of previous crop on flour soluble protein content (A) and insoluble glutenin content (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift Current-00 (■), Brandon-01 (●), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



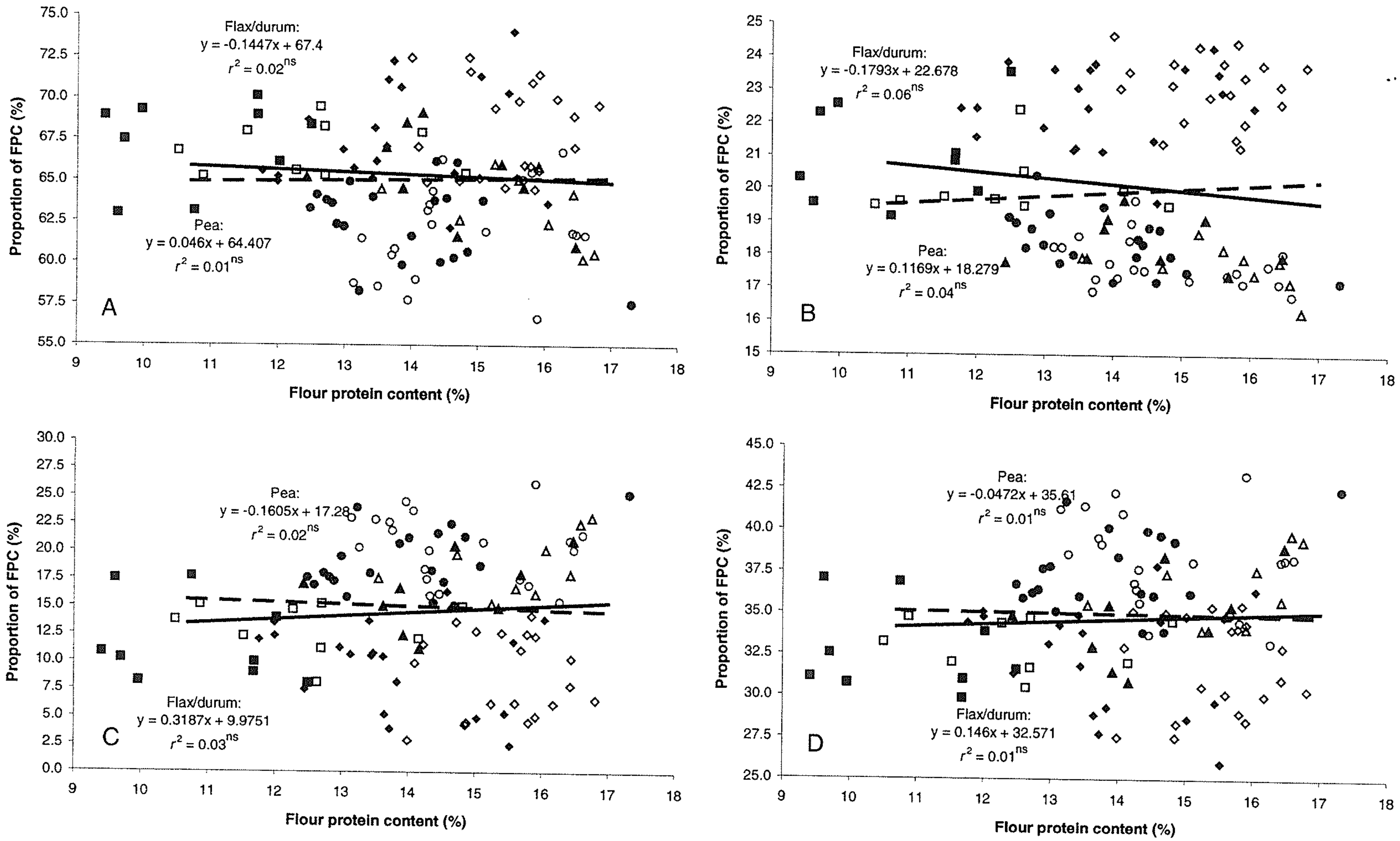
[a] ns, **** = not significant, significant at $P < 0.0001$, respectively.

Figure 5. 2. Effect of previous crop on flour residue protein content (A) and insoluble protein content (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



[a] ns = not significant.

Figure 5. 3. Effect of previous crop on the ratio of flour soluble protein to insoluble glutenin (A) and the ratio of soluble protein to insoluble protein (B). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (●), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



[a] ns = not significant.

Figure 5. 4. Effect of previous crop soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (●), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]

Protein Composition	Protein Composition										
	FPC	SP	IG	RP	IP	%SP	%IG	%RP	%IP	SP:IG	SP:IP
FPC	----										
SP	0.88***	----									
IG	0.64***	0.84***	----								
RP	0.27*	-0.21^{ns}	-0.50***	----							
IP	0.71***	0.28*	0.04^{ns}	0.85***	----						
%SP	-0.03^{ns}	0.46***	0.55***	-0.92***	-0.72***	----					
%IG	-0.02^{ns}	0.76***	0.76***	-0.87***	-0.54***	0.74***	----				
%RP	0.03^{ns}	-0.87***	-0.67***	0.97***	0.70***	-0.96***	-0.90***	----			
%IP	0.03^{ns}	-0.74***	-0.55***	0.92***	0.72***	-1.00***	-0.74***	0.96***	----		
SP:IG	0.04^{ns}	-0.14^{ns}	-0.66***	0.61***	0.30*	-0.36**	-0.89***	0.61***	0.36**	----	
SP:IP	0.00^{ns}	0.47***	0.57***	-0.91***	-0.70***	1.00***	0.74***	-0.95***	-1.00***	-0.37***	----

[a] ns, *, **, *** not significant. significant at P <0.01, 0.001, and 0.0001, respectively.

Table 5. 6. Coefficients of correlation (r) among selected protein composition parameters for the pooled dataset (n = 110).[a]

Differences in protein composition among site years were also evident and could not be explained by experimental error or differences in environmental conditions during the growing season (Table 5.7). For example, extraction efficiency (i.e. quantity of SP and IG) was higher for Carman-00 and, to a lesser extent, Swift Current-00, relative to the Carman-01, Brandon-01 and Swift Current-01 sites. The higher extraction efficiency resulted in Carman-00 (and to a lesser extent Swift Current-00) samples having lower quantities of SP (Figure 5.1) and IG (Figure 5.2) at the same FPC compared to the other three site years.

Our observations of the relative proportions of individual protein fractions are comparable to those of Sapirstein and Fu (1998), who reported SP, IG, and RP of the CWRS cultivar Katepwa represented 62.9%, 19.9%, and 17.2% of FPC, respectively. For example, the average proportions of SP, IG, and RP of Brandon-01 samples were 62.2%, 18.1%, and 19.7%, respectively, while SP, IG, and RP represented 66.9%, 22.9%, and 10.2% of FPC, respectively, for Carman-00 samples.

Although the quantity of individual protein fractions increased as FPC increased in our study, correlation analysis demonstrated there was no strong, consistent trend in the relationship between FPC and the proportion of individual protein fractions, SP:IG ratio, or SP:IP ratio (Table 5.8). The proportion of SP tended to increase slightly (1-2%) as fertilizer N rate increased, and was accompanied by a similar decrease in the proportion of RP. The only instance where a strong relationship was observed between

Parameter[a]	Carman-00		Swift Current-00		Carman-01		Brandon-01		Swift Current-01	
	Location									
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
FPC	14.6	1.3	11.6	1.5	16.4	0.4	14.3	1.2	15.1	1.3
SP	9.93	1.06	7.81	1.06	10.39	0.28	8.92	0.84	9.68	0.67
IG	3.34	0.37	2.39	0.33	3.16	0.09	2.59	0.18	2.71	0.20
RP	1.36	0.56	1.44	0.41	2.85	0.34	2.83	0.54	2.66	0.65
IP	4.70	0.57	3.83	0.54	6.01	0.28	5.42	0.61	5.38	0.74
% SP	67.8	3.0	67.1	2.1	63.4	1.2	62.2	2.6	64.4	2.6
% IG	22.8	1.1	20.6	1.3	19.3	0.8	18.1	0.8	18.0	0.8
% RP	9.4	3.8	12.3	3.1	17.4	1.8	19.7	3.0	17.5	3.2
% IP	32.2	3.0	32.9	2.1	36.6	1.2	37.8	2.6	35.6	2.6
SP:IG	2.98	0.13	3.27	0.15	3.29	0.11	3.44	0.18	3.57	0.10
SP:IP	2.14	0.30	2.05	0.19	1.73	0.09	1.66	0.18	1.82	0.21

[a] FPC = flour protein content, SP = soluble protein content, IG = insoluble glutenin content, RP = residue protein content, and IP = insoluble protein content. % SP = soluble protein as a proportion of FPC, % IG = insoluble glutenin as a proportion of FPC, % RP = residue protein as a proportion of FPC, % IP = insoluble protein as a proportion of FPC. SP:IG = ratio of soluble protein to insoluble glutenin, SP:IP = ratio of soluble protein to insoluble protein.

Table 5.7. Summary of the protein composition characteristics of the experimental sites.[a]

Parameter	Carman-00	Swift Current-00	Brandon-01	Swift Current-01
SP	0.91***	0.97***	0.89***	0.87***
IG	0.90***	0.89***	0.84***	0.84***
RP	0.05[ns]	0.48*	0.60***	0.77***
IP	0.64***	0.90***	0.78***	0.90***
%SP	0.17[ns]	0.07[ns]	-0.02[ns]	-0.56*
%IG	0.19[ns]	-0.10[ns]	-0.54***	-0.45[ns]
%RP	-0.19[ns]	-0.01[ns]	0.18[ns]	0.56*
%IP	-0.17[ns]	-0.07[ns]	0.02[ns]	0.56*
SP:IG	-0.07[ns]	0.18[ns]	0.45**	-0.09[ns]
SP:IP	0.17[ns]	0.06[ns]	0.00[ns]	-0.55*

[a] ns, *, **, *** not significant. significant at $P < 0.05$, 0.01, and 0.001, respectively.

Table 5.8. Coefficients of correlation (r) between selected protein composition parameters and FPC for the Carman-00, Swift Current-00, Brandon-01, and Swift Current-01 sites.[a]

FPC and SP:IG was at the Brandon-01 site, where SP:IG increased as FPC increased ($r = 0.45$). Wieser and Seilmeier (1998) and Triboi et al. (2000) found N fertilization had a more pronounced effect on the percentage increase in the quantity of gliadin compared to FPC or glutenin, resulting in an increase in the ratio of gliadin to glutenin, while Johansson et al. (2001), found increased N supply resulted in no change in the ratio of gliadin to glutenin.

We reported previously that the most striking differences in technological quality among site years was the dough weakness exhibited by samples from the Swift Current-01 site at the same FPC as samples from the Carman-00 and Brandon-01 sites. The Swift Current-01 site was subjected to a prolonged period of dryness, and yields were low relative to the other four site years evaluated (Appendix G). Heat or drought stress during the growing season has been demonstrated to alter gliadin composition (Ciaffi et al. 1996; Daniel and Triboi 2001), the balance of gliadin and glutenin (Blumenthal et al. 1993; Daniel and Triboi 2000; Daniel and Triboi 2001), and glutenin polymerization (Altenbach et al. 2002; Perrotta et al. 1998; Stone and Nicolas 1996b; Triboi and Leblevenec 1995). As such, compared to the other site years, we expected there could be considerable differences in protein composition for Swift Current-01 samples compared to the other site years, possibly an increase in the proportion of SP or a reduction in the proportion of IG or IP. An increase in the proportion of gliadin, which comprises the majority of the SP fraction, is associated with an increase in dough extensibility and a decrease in dough strength (Fido et al. 1997; MacRitchie 1987; Uthayakumuran et al. 2000; Wooding et al. 2000b), which would explain the short dough development time and low WIP and SI exhibited by the Swift Current-01 samples (Chapter 4).

However, based on the extraction procedure utilized in this study, protein composition could not be used to explain the poor dough properties of the Swift Current-01 samples. Besides protein composition, the poor technological quality of the Swift Current-01 samples may be due to the effect of the adverse weather conditions on starch properties (Jenner 1994; Panozzo and Eagles 1998) or other physiological processes in the kernel. The most likely explanation for the poor dough strength of the Swift Current-01 samples is elevated levels of α-amylase or starch damage as a result of physiological immaturity (Preston et al. 1991). Although visibly green kernels were removed by hand prior to milling, kernels that were normal in appearance (and as such were left in the sample) may also have been affected by physiological immaturity, thereby influencing dough strength properties.

5.4.3 Relationships among Quality Attributes

A number of interesting relationships were observed among quality attributes and protein composition based on the restricted dataset (Table 5.9). In a number of instances, individual protein fractions were considerably more strongly correlated to a given quality attribute than FPC, emphasizing the importance of protein composition to technological quality (Gupta et al. 1992; Hamada et al. 1982; MacRitchie 1992; Schofield 1986; Shewry et al. 1986; Wall 1979). The RP fraction and the ratio of SP:IP were generally poorly correlated with technological quality; while IP was poorly correlated with micro-extension test parameters.

With respect to Mixograph parameters, dough development time (MDT) showed a moderate negative correlation with SP:IG, RP, IP, and %RP; %IG was moderately and positively correlated to MDT. Peak dough resistance, which was the quality attribute most strongly correlated with FPC, was strongly correlated to SP and IG, although the relationship between PDR and SP was stronger than the relationship between PDR and IG. Work input-to-peak (WIP) was weakly correlated with FPC, SP, and IG. However, there was a moderate inverse correlation between WIP and SP:IG ratio and a moderate, positive correlation between WIP and %IG. Peak bandwidth (PBW) was also poorly correlated to FPC; IG showed a moderate and positive correlation to PBW, while the SP:IG ratio was negatively correlated to PBW. Dough breakdown resistance was most strongly correlated to SP, while the only parameters moderately correlated to dough strength index were SP:IG ratio and %IG.

As was the case with PBW and WIP, IG, %IG and the SP:IG ratio were moderately correlated with dough maximum resistance to extension (Rmax), an indicator

Parameter	Protein Composition										
	FPC	SP	IG	RP	IP	%SP	%IG	%RP	%IP	SP:IG	SP:IP
Mixograph											
MDT	-0.73***	-0.55***	-0.17^{ns}	-0.46***	-0.63***	0.18^{ns}	0.40***	-0.28*	-0.18^{ns}	-0.46***	0.17^{ns}
PDR	0.91***	0.89***	0.76***	0.03^{ns}	0.50***	0.17^{ns}	0.21^{ns}	-0.20^{ns}	-0.17^{ns}	0.18^{ns}	0.18^{ns}
WIP	-0.36**	-0.16^{ns}	0.25*	-0.54***	-0.47***	0.29*	0.61***	-0.44***	-0.29*	-0.68***	0.30*
PBW	0.17^{ns}	0.15^{ns}	0.40***	-0.11^{ns}	0.11^{ns}	-0.03^{ns}	0.35**	-0.13^{ns}	0.03^{ns}	-0.50***	0.01^{ns}
BR	0.66***	0.58***	0.26*	0.26*	0.46***	0.01^{ns}	-0.20^{ns}	0.08^{ns}	-0.01^{ns}	0.31**	0.00^{ns}
SI	-0.38***	-0.27*	0.14^{ns}	-0.37***	-0.35**	0.10^{ns}	0.49***	-0.27*	-0.10^{ns}	-0.63***	0.11^{ns}
Micro-extension											
Rmax	0.06^{ns}	0.05^{ns}	0.35**	-0.15^{ns}	0.04^{ns}	-0.04^{ns}	0.38***	-0.14^{ns}	0.04^{ns}	-0.55***	0.00^{ns}
E at Rmax	0.63***	0.68***	0.49***	-0.05^{ns}	0.25*	0.28*	0.11^{ns}	-0.23^{ns}	-0.27*	0.05^{ns}	0.28*
E Area	0.41***	0.44***	0.64***	-0.20^{ns}	0.17^{ns}	0.14^{ns}	0.47***	-0.298	-0.14^{ns}	-0.55***	0.17^{ns}
E	0.59***	0.64***	0.41***	0.00^{ns}	0.25*	0.24^{ns}	0.03^{ns}	-0.17^{ns}	-0.24^{ns}	0.14^{ns}	0.25*
Rmax/E	-0.29*	-0.33**	-0.03^{ns}	-0.06^{ns}	-0.09^{ns}	-0.19^{ns}	0.19^{ns}	0.04^{ns}	0.19^{ns}	-0.40***	-0.17^{ns}
Baking											
FAB	0.76***	0.76***	0.65***	-0.01^{ns}	0.39***	0.20^{ns}	0.21^{ns}	-0.22^{ns}	-0.20^{ns}	-0.13^{ns}	0.21^{ns}
LV	0.83***	0.73***	0.50***	0.23^{ns}	0.58***	-0.01^{ns}	-0.05^{ns}	0.03^{ns}	0.01^{ns}	0.10^{ns}	0.00^{ns}

[a] MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak band width, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FAB = Farinograph water absorption, LV = loaf volume.

[b] ns, *, **, *** not significant. significant at P <0.01, 0.001, and 0.0001, respectively.

Table 5. 9. Coefficients of correlation (r) among selected quality attributes for the pooled dataset (n = 110).[a,b]

of dough strength. Dough extensibility was most strongly correlated to SP, while extensigram area (E Area) was more strongly correlated to IG, %IG, and the SP:IG ratio than SP or FPC. Farinograph water absorption (FAB) and loaf volume (LV) were most strongly correlated to SP, IG, and IP, although FPC was as strongly or more strongly correlated to both parameters.

Sapirstein and Fu (1998) reported a strong and positive correlation between IG and MDT, WIP, Rmax, E Area, and LV, while there was a strong and inverse relationship between these parameters and SP. Generally speaking, in this study indicators of dough strength were more strongly correlated to IG or SP:IG ratio than SP, while the opposite was true of measures of dough extensibility, but by no means were the correlations as well-defined as in the aforementioned study. The authors also reported RP was negatively correlated to all quality parameters. We found moderate, negative correlations between RP and MDT, WIP, and SI.

The SP:IG ratio was much more strongly correlated to a number of quality attributes than FPC, including WIP, PBW, SI, and Rmax. Furthermore, the average SP:IG of the Brandon-01 and Swift Current-01 samples was much higher on average compared to the other three site years (Table 5.7), and corresponded reasonably well to relative dough strength. Unlike the results of the analysis of variance, results of the correlation analysis demonstrate the SP:IG ratio appears to be a good predictor of end-use quality, particularly in this case where wheat from a number of diverse environments is being considered in the analysis.

5.4.4 Effect of Previous Crop on End-Use Quality Across a Similar Range of Flour Protein Content

In a previous study (Chapter 4), we reported an interaction between previous crop and FPC for a number of end-use quality parameters. At the same FPC, P-W tended to be more extensible, have a shorter MDT, and exhibit lower WIP and SI compared to F-W (Chapter 4). Therefore, we were interested in whether interactions occurred when FPC was replaced by SP, IG, IP, SP:IG or SP:IP in the analysis. Results of the regression analysis provided some insight into why there was an interaction in some instances between previous crop and FPC (Table 5.10). Also of note was the observation that all of the interactions reported previously between previous crop and FPC were also observed when SP was used in place of FPC in the analysis. At the same SP, P-W had shorter MDT and lower WIP compared to F-W. Though not statistically significant, P-W tended to have a lower dough SI and was more extensible at the same SP compared to F-W. There was also a significant interaction between MDT and IP as well as between MDT and SP:IG ratio. Also of note was a moderately strong interaction between E at Rmax and previous crop for SP:IG ratio. The results of this analysis suggest that the balance of protein fractions, rather than a sole protein fraction, is responsible for the differences in end-use quality attributed to previous crop observed in this study.

We speculated previously that effect of previous crop on breadmaking quality was due to the effect of previous crop on the pattern of N uptake. In theory, protein composition is influenced by the alteration of the pattern of N availability during protein synthesis. For example, the synthesis of relatively large glutenin molecules occurs in the late stages of kernel development (Daniel and Triboi 2002; Gupta et al. 1996; Stone and

Parameter	Protein Composition									
	SP	IG	RP	IP	%SP	%IG	%RP	%IP	SP:IG	SP:IP
	Previous Crop*Protein Composition (Pr>F)									
Mixograph										
MDT	0.0164*	0.82^{ns}	0.0699^{ns}	0.0494*	0.79^{ns}	0.0248*	0.26^{ns}	0.79^{ns}	0.0191*	0.89^{ns}
PDR	0.92^{ns}	0.60^{ns}	0.11^{ns}	0.28^{ns}	0.23^{ns}	0.0431*	0.12^{ns}	0.23^{ns}	0.0422*	0.25^{ns}
WIP	0.0209*	0.41^{ns}	0.48^{ns}	0.25^{ns}	0.60^{ns}	0.40^{ns}	0.95^{ns}	0.60^{ns}	0.49^{ns}	0.53^{ns}
PBW	0.58^{ns}	0.75^{ns}	0.22^{ns}	0.33^{ns}	0.21^{ns}	0.34^{ns}	0.23^{ns}	0.21^{ns}	0.34^{ns}	0.18^{ns}
BR	0.81^{ns}	0.86^{ns}	0.87^{ns}	0.45^{ns}	0.83^{ns}	0.81^{ns}	0.96^{ns}	0.83^{ns}	0.89^{ns}	0.75^{ns}
SI	0.0683^{ns}	0.83^{ns}	0.66^{ns}	0.59^{ns}	0.55^{ns}	0.26^{ns}	0.95^{ns}	0.56^{ns}	0.16^{ns}	0.46^{ns}
Micro-extension										
Rmax	0.45^{ns}	0.95^{ns}	0.68^{ns}	0.77^{ns}	0.50^{ns}	0.96^{ns}	0.67^{ns}	0.50^{ns}	0.92^{ns}	0.51^{ns}
E at Rmax	0.12^{ns}	0.78^{ns}	0.32^{ns}	0.33^{ns}	0.71^{ns}	0.14^{ns}	0.45^{ns}	0.71^{ns}	0.0621^{ns}	0.97^{ns}
E Area	0.84^{ns}	0.84^{ns}	0.38^{ns}	0.47^{ns}	0.41^{ns}	0.41^{ns}	0.42^{ns}	0.40^{ns}	0.27^{ns}	0.43^{ns}
E	0.18^{ns}	0.87^{ns}	0.35^{ns}	0.37^{ns}	0.68^{ns}	0.15^{ns}	0.44^{ns}	0.68^{ns}	0.0913^{ns}	0.74^{ns}
Rmax/E	0.20^{ns}	0.99^{ns}	0.80^{ns}	0.76^{ns}	0.73^{ns}	0.34^{ns}	0.91^{ns}	0.73^{ns}	0.17^{ns}	0.73^{ns}
FAB	0.74^{ns}	0.24^{ns}	0.77^{ns}	0.70^{ns}	0.56^{ns}	0.97^{ns}	0.77^{ns}	0.55^{ns}	0.81^{ns}	0.62^{ns}
LV	0.90^{ns}	0.93^{ns}	0.99^{ns}	0.50^{ns}	0.81^{ns}	0.62^{ns}	0.96^{ns}	0.82^{ns}	0.55^{ns}	0.83^{ns}

[a] ns, *, **, ***, **** not significant, significant at $P < 0.05$, 0.01, 0.001, and 0.0001, respectively.

Table 5. 10. Degree of significance of the interaction between previous crop and protein composition parameters for selected quality attributes.[a]

Nicolas 1996a; Zhu and Khan 1999). Therefore, in theory, increasing N availability later in the filling period by increasing the proportion of N taken up after anthesis (namely F-W) enhances glutenin synthesis and therefore increases dough strength. Conversely, where the majority of N uptake occurs prior to anthesis (i.e. P-W), there is a higher proportion of N available during the most rapid phase of gliadin synthesis, namely the first half of kernel development (Panozzo et al. 2001; Stone and Nicolas 1996a; Stone and Savin 1999). Therefore, P-W would be expected to produce weaker, more extensible dough due to a higher proportion of gliadin and/or a lower proportion of polymeric protein compared to F-W.

Given the results of the regression analysis reported in Table 5.10, we expected previous crop might have a significant effect on SP, since the same interactions were reported where SP replaced FPC in the regression analysis. However, when the interaction between previous crop and protein composition parameters was evaluated, no significant interactions were observed for SP or any other protein composition parameter (Table 5.11).

The regression analysis is complicated by the fact that the SP fraction contains a number of sub-fractions of protein, namely gliadin (and its various sub-fractions) and LMW glutenin (Sapirstein and Fu 1998). However, gliadin is similar to LMW glutenin with respect to molecular structure and end-use quality effects, since both are classified as S-rich prolamins (Shewry et al. 1986). LMW glutenin is similar in amino acid composition and structure to α-, β-, and γ-gliadin (Shewry and Tatham 1997), and are rich in cysteine and methionine residues when compared to HMW glutenin or ω–gliadin.

Parameter	Pr > F								
	SP	IG	RP	IP	%SP	%IG	%RP	%IP	SP:IG
FPC	0.88^{ns}	0.84^{ns}	0.56^{ns}	0.99^{ns}	0.72^{ns}	0.39^{ns}	0.55^{ns}	0.72^{ns}	0.43^{ns}
SP	------	1.00^{ns}	0.52^{ns}	0.99^{ns}	0.61^{ns}	0.23^{ns}	0.51^{ns}	0.61^{ns}	0.16^{ns}
IG	0.23^{ns}	------	0.41^{ns}	0.75^{ns}	0.20^{ns}	0.15^{ns}	0.23^{ns}	0.20^{ns}	0.0923^{ns}
RP	0.63^{ns}	0.77^{ns}	------	0.75^{ns}	0.18^{ns}	0.38^{ns}	0.46^{ns}	0.18^{ns}	0.17^{ns}
IP	0.89^{ns}	0.76^{ns}	0.42^{ns}	------	0.95^{ns}	0.95^{ns}	0.67^{ns}	0.95^{ns}	0.59^{ns}
%SP	0.99^{ns}	0.92^{ns}	0.39^{ns}	0.76^{ns}	------	0.50^{ns}	0.59^{ns}	0.33^{ns}	0.19^{ns}
%IG	0.30^{ns}	0.89^{ns}	0.93^{ns}	0.91^{ns}	0.23^{ns}	------	0.55^{ns}	0.23^{ns}	0.28^{ns}
%RP	0.66^{ns}	1.00^{ns}	0.41^{ns}	0.90^{ns}	0.25^{ns}	0.51^{ns}	------	0.24^{ns}	0.21^{ns}
%IP	1.00^{ns}	0.92^{ns}	0.38^{ns}	0.75^{ns}	0.34^{ns}	0.95^{ns}	0.58^{ns}	------	0.19^{ns}
SP:IG	0.22^{ns}	0.83^{ns}	0.66^{ns}	0.70^{ns}	0.23^{ns}	0.64^{ns}	0.53^{ns}	0.23^{ns}	------

[a] ns, * = not significant.

Table 5. 11. Degree of significance of the interaction between previous crop and protein composition parameters for selected protein composition parameters.[a]

As such, particularly when compared to HMW glutenin, gliadin and LMW glutenin are also similar in their effects on dough strength properties (Sapirstein and Fu 1998).

Given a high proportion of the SP fraction is composed of gliadin, it stands to reason that differences in gliadin composition are responsible for the differences in end-use quality attributed to previous crop. A more sophisticated method of protein composition evaluation than the extraction procedure utilized in this study, such as size exclusion-high performance liquid chromatography (SE-HPLC) might provide better insight into the differences in technological quality observed at the same FPC attributed to previous crop. Analysis of the SP fraction through SE-HPLC analysis would permit the quantification of LMW glutenin, as well as the various gliadin sub-fractions, thereby providing a much clearer picture of the composition of SP as well as the balance between gliadin and glutenin and their representative sub-fractions.

5.5 Conclusions

A protein extraction method based on the differential solubility of flour protein in 50% 1-propanol was used to evaluate the effect of previous crop and N fertilization on the protein composition of CWRS wheat in a series of small plot experiments carried out at Carman, MB, Brandon, MB, and Swift Current, SK. The quantity of SP, IG and IP increased as FPC increased, while the effect was less prominent for RP. The proportion of each fraction remained relatively stable as N supply and FPC increased, although unexplainable differences in protein composition among site years were observed.

FPC was a poorer predictor of technological quality in many instances compared to individual protein fractions or the ratio of SP to IG. IG and the SP:IG ratio were generally more strongly correlated with measures of dough strength than SP, while the opposite was true of measures of dough viscosity. The previous crop*FPC interaction for a number of technological quality parameters was observed for the same parameters when SP was evaluated. Fewer interactions between previous crop and two other protein composition parameters, most notably the SP:IG ratio, were also observed and could not be explained by differences in protein composition. More sensitive methods of protein composition analysis such as SE-HPLC may help to explain the FPC*previous crop interactions observed and would provide more insight into the effect of soil N status on the protein composition of CWRS wheat.

6.0 GENERAL DISCUSSION AND CONCLUSIONS

One of the major aspects of the research carried out in this study was the effect of crop management practices on the quantity of N available to a wheat crop, as well as the temporal availability of N. A number of researchers in semiarid and subhumid regions of western Canada have pointed out one means of increasing N use efficiency in field crop production is to improve the synchrony of N availability and crop demand. However, in most instances in western Canada, fertilizer N is applied solely during or prior to planting. Mid-season N application is made difficult since crops are solid-seeded, reducing N application options. Furthermore, in most areas of western Canada, precipitation following mid-season broadcast application of fertilizers such as ammonium nitrate (AN) or urea is unreliable, thereby reducing fertilizer N efficiency. Given the high cost of N fertilizer, maximizing N use efficiency and the N-supplying potential of cropping systems is important to western Canadian producers.

The inclusion of annual grain legumes in rotation, as well as controlled-release N fertilizer technology, are both considered to increase N availability later in the growing season when N contributes more to protein content (PC) relative to grain yield. Western Canadian producers have become more interested in producing high PC wheat, particularly since premiums for high protein wheat of acceptable quality have been high in recent years, particularly for Canada Western Red Spring wheat.

Grain legume residues tend to have lower carbon to nitrogen ratios than cereal or oilseed residues. Therefore, grain legumes enhance N availability from the residues to a succeeding cereal crop due to more rapid decomposition and net mineralization. In most studies conducted in the Northern Plains, the increased N availability from annual grain legumes has been attributed to mineralization during the growing season. However, the inclusion of legumes in crop rotations may also indirectly increase N availability through the conservation of soil N as a result of biological N fixation.

The first two objectives of the study was to determine the quantity and timing of N availability from two previous crops (field pea and flax) and two fertilizer N sources (AN and CRU) to a wheat crop, and to determine the extent to which N made available by the two previous crops or fertilizer N sources was recovered by the wheat crop. We theorized that field pea stubble would contain a higher quantity of plant-available N at planting, and that N availability would increase further during the growing season due to mineralization of field pea residue. Furthermore, we postulated that the N release pattern of CRU would mimic field pea stubble, namely increased N availability post-anthesis. As expected, soil NO_3-N to a depth of 120 cm was significantly higher for field pea stubble relative to flax stubble at two of three Manitoba sites (Carman-00 and Brandon-01). We initially attributed the higher N availability for field pea stubble to the sparing of soil N. However, we found no evidence of increased N availability later in the growing season (i.e. higher apparent net N mineralization) for wheat crop grown on field pea stubble (P-W) compared to wheat grown on flax stubble (F-W). Surprisingly, we found the opposite was true. Apparent net mineralized N during the growing season and proportion of post-anthesis N uptake were higher for F-W compared to P-W at both Carman-00 and Brandon-01.

The results suggest that the net release of N from field pea stubble occurred quickly after the field pea harvest well ahead of planting the subsequent wheat crop. Comparable studies carried out in western Canada have been conducted in semiarid regions of Saskatchewan. However, environmental conditions in southern Manitoba are considerably different than in more northerly or westerly areas of the Prairies, and are much more conducive to mineralization during the post-harvest period. Although western Saskatchewan has adequate post-harvest soil temperatures to facilitate mineralization, post-harvest precipitation is usually considerably lower than in southern Manitoba. More northerly areas of the Prairies have adequate soil moisture to promote mineralization but lack sufficient soil temperatures to allow mineralization to proceed at a rapid rate.

As a result, higher soil NO_3-N under field pea stubble compared to flax stubble at Carman-00 and Brandon-01 was likely present post-harvest as a result of both soil N conservation and N mineralization. Therefore, the potential for N losses such as leaching and denitrification increased, both of which are of considerable concern in southern Manitoba, particularly given the potential for wet post-harvest conditions. In western Europe, for example, N leaching following legume production is a serious issue, since the post-harvest period is much wetter and warmer than even in southern Manitoba, facilitating rapid decomposition and mineralization of crop residues.

Furthermore, at the Carman sites in particular, post-anthesis N uptake was similar to post-anthesis NMN, meaning significant quantities of inorganic N was present for all treatments following wheat harvest. Therefore, selection of crops that are effectively able to accumulate N during the autumn are essential following production of annual grain legumes, since conserved N and N made available through mineralization of legume is subject to leaching. While the inclusion of annual grain legumes such as field pea may increase overall soil N supply, the temporal N availability is not always in synchrony with plant demand in annual cropping systems, meaning N use efficiency is reduced.

Like field pea stubble, controlled-release urea (CRU) was expected to result in increased N availability later in the growing season due to its delayed N release pattern. The CRU product used in this study was designed to achieve 80 to 100% N release in 40 to 50 d. As expected, given the rapid N release pattern of AN relative to CRU, total N uptake at anthesis was significantly higher for wheat grown with AN compared to wheat grown with CRU at Carman-00 and Brandon-01.

However, contrary to the findings of the previous CRU study, we found inconsistent results with respect to the effect of CRU on post-anthesis N uptake. The N release pattern of CRU at the Brandon-01 site was in line with expectations. However, at the Carman sites, post-anthesis N uptake was similar for both fertilizer N sources, although treatment effects may have been masked by the high soil N levels prior to planting in both Carman site years. Given the previous crop effects observed, the N release pattern of CRU was generally more similar to that of flax stubble. The inconsistency of the CRU results suggests that the perceived benefits of the CRU are likely strongly dependent on soil N supply. However, in situations similar to southern Manitoba, where a combination of high soil N supply and plentiful moisture results in a high risk of lodging, CRU may be better agronomically as a source of fertilizer N than other N sources with more rapid N release.

Although PC is traditionally recognized as the most influential factor affecting breadmaking quality, protein composition also plays a significant role in determining end-use quality. Where end-use quality differs significantly among samples with similar PC, differences in end-use quality can be attributable to differences in protein quality or composition. The gliadin fraction, which is synthesized in the kernel most rapidly during the early stages of kernel development, is responsible for the viscous properties of dough during mixing. Conversely, the glutenin fraction, which is synthesized in the latter half of kernel development, is composed of polymeric protein and is responsible for dough strength. A proper balance of gliadin and glutenin is responsible for the unique visco-elastic properties of dough; altering the balance of these two protein fractions results in altered end-use quality.

The third objective of this study was to determine whether across a similar range of PC, previous crop or fertilizer N source produced wheat with different end-use quality characteristics that could be explained by differences in protein composition. Given the asynchronous pattern of protein synthesis as well as the dramatically different effects of individual protein fractions on end-use quality, we theorized that since previous crop altered the N accumulation pattern of wheat, protein composition might also be affected, thereby influencing dough properties and breadmaking quality. To our knowledge, this is the first study of its kind ever conducted.

Evaluating end-use quality with the Mixograph, a dough micro-extension test, and the Canadian Short Process bake test, we demonstrated that P-W had a shorter Mixograph dough development time (MDT) and produced a lower work input-to-peak (WIP) than F-W. P-W also tended to be more extensible and tended to have a lower dough strength index (SI) than F-W. Whether weaker or stronger dough is more desirable to end-users is not the issue with respect to the previous crop effects observed. What is particularly important is the observation that at the same FPC, end-use quality was not consistent.

Based on the higher proportion of N accumulated prior to anthesis for P-W, it stood to reason that if a greater proportion of N was made available to the kernel during the early stages of kernel development, a higher proportion of gliadin might be synthesized, in turn producing dough that was weaker and more extensible. Conversely, increasing the proportion of N accumulated post-anthesis for F-W might result in preferential synthesis of glutenin, thereby increasing dough strength. The relative dough weakness of the P-W samples lends merit to this theory. Therefore, we were interested in whether protein composition was indeed altered by previous crop.

Compared to the effect of previous crop, the effect of site year (i.e. environmental conditions during the growing season) on end-use quality was much more pronounced. For example, Swift Current-01 samples took longer to reach Mixograph MDT, displayed reduced resistance to mixing at MDT, and broke down more rapidly after MDT than wheat with similar FPC from other site years. The Swift Current-01 site was subjected to substantial drought stress during the growing season; the results of the Swift Curent-01 sample analysis are in agreement with other studies conducted in Australia that have demonstrated the adverse effect of stress during the grain filling period on dough strength, specifically with respect to the effect of stress on protein composition. We theorized that differences in protein composition might be responsible for the site year effects.

A protein extraction method based on the differential solubility of flour protein in 50% 1-propanol was used to evaluate the effect of environment and increasing N supply on the protein composition of CWRS wheat under western Canadian growing conditions. Four protein fractions were quantified, namely soluble protein (SP), insoluble glutenin (IG), residue protein (calculated as flour protein content minus the sum of SP+IG) and total insoluble protein (IP) increased as flour protein content (FPC) increased. The ratios of SP to IG and SP to IP were also calculated. Evaluation of the interaction between previous crop and the various protein composition parameters provided little insight into why there was an interaction in some instances between previous crop and FPC. All of the interactions reported previously between previous crop and FPC were also present when SP replaced FPC in the analysis. The interaction between previous crop and fractions other than SP was less consistent, although replacing FPC with ratio of SP to IG also yielded a number of interactions.

The results of this analysis suggested that the balance of protein fractions, rather than a sole protein fraction, is responsible for the differences in end-use quality observed in this study attributed to previous crop, or that factors other than protein composition such as starch properties might explain the differences in end-use quality. Furthermore, protein composition could not be used to explain the poor dough properties of the Swift

Current-01 samples. The effect of adverse growing season conditions on starch properties was theorized to be the reason for the site year effects observed.

Interestingly, despite the poor dough strength of the Swift Current-01 samples, the samples graded as No. 1 CWRS, and as such were considered to be of greater value than samples from the Carman or Brandon sites that were downgraded as a result of *Fusarium* damage. The results of the study point to the strong conclusion that FPC is by no means the only measure of wheat end-use quality, and that grade was also a poor indicator of relative value among site years.

Furthermore, compared to the effect of previous crop, it is clearly much more difficult to eliminate the effects of environment on quality at a given delivery point by blending, since conditions such as drought stress would most certainly be prevalent throughout most of the area surrounding the high throughput elevator. As the importance of grain shipments by rail from individual delivery points increases, as well as the trend towards contract production and marketing, identity-preserved grain handling, and specification-based sales, quality consistency among delivery points will become a much greater concern in future years, particularly given western Canada's reputation for quality consistency.

7.0. LITERATURE CITED

Abrol, Y. P., Kumar, P. A., and Nair, T. V. R. 1984. Nitrate uptake and assimilation and grain nitrogen accumulation. p. 1-48. In: Advances in Cereal Science and Technology Vol. 6. Pomeranz, Y. ed. American Association of Cereal Chemists, St. Paul, MN.

Adderley, D. R., Schoenau, J. J., and Holm, F. A. 1998. Availability of soil nitrogen released from pea and lentil residue to subsequent cereal crops under reduced tillage. p. 339-344. In: Proc. Saskatchewan Soils and Crops Workshop. February 19-20, 1998. University of Saskatchewan, Saskatoon, SK.

Agrium. 2000. Duration cr Polymer Coated Urea Type I (43-0-0) 260 SGN. Agrium Partnership, Calgary, AB. March 31, 2000.

Alcoz, M. M., Hons, F. M., and Haby, V. A. 1993. Nitrogen fertilization timing effect on wheat production, nitrogen uptake efficiency, and residual soil nitrogen. Agron. J. 85: 1198-1203.

Alkier, A. C., Racz, G. J., and Soper, R. J. 1972. Effects of foliar- and soil-applied nitrogen and soil nitrate-nitrogen level on the protein content of Neepawa wheat. Can. J. Soil Sci. 52: 301-309.

Altenbach, S. B., Kothari, K. M., and Lieu, D. 2002. Environmental conditions during wheat grain development alter temporal regulation of gluten protein genes. Cereal Chem. 79: 279-285.

Amato, M., Jackson, R. B., Butler, J. H. A., and Ladd, J. N. 1984. Decomposition of plant material in Australian soils. II. Residual organic ^{14}C and ^{15}N from legume plant parts decomposing under field and laboratory conditions. Aust. J. Soil Res. 22: 331-341.

American Association of Cereal Chemists. 2000. Approved methods of the AACC, 9th ed. Method 54-21, Farinograph method for flour. AACC, St. Paul, MN.

Androsoff, G. L., van Kessel, C., and Pennock, D. J. 1995. Landscape-scale estimates of dinitrogen fixation by *Pisum sativum* by nitrogen-15 natural abundance and enriched isotope dilution. Biol. Fertil. Soils 20: 33-40.

Antes, S., and Wieser, H. 2001. Effects of high and low molecular weight glutenin subunits on rheological dough properties and breadmaking quality of wheat. Cereal Chem. 78: 157-159.

Armstrong, E. L., Pate, J. S., and Unkovich, M. J. 1994. Nitrogen balance of field pea crops in south western Australia, studied using the ^{15}N natural abundance technique. Aust. J. Plant Physiol. 21: 533-549.

Aussenac, T., and Carceller, J. L. 2000. SDS-unextractable glutenin polymer formation in wheat kernels. p. 475-479. In: Wheat Gluten. Shewry, P. R., and Tatham, A. S. eds. Royal Society of Chemistry, Cambridge, UK.

Axford, D. W. E., McDermott, E. E., and Redman, D. G. 1979. Note on the sodium dodecyl sulfate test of breadmaking quality: comparison with Pelshenke and Zeleny tests. Cereal Chem. 56: 582-584.

Ayoub, M., Guertin, S., Fregeau-Reid, J., and Smith, D. L. 1994. Nitrogen fertilizer effect on breadmaking quality of hard red spring wheat in eastern Canada. Crop Sci. 34: 1346-1352.

Badaruddin, M., and Meyer, D. W. 1994. Grain legume effects on soil nitrogen, grain yield, and nitrogen nutrition of wheat. Crop Sci. 34: 1304-1309.

Bangur, R., Batey, I. L., McKenzie, E., and MacRitchie, F. 1997. Dependence of extensograph parameters on wheat protein composition measured by SE-HPLC. J. Cer. Sci. 25: 237-241.

Batey, I. L., Gupta, R. B., and MacRitchie, F. 1991. Use of size-exclusion high-performance liquid chromatography in the study of wheat flour proteins: an improved chromatographic procedure. Cereal Chem. 68: 207-209.

Bauer, A., Black, A. L., and Frank, A. B. 1989. Soil water use by plant development stage of spring and winter wheat. Agric. Exp. Stn. Bull. 519.

Bauer, A., Frank, A. B., and Black, A. L. 1987a. Aerial parts of hard red spring wheat. I. Dry matter distribution by plant development stage. Agron. J. 79: 845-852.

Bauer, A., Frank, A. B., and Black, A. L. 1987b. Aerial parts of hard red spring wheat. II. Nitrogen and phosphorous concentration and content by plant development stage. Agron. J. 79: 852-858.

Beckie, H. J., and Brandt, S. A. 1997. Nitrogen contribution of field pea in annual cropping systems. 1. Nitrogen residual effect. Can. J. Plant Sci. 77: 311-322.

Beckie, H. J., Brandt, S. A., Schoenau, J. J., Campbell, C. A., Henry, J. L, and Janzen, H. H. 1997. Nitrogen contribution of field pea in annual cropping systems. 2. Total nitrogen benefit. Can. J. Plant Sci. 77: 323-331.

Bénétrix, F., Kaan, F., and Autran, J. C. 1994. Changes in protein complexes of durum wheat in developing seed. Crop Sci. 34: 462-468.

Biederbeck, V. O., and Campbell, C. A. 1973. Soil microbial activity as influenced by temperature trends and fluctuations. Can. J. Soil Sci. 53: 363-376.

Biederbeck, V. O., Rice, W. A., van Kessel, C., Bailey, L. D., and Huffman, E. C. 1996. Present and potential future nitrogen gains from legumes in major soil zones of the Prairies. p. 441-455. In: Proc. Saskatchewan Soils and Crops Workshop. February 22-23, 1996. University of Saskatchewan, Saskatoon, SK.

Black, A. L. 1982. Long-term N-P fertilizer and climate influences on morphology and yield components of spring wheat. Agron. J. 74: 651-657.

Black, C. A., Evans, D. D., White, J. L., Ensminger, L. E., and Clark, F. E. 1965. Methods of Soil Analysis Part I. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. American Society of Agronomy, Inc. Madison, WI.

Blumenthal, C. S., Barlow, E. W. R., and Wrigley, C. W. 1993. Growth environment and wheat quality: the effect of heat stress on dough properties and gluten proteins. J. Cer. Sci. 18: 3-21.

Boatwright, G. O., and Haas, H. J. 1961. Development and composition of spring wheat as influenced by nitrogen and phosphorous fertilization. Agron. J. 53: 33-36.

Bourgeois, L., and Entz, M. H. 1996. Influence of previous crop type on yield of spring wheat: Analysis of commercial field data. Can. J. Plant Sci. 76: 457-459.

Bole, J. B., and Dubetz, S. 1986. Effect of irrigation and nitrogen fertilizer on the yield and protein content of soft white spring wheat. Can J. Plant Sci. 66: 281-289.

Bole, J. B., and Pittman, U. J. 1980. Spring soil water, precipitation, and nitrogen fertilizer: effect on barley grain protein content and nitrogen yield. Can. J. Soil Sci. 60: 471-477.

Bollini, R., Manzocchi, L. A., Cattaneo, M., and Borghi, B. 1981. Electrophoretic patterns of proteins in wheat kernels (*Triticum aestivum* L.) during development. J. Agron. Crop Sci. 150: 71-79.

Bond, J. J., Power, J. F., and Willis, W. O. 1971. Soil water extraction by N-fertilized spring wheat. Agron. J. 63: 280-283.

Borghi, B. 1999. Nitrogen as determinant of wheat growth and yield. p. 67-84. In: Wheat: Ecology and Physiology of Yield Determination. Satorre, E. H. and Slafer, G. A. eds. Food Products Press. New York.

Borghi, B., Corbellini, M., Ciaffi, M., Lafiandra, D., De Stefanis, E., Sgruletta, D., Boggini, G., and Di Fonzo, N. 1995. Effect of heat shock during grain filling on grain quality of bread and durum wheats. Aust. J. Agric. Res. 46: 1365-1380.

Branlard, G., Barloy, D., and Triboi, E. 1985. Influence des techniques culturales sur les fractions protéiques du grain du blé. p. 223-251. In: Journées de Versailles sur l'ecophysiologie du blé. INRA, Paris, France.

Branlard, G., and Dardavet, M. 1985. Diversity of grain proteins and bread wheat quality I. Correlation between gliadin bands and flour quality characteristics. J. Cer. Sci. 3: 329-343.

Bremer, E., and van Kessel, C. 1992. Plant-available nitrogen from lentil and wheat residues during a subsequent growing season. Soil Sci. Soc. Am. J. 56: 1155-1160.

Broadbent, F. E. 1984. Plant use of soil nitrogen. p. 171-182. In: Nitrogen in Crop Production. Hauck, R. D. et al. eds. ASA-CSSA-SSSA, Madison, WI., USA.

Bronson, K. F., Touchton, J. T., Hauck, R. D., and Kelley, K. R. 1991. Nitrogen-15 recovery in winter wheat as affected by application timing and dicyandiamide. Soil Sci. Soc. Am. J. 55: 130-135.

Brown, P. L. 1971. Water use and soil water depletion by dryland winter wheat as affected by nitrogen fertilization. Agron. J. 63: 43-46.

Bushuk, W. 1966. Distribution of water in dough and bread. Bakers Digest 40: 38-40.

Bushuk, W., Briggs, K. G., and Shebeski, L. H. 1969. Protein quantity and quality as faxtors in the evaluation of bread wheats. Can. J. Plant Sci. 49: 113-122.

Bushuk, W., and MacRitchie, F. 1989. Wheat proteins: aspects of structure that determine breadmaking quality. p. 345-369. In: Protein Quality and the Effects of Processing. Phillips, R. D. and Finley, J. eds. Marcel Dekker, Inc. New York, Basel.

Camberato, J. J., and Bock, B. R. 1990a. Spring wheat response to enhanced ammonium supply: I. dry matter and nitrogen content. Agron. J. 82: 463-467.

Camberato, J. J., and Bock, B. R. 1990b. Spring wheat response to enhanced ammonium supply: II. tillering. Agron. J. 82: 467-473.

Campbell, C. A., and Biederbeck, V. O. 1972. Influence of fluctuating temperatures and constant soil moistures on nitrogen changes in amended and unamended loam. Can. J. Soil Sci. 52: 323-336.

Campbell, C. A., Cameron, D. R., Nicholaichuk, W., and Davidson, H. R. 1977a. Effects of fertilizer N and soil moisture on growth, N content, and moisture use by spring wheat. Can. J. Plant Sci. 57: 289-310.

Campbell, C. A., Cutforth, H. W., Selles, F., DePauw R. M., and Clarke, J. M. 1990. Dynamics of dry matter, N and P accumulation in the developing kernels of four spring wheat cultivars for irrigation and dryland. Can. J. Plant Sci. 70: 1043-1056.

Campbell, C. A., and Davidson, H. R. 1976. Effect of temperature, nitrogen fertilization and moisture stress on yield, yield components, protein content and moisture use efficiency of Manitou spring wheat. Can. J. Plant Sci. 59: 963-974.

Campbell, C. A., and Davidson, H. R. 1979. Effects of temperature, nitrogen fertilization and moisture stress on growth, assimilate distribution and moisture use by Manitou spring wheat. Can. J. Plant Sci. 59: 603-626.

Campbell, C. A., Davidson, H. R., and Warder, F. G. 1977b. Effects of fertilizer N and soil moisture on yield, yield components, protein content and N accumulation in the aboveground parts of spring wheat. Can. J. Plant Sci. 57: 311-327.

Campbell, C. A., Davidson, H. R., and Winkleman, G. E. 1981. Effect of nitrogen, temperature, growth stage and duration of moisture stress on yield components and protein content of Manitou spring wheat. Can. J. Plant Sci. 61: 549-563.

Campbell, C. A., Nuttall, W., Ukrainetz, H., Selles, F., and Wright, T. 1991. Effect of nitrogen source and time of application on winter wheat production in Saskatchewan. Can. J. Soil Sci. 71: 177-187.

Campbell, C. A., Selles, F., Zentner, R. P., and McConkey, B. G. 1993. Available water and nitrogen effects on yield components and grain nitrogen of zero-till spring wheat. Agron. J. 85: 114-120.

Campbell, C. A., Selles, F., Zentner, R. P., McConkey, B. G., McKenzie, R. C., and Brandt, S. A. 1997. Factors influencing grain N concentration of hard red spring wheat in the semiarid prairie. Can. J. Plant Sci. 77: 53-62.

Campbell, C. A., and Zentner, R. P. 1996. Disposition of nitrogen in the soil-plant system for flax and spring wheat-containing rotations in the Brown soil zone. Can. J. Plant Sci, 76: 407-412.

Campbell, C. A., Zentner, R. P., Selles, F., Biederbeck, V. O., and Leyshon, A. J. 1992. Comparative effects of grain lentil-wheat and monoculture wheat on crop production, N economy, and N fertility in a Brown Chernozem. Can. J. Plant Sci. 72: 1091-1107.

Canadian Fertilizer Institute. 2001. Canadian fertilizer information system: western retail sales statistics – fertilizer year ended June 30, 2001. Canadian Fertilizer Institute, Ottawa, ON.

Canadian Grain Commission. 1992. Quality evaluation methods for red spring wheat (2nd ed.). Canadian Grain Commission, Winnipeg, MB.

Cassman, K. G., and Munn, D. N. 1980. Nitrogen mineralization as affected by soil moisture, temperature, and depth. Soil Sci. Soc. Am. J. 44: 1233-1237.

Castle, S. L., and Randall, P. J. 1987. Effects of sulfur deficiency on the synthesis and accumulation of proteins in the developing wheat seed. Aust. J. Plant Physiol. 14: 503-516.

Chalk, P. M., Smith, C. J., Hamilton, S. D., and Hopmans, P. 1993. Characterization of the N benefit of a grain legume (*Lupinus angustifolius* L.) to a cereal (*Hordeum vulgare* L.) by an in situ ^{15}N isotope dilution technique.

Ciaffi, M., Tozzi, L., Borghi, B., Corbellini, M., and Lafiandra, D. 1996. Effect of heat shock during grain filling on the gluten protein composition of bread wheat. J. Cer. Sci. 24: 91-100.

Clarke, J. M., Campbell, C. A., Cutforth, H. W., DePauw, R. M., and Winkleman, G. E. 1990. Nitrogen and phosphorous uptake, translocation, and utilization efficiency of wheat in relation to environment and cultivar yield and protein levels. Can. J. Plant Sci. 70: 965-977.

Clesceri, L. S., Greenberg, A. E., and Eaton, A. D. 1998. Standard Methods for the Examination of Water and Wastewater. 20th ed. 4500–NO_3^- (automated cadmium reduction method); 4500–NH_3 (automated phenate method); 4500-K (flame photometric method); 4500-P (stannous chloride method); 4500-SO_4^{2-} (turbidimetric method). American Public Health Association (APHA).Washington, DC.

Cochran, V. L., Warner, R. L., and Papendick, R. I. 1978. Effect of N depth and application rate on yield, protein content, and quality of winter wheat. Agron. J. 70: 964-968.

Corbellini, M., Canevar, M. G., Mazza, L., Ciaffi, M., Lafiandra, D., and Borghi, B. 1997. Effect of the duration and intensity of heat shock during grain filling on dry matter and protein accumulation, technological quality and protein composition in bread and durum wheat. Aust. J. Plant Physiol. 24: 245-260.

Cowell, L. E., and Doyle, P. J. 1993a. The changing fertility of prairie soils. p. 26-48. In: A Review of the Impact of Macronutrients on Crop Responses and Environmental Sustainability on the Canadian Prairies. Rennie, D. A., Campbell, C. A., and Roberts, T. L. eds. Canadian Society of Soil Science.

Cowell, L. E., and Doyle, P. J. 1993b. Nitrogen use efficiency. p. 49-109. In: A Review of the Impact of Macronutrients on Crop Responses and Environmental Sustainability on the Canadian Prairies. Rennie, D. A., Campbell, C. A., and Roberts, T. L. eds. Canadian Society of Soil Science.

Crow, G. H. 2002. Personal communication.

Dachkevitch. T., and Autran, J. C. 1989. Prediction of baking quality of bread wheats in the breeding programs by size-exclusion high-performance liquid chromatography. Creeal Chem. 66: 448-456.

Daniel, C., and Triboi, E. 2000. Effects of temperature and nitrogen nutrition on the grain composition of winter wheat: effects on gliadin content and composition. J. Cer. Sci. 32: 45-56.

Daniel, C., and Triboi, E. 2001. Effects of temperature and nitrogen nutrition on the accumulation of gliadins analysed by RP-HPLC. Aust. J. Plant Physiol. 28: 11971205.

Daniel, C., and Triboi, E. 2002. Changes in wheat protein aggregation during grain development: effects of temperatures and water stress. Eur. J. Agron. 16: 1-12.

Darroch, B. A., and Fowler, D. B. 1990. Dry matter production and nitrogen accumulation in no-till winter wheat. Can. J. Plant Sci. 70: 461-472.

Darwinkel, A. 1983. Ear formation and grain yield of winter wheat as affected by time of nitrogen supply. Neth. J. Agric. Sci. 31: 211-225.

Davidson, H. R., and Campbell, C. A. 1984. Growth rates, harvest index and moisture use of Manitou spring wheat as influenced by nitrogen, temperature and moisture. Can. J. Plant Sci. 64: 825-839.

Dell'aquila, A., Colaprico, G., Taranto, G., and Carella, G. 1983. Endosperm protein changes in developing and germinating *T. aestivum*, *T. turgidum*, and *T. monococcum* seeds. Cereal. Res. Commun. 11: 107-113.

Dexter, J. E., and Nowicki, T. W. 2001. Safety and quality assurance issues associated with Fusarium head blight in wheat. In: Fusarium Head Blight of Wheat and Barley. Leonard, K., and Bushnell, W. (eds.). American Phytopathological Society, St. Paul, MN.

Doekes, G. J., and Wennekes, L. M. J. 1982. Effect of nitrogen fertilization on quantity and composition of wheat flour protein. Cereal Chem. 59: 276-278.

Doyle, A. D., Moore, K. J., and Herridge, D. F. 1988. The narrow-leafed lupin (*Lupinus angustifolius* L.) as a nitrogen-fixing rotation crop for cereal production. III. Residual effects of lupins on subsequent cereal crops. Aust. J. Agric. Res. 39: 1029-37.

Dubetz, S., Gardiner, E. E., Flynn, D., and de la Roche, A. I. 1979. Effect of nitrogen fertilizer on nitrogen fractions and amino acid composition of spring wheat. Can. J. Plant Sci. 59: 299-305.

El-Haris, M. K., Cochran, V. L., Elliott, L. F., and Bezdicek, D. F. 1983. Effect of tillage, cropping, and fertilizer management on soil nitrogen mineralization potential. Soil Sci. Soc. Am. J. 47: 1157-1161.

Elliott, L. F., Papendick, R. I., and Bezdicek, D. F. 1987. Cropping practices using legumes with conservation tillage and soil benefits. p. 81-89. In: Soil Conservation Society of America. Power, J. F. (ed.). Madison, WI, USA.

Entz, M. H., and Fowler, D. B. 1988. Critical stress periods affecting productivity of no-till winter wheat in western Canada. Agron. J. 80: 987-992.

Entz, M. H., and Fowler, D. B. 1989. Response of winter wheat to N and water: growth, water use, and grain protein. Can. J Plant Sci. 69: 1135-1147.

Evans, J., Fettell, N. A., Coventry, D. R., O'Connor, G. E., Walsgott, D. N., Mahoney, J., and Armstrong, E. L. 1991. Wheat response after temperate crop legumes in south-eastern Australia. Aust. J. Agric. Res. 42: 31-43.

Evans, J., O'Connor, G. E., Turner, G. L., Coventry, D. R., Fettell, N., Mahoney, J., Armstrong, E. L., and Walsgott, D. N. 1989. N_2 fixation and its value to soil N increase in lupin, field pea and other legumes in south-eastern Australia. Aust. J. Agric. Res. 40: 791-805.

Felton, W. L., Marcellos, H., Alston, C., Martin, R. J., Backhouse, D., Burgess, L. W., and Herridge, D. F. 1998. Chickpea in wheat-based cropping systems of northern New South Wales II. Influence on biomass, grain yield, and crown rot in the following wheat crop. Aust. J. Agric. Res. 49: 401-407.

Fenn, L. B., and L. R. Hossner. 1985. Ammonia volatilization from ammonium or ammonium-forming nitrogen fertilizers. Adv. Soil. Sci. 1: 123-169.

Fido, R. J., Békés, F., Gras, P. W., and Tatham, A. S. 1997. Effects of α-, β-, γ-, and ω-gliadins on the dough mixing properties of wheat flour. J. Cer. Sci. 26: 271-277.

Finney, K. F. 1945. Methods of estimating and the effect of variety and protein level on the baking absorption of flour. Cereal Chem. 22: 149-160.

Finney, K. F., and Barmore, M. A. 1948. Loaf volume and protein content of hard winter and spring wheats. Cereal Chem. 25: 291-312.

Firestone, M. K. 1982. Biological denitrification. p. 289-326. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI, USA.

Flaten, B., and Greer, K. 1998. Nitrogen supplying power of canola versus pea stubble under zero and conventional tillage systems. p. 327-330. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Flaten, G., Przednowek, D., and Flaten, D. 2000. Protein profits in the market place – watch for the signals. p. 217-235. In: Proc. Saskatchewan Soils and Crops Workshop. February 24-25, 2000. University of Saskatchewan, Saskatoon, SK.

Fowler, D. B., and Brydon, J. 1989. No-till winter wheat production on the Canadian Prairies: placement of urea and ammonium nitrate fertilizers. Agron. J. 81: 518-524.

Fowler, D. B., Brydon, J., Darroch, B. A., Entz, M. H., and Johnston, A. M. 1990. Environment and genotype influence on grain protein concentration of wheat and rye. Agron. J. 82: 655-664.

Fowler, D. B., Kovacs, M. I. P., Sarkar, A., and Dahlke, G. 1998. Influence of genotype and environment on wheat quality. p. 275-277. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Fox, R. H., Myers, R. J. K., and Vallis, I. 1990. The nitrogen mineralization rate of legume residues in soil as influenced by their polyphenol, lignin, and nitrogen contents. Plant Soil 129: 251-259.

Francis, G. S., Haynes, R. J., and Williams, P. H. 1994. Nitrogen mineralization, nitrate leaching and crop growth after ploughing-in leguminous and non-leguminous grain crop residues. J. Agric. Sci. Camb. 123: 81-87.

Frank, A. B., Bauer, A., and Black, A. L. 1989. Carbohydrate, nitrogen, and phosphorous concentrations of spring wheat leaves and stems. Agron. J. 81: 524-528.

Fu, B. X., Kovacs, M. I. P., and Wang, C. 1998. Progress in screening for wheat protein quality. p. 214-218. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Fu, G., Walley, F., and van Kessel, C. 1998. Does crop residue N influence soil N availability? p. 100-105. In: Proc. Saskatchewan Soils and Crops Workshop. February 19-20, 1998. University of Saskatchewan, Saskatoon, SK.

Fullington, J. G., Miskelly, D. M., Wrigley, C. W., and Kasarda, D. D. 1987. Quality-related endosperm proteins in the developing wheat seed. J. Cer. Sci. 5: 233-245.

Gauer, L. E., Grant, C. A., Gehl, D. T., and Bailey, L. D. 1992. Effects of nitrogen fertilization on grain protein content, nitrogen uptake, and nitrogen use efficiency of six spring wheat (*Triticum aestivum L.*) cultivars, in relation to estimated moisture supply. Can. J. Plant Sci. 72: 235-241.

Gianibelli, M. C., Larroque, O. R., MacRitchie, F., and Wrigley, C. W. 2001. Biochemical, genetic, and molecular characterization of wheat glutenin and its component subunits. Cereal Chem. 78: 635-646.

Goos, R. J., Schimelfenig, J. A., Bock, B. R., and Johnson, B. E. 1999. Response of spring wheat to nitrogen fertilizers of different nitrification rates. Agron. J. 91: 287-293.

Grant, C. A., and Flaten, D. N. 1998. Fertilizing for protein content in wheat. p. 151-168. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Grant, C. A., Gauer, L. E., Gehl, D. T., and Baliey, L. D. 1991. Protein production and nitrogen utilization by barley cultivars in response to nitrogen fertilizer under varying moisture conditions. Can. J. Plant Sci. 71: 997-1009.

Grant, C. A., S. Jia, K. R. Brown, and L. D. Bailey. 1996. Volatile losses of NH_3 from surface-applied urea and urea ammonium nitrate with and without the urease inhibitors NBPT or ammonium thiosulphate. Can. J. Soil Sci. 76: 417-419.

Grant, C. A., Peterson, G. A., and Campell, C. A. 2002. Nutrient considerations for diversified cropping systems in the Northern Great Plains. Agron. J. 94: 186-198.

Graybosch, R. A., Peterson, C. J., Baenziger, P. S., and Shelton, D. R. 1995. Environmental modification of hard red winter wheat flour protein composition. J. Cer. Sci. 22: 45-51.

Graybosch, R. A., Peterson, C. J., Shelton, D. R., and Baenziger, P. S. 1996. Genotypic and environmental modification of wheat protein composition in relation to end-use quality. Crop Sci. 36: 296-300.

Grenier, M. R. 1992. Effect of annual legumes on the nitrogen status of soils. M. Sc. Thesis. University of Manitoba.

Gupta, R. B., Batey, I. L., and MacRitchie, F. 1992. Relationships between protein composition and functional properties of wheat flours. Cereal Chem. 69: 125-131.

Gupta, R. B., Khan, K., and MacRitchie, F. 1993. Biochemical basis of flour properties in bread wheats. I. Effects of variation in the quantity and size distribution of polymeric protein. J. Cer. Sci. 18: 23-41.

Gupta, R. B., and MacRitchie, F. 1991. Relative contribution of the LMW and HMW glutenin subunits to dough strength and dough stickiness of bread wheat. p. 71-80. In: Gluten Proteins 1990. Bushuk, W., and Tkachuk, R. eds. American Association of Cereal Chemists, St. Paul, MN.

Gupta, R. B., Masci, S., Lafiandra, D., Bariana, H. S., and MacRitchie, F. 1996. Accumulation of protein subunits and their polymers in developing grains of hexaploid wheats. J. Exp. Bot. 47: 1377-1385.

Haderlein, L., Jensen, T. L., Dowbenko, R. E., and Blaylock, A. D. 2001. Controlled release urea as a nitrogen source for spring wheat in western Canada: yield, grain N content, and N use efficiency. In: Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International itrogen Conference on Science and Policy. TheScientificWorld 1.

Hamada, A. S., McDonald, C. E., and Sibbitt, L. D. 1982. Relationship of protein fractions of spring wheat flour to baking quality. Cereal Chem. 59: 296-301.

Harapiak, J. T., Kucey, R. M. N., and Flaten, D. 1987. Nitrogen sources and placement in wheat production. p. 87-135. In: Wheat Production in Canada. Proceedings of the Canadian Wheat Production Symposium. Slinkard, A. E., and Fowler, D. B. eds. Crop Development Centre, University of Saskatchewan, Saskatoon, SK.

Harapiak, J. T., Malhi, S. S., Campbell, C. A., and Nyborg, M. 1993. Fertilizer N application practices. p. 251-313. In: A Review of the Impact of Macronutrients on Crop Responses and Environmental Sustainability on the Canadian Prairies. Rennie, D. A., Campbell, C. A., and Roberts, T. L. eds. Canadian Society of Soil Science.

Harper, L. A., Sharpe, R. R., Langdale, G. W., and Giddens, J. E. 1987. Nitrogen cycling in a wheat crop: soil, plant, and aerial nitrogen transport. Agron. J. 79: 965-973.
Hauck, R. D. 1985. Slow-release and bioinhibitor-amended nitrogen fertilizers. p. 293-322. In: Fertilizer Technology and Use 3rd ed. Engelstad, O. P. et al. eds. SSSA, Madison, WI USA.

Hedlin, R. A., Smith, R. E., and Leclaire, F. P. 1957. Effect of crop residues and fertilizer treatments on the yield and protein content of wheat. Can. J. Soil Sci. 37: 34-40.

Heenan, D. P., McGhie, W. J., and Collins, D. 1998. Impact of lupins, grazed or ungrazed subterranean clover, stubble retention, and lime on soil nitrogen supply and wheat nitrogen uptake, grain yields, and grain protein. Aust. J. Agric. Res. 49: 487-494.

Henry, J. L., Bole, J. B., McKenzie, R. C. 1987. Effect of nitrogen water interactions on yield and quality of wheat n western Canada. p. 165-191. In: Wheat Production in Canada. Proceedings of the Canadian Wheat Production Symposium. Slinkard, A. E., and Fowler, D. B. eds. Crop Development Centre, University of Saskatchewan, Saskatoon, SK.

Hogg, T. J., and Brown, S. 1997. Late nitrogen application to improve grain protein of irrigated Sceptre durum wheat. p. 265-273. In: Proc. Saskatchewan Soils and Crops Workshop. February 20-21, 1997. University of Saskatchewan, Saskatoon, SK.

Holford, I. C. R., and Crocker, G. J. 1997. A comparison of chickpeas and nitrogen status of subsequent wheat. Aust. J. Agric. Res. 48: 305-315.

Hoseney, R. C. 1988. Gluten proteins. p. 197-211. In: Principles of Cereal Science and Technology 2nd ed. Hoseney, R. C. ed. American Association of Cereal Chemists. St. Paul, MN.

Huang, D. Y., and Khan, K. 1997. Quantitative determination of high molecular weight glutenin subunits of hard red spring wheat by SDS-PAGE. I. Quantitative effects of total amounts on breadmaking quality characteristics. Cereal Chem. 74: 781-785.

Hucklesby, D. P., Brown, C. M., Howell, S. E., and Hageman, R. H. 1971. Late spring applications of nitrogen for efficient utilization and enhanced production of grain and grain protein of wheat. Agron. J. 63: 274-276.

Huebner, F. R., and Bietz, J. A. 1988. Quantitative variation among gliadins of wheats grown in different environments. Cereal Chem. 65: 362-366.

Huebner, F. R., Kaczkowski, J., and Bietz, J. A. 1990. Quantitative variation of wheat proteins from grain at different stages of maturity and from different spike locations. Cereal Chem. 67: 464-470.

Huebner, F. R., Nelsen, T. C., Chung, O. K., and Bietz, J. A. 1997. Protein distributions among hard red winter wheat varieties as related to environment and baking quality. Cereal Chem. 74: 123-128.

Huebner, F. R., and Wall, J. S. 1976. Fractionation and quantitative differences of glutenin from wheat varieties varying in baking quality. Cereal Chem. 53: 258-269.

Hussain, A., and Lukow, O. 1995. Transient changes in wheat endosperm polymeric proteins during the later stages of grain development. Can. J. Plant Sci. 75: 195-198.

Hutcheon, W. L., and Paul, E. A. 1966. Control of the protein content of Thatcher wheat by nitrogen fertilization and moisture stress. Can. J. Plant Sci. 46: 101-108.

Jamieson, P. D., Stone, P. J., and Semenov, M. A. 2001. Towards modeling quality in wheat – from grain nitrogen concentration to protein composition. Asp. Appl. Biol. 64: 111-126.

Janssen, A. M., Vereijken, J. M., Beintema, J. J., and Witholt, B. 1991. Rheological studies on gluten. p. 180-186. In: Gluten Proteins 1990. Bushuk, W., and Tkachuk, R. eds. American Association of Cereal Chemists, St. Paul, MN.

Jansson, S. L., and Persson, J. 1982. Mineralization and immobilization of soil nitrogen. p. 229-252. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI., USA.

Janzen, H. H., Bole, J. B., Biederbeck, V. O., and Slinkard, A. E. 1990. Fate of N applied as green manure or ammonium fertilizer to soil subsequently cropped with spring wheat at three sites in western Canada. Can. J. Soil Sci. 70: 313-323.

Janzen, H. H., and Kucey, R. M. N. 1988. C, N, and S mineralization of crop residues as influenced by crop species and nutrient regime. Plant Soil 106: 35-41.

Jenner, C. F. 1994. Starch synthesis in the kernel of wheat under high temperature conditions. Aust. J. Plant Physiol. 21: 791-806.

Jensen, E. S. 1993. Availability of nitrogen in 15N-labelled mature pea residues to subsequent crops in the field. Soil Biol. Biochem. 4: 465-472.

Jensen, E. S. 1996. Rhizodeposition of N by pea and barley and its effect on soil N dynamics. Soil Biol. Biochem. 28: 65-71.

Jia, Y. Q., Fabre, J. L., and Aussenac, T. 1996b. Effects of growing location on response of protein polymerization to increased nitrogen fertilization for the common wheat cultivar Soissons: Relationship with some aspects of the breadmaking quality. Cereal Chem. 73: 526-532.

Jia, Y. Q., Masbou, V., Aussenac, T., Fabre, J. L., and Debaeke, P. 1996b. Effects of nitrogen fertilization and maturation conditions on protein aggregates and on the breadmaking quality of Soissons, a common wheat cultivar. Cereal Chem. 73: 123-130.

Johansson, E. 2000. Environmental effects on wheat proteins. p. 480-483. In: Wheat Gluten. Shewry, P. R.., and Tatham, A. S. eds. Royal Society of Chemistry, Cambridge, UK.

Johansson, E., Oscarson, P., Heneen, W. K., and Lundborg, T. 1994. Differences in accumulation of storage proteins between wheat cultivars during development. J. Sci. Food Agric. 64: 305-313.

Johansson, E., Prieto-Linde, M. L., and Jönsson, J. Ö. 2001. Effects of wheat cultivar and nitrogen application on storage protein composition and breadmaking quality. Cereal Chem. 78: 19-25.

Johnston, A., Entz, M., Brandt, S., Lafond, G., and Campbell, C. 1996. Management of water use by crops in crop rotations on the Canadian Prairies. p. 384-393. In: Proc. Saskatchewan Soils and Crops Workshop. February 22-23, 1996. University of Saskatchewan, Saskatoon, SK.

Johnston, A. M., and Fowler, D. B. 1991a. No-till winter wheat dry matter and tissue nitrogen response to nitrogen fertilizer form and placement. Agron. J. 83: 1035-1043.

Johnston, A. M., and Fowler, D. B. 1991b. No-till winter wheat dry matter and tissue N response to nitrogen fertilizer form and placement. Agron. J. 83: 1035-1043.

Jowkin, V., and Schoenau, J. J. 1995. Changes in available nitrogen over a fallow season in an undulating landscape in southwestern Saskatchewan. p. 299-309. In: Proc. Saskatchewan Soils and Crops Workshop. February 23-24, 1995. University of Saskatchewan, Saskatoon, SK.

Jung, J., Dressel, J., and Kuchenbuch, R. 1989. Nitrogen balance of legume-wheat cropping sequences. J. Agron. Crop Sci. 162: 1-9.

Kaczkowski, J., Kos, S., and Piór, H. 1988. The level changes of nitrogen containing fractions during the development of wheat (*Triticum aestivum*) grains. Acta. Physiol. Planta. 10: 31-40.

Kaczkowski, J., Piór, H., Kwinta, J., Kos, S., and Bushuk, W. 1987. Some analytical data of protein behaviour in developing wheat kernel. p. 400-416. In: Proceedings of the 3rd International Workshop on Gluten Proteins. Lasztity, R., and Bekes, F. eds. May 9-12. 1987. Budapest, Hungary. World Scientific, Singapore.

Karlen, D. L., and Whitney, D. A. 1980. Dry matter accumulation, mineral concentrations, and nutrient distribution in winter wheat. Agron. J. 72: 281-288.

Kasarda, D. D. 1989. Glutenin structure in relation to wheat quality. p. 277-302. In: Wheat Is Unique: Structure, Composition, Processing, End-Use Properties, and Products. Pomeranz, Y. ed. American Association of Cereal Chemists, St. Paul, MN.

Kettlewell, P. S., Griffiths, M. W., Hocking, T. J, and Wallington, D. J. 1998. Dependence of wheat dough extensibility on flour sulfhur and nitrogen concentrations and the influence of foliar-applied sulphur and nitrogen fertilizers. J. Cer. Sci. 28: 15-23.

Khan, K., and Bushuk, W. 1976. Studies of glutenin. VII. Subunit composition at different stages of grain maturity. Cereal Chem: 53: 566-573.

Khatkar, B. S., Bell, A. E., and Schofield, J. D. 1995. The dynamic rheological properties of glutens and gluten sub-fractions from wheats of good and poor bread making quality. J. Cer. Sci. 22: 29-44.

Kissel, D. E., and M. L. Cabrera. 1988. Factors affecting urea hydrolysis. p. 53-66. In: Ammonia Volatilization from Urea Fertilizers. Bock, B. R., and Kissel, D. E. eds. National Fertilizer Development Center, Muscle Shoals, Alabama.

Knott, D. R. 1974. Effects of nitrogen on the protein content of barley. Can. J. Plant Sci. 55: 873-879.

Koelliker, J. K., and Kissel, D. E. 1988. Chemical equilibria affecting ammonia volatilization. p. 37-52. In: Ammonia Volatilization from Urea Fertilizers. Bock, B. R., and Kissel, D. E. eds. National Fertilizer Development Center, Muscle Shoals, Alabama.

Kolster, P., Krechting, K. F., and van Gelder, M. J. 1991. Quantitative variation of total and individual high molecular weight glutenin subunits of wheat in relation to variation in environmental conditions. J. Sci. Food Agriv. 57: 405-415.

Kosmolak, F. G., and Crowle, L. 1980. An effect of nitrogen fertilization on the agronomic traits and dough mixing strength of five Canadian hard red spring wheat cultivars. Can. J. Plant Sci. 60: 1071-1076.

Ladd, J. N., and Amato, M. 1986. The fate of nitrogen from legume and fertilizer sources in soils successively cropped with wheat under field conditions. Soil Biol. Biochem. 4: 417-425.

Ladd, J. N., Amato, M., Jackson, R. B., and Butler, J. H. A. 1983. Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. Soil Biol. Biochem. 3: 231-238.

Ladd, J. N., Oades, J. M., and Amato, M. 1981. Distribution and recovery of nitrogen from legume residues decomposing in soils sown to wheat in the field. Soil. Biol. Biochem. 13: 251-256.

Lafond, G. P., Loeppky, H., and Derksen, D. A. 1002. The effects of tillage systems and crop rotations on soil water conservation, seedling establishment and crop yield. Can. J. Plant Sci. 72: 103-115.

Leco Corporation. 1996. Leco CNS 2000 Elemental Analyzer Instruction Manual. Version. 4.0.

Levy, A. A., Galili, G., and Feldman, M. 1985. The effect of additions of *Aegilops longissima* chromosomes on grain protein in common wheat. Theor. Appl. Genet. 69: 429-435.

Lew, E. J. L., Kuzmicky, D. D., and Kasarda, D. D. 1992. Characterization of low molecular weight glutenin subunits by reversed-phase high-performance liquid chromatography, sodium dodecyl sulfate-polyacrylamide gel electrophoresis, and N-terminal amino acid sequencing. Cereal Chem. 69: 508-515.

Lloveras, J., Lopez, A, Ferran, J., Espachs, S., and Solsona, J. 2001. Bread-making wheat and soil nitrate as affected by nitrogen fertilization in irrigated Mediterranean conditions. Agron. J. 93: 1183-1190.

Lohnis, F. 1926. *Reported in* Jansson, S. L., and Persson, J. 1982. Mineralization and immobilization of soil nitrogen. p. 229-252. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI., USA.

Lotfollahi, M., Alston, A. M., and McDonald, K. G. 1997. Effect of nitrogen fertilizer placement on grain protein concentration of wheat under different water regimes. Aust. J. Agric. Res. 48: 241-250.

Lukow, O. M., and McVetty, P. B. E. 1991. Effect of cultivar and environment on quality characteristics of spring wheat. Cereal Chem. 68: 597-601.

Lukow, O. M., Payne, P. I., and Tkachuk, R. 1989. The HMW glutenin subunit composition of Canadian wheat cultivars and their association with bread-making quality. J. Sci. Food Agric. 41: 451-460.

Lukow, O. M., and Preston, K. R. 1998. Effects of protein content on wheat quality. p. 48-52. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Luo, C., Branlard, G., Griffin, W. B., and McNeil, D. L. 2000. The effect of nitrogen and sulphur fertilization and their interaction with genitype on wheat glutenins and quality parameters. J. Cer. Sci. 31: 185-194.

MacRitchie, F. 1987. Evaluation of contributions from wheat protein fractions to dough mixing and breadmaking. J. Cer. Sci. 6: 259-268.

MacRitchie, F. 1992. Physiochemical properties of wheat proteins in relation to functionality. Adv. Food Nutrition Res. 36: 1-87.

MacRitchie, F., and Gupta, R. B. 1993. Functionality-composition relationships of wheat flour as a result of variation in sulfur availability. Ayst. J. Agric. Res. 44: 1767-1774.

MacRitchie, F., du Cros, D. L., and Wrigley, C. W. 1990. Flour polypeptides related to wheat quality. p. 79-145. In: Advances in Cereal Science and Technology Vol. 10. Pomeranz, Y. ed. American Association of Cereal Chemists, St. Paul, MN.

MacRitchie, F., Kasarda, D. D., and Kuzmicky, D. D. 1991. Characterization of wheat protein fractions differing in contributions to breadmaking quality. Cereal Chem. 68: 122-130.

Malhi, S. S., M. Nyborg, and E. D. Solberg. 1996. Influence of source, method of placement, and simulated rainfall on the recovery of ^{15}N-labelled fertilizers under zero tillage. Can. J. Soil Sci. 76: 93-100.

Manitoba Agriculture and Food. 2001. Soil Fertility Guide.

Marcellos, H. 1984. Influence of prior crops of chickpeas, fababeans and lupins on wheat. Technical notes. J. Aust. Inst. Agric. Sci. 50: 111-113.

Marchylo, B. A., Kruger, J. E., and Hatcher, D. W. 1990. Effect of environment on wheat storage proteins as determined by quantitative reversed-phase high-performance liquid chromatography. Cereal Chem. 67: 372-376.

Martin, R. J., Sutton, K. H., Moyle, T. N., Hay, R. L., and Gillespie. 1992. Effect of nitrogen fertiliser on the yield and quality of six cultivars of autumn-sown wheat. N. Z. J. Crop. Hortic. Sci. 20: 273-282.

Matus, A., Hnatowich, G., Walley, F.; van Kessel, C., and Knight, J. D. 1999. Nitrogen-15 recovery by spring wheat as influenced by landscape position and nitrogen fertilizer sources. p. 287-293. In: Proc. Saskatchewan Soils and Crops Workshop. February 25-26, 1999. University of Saskatchewan, Saskatoon, SK.

Matus, A., Hnatowich, G. L., and van Kessel, C. 1996. Effects of different nitrogen fertilizer sources, placements, and rates on agronomic traits of barley grown at the landscape scale. p. 431-440. In: Proc. Saskatchewan Soils and Crops Workshop. February 22-23, 1996. University of Saskatchewan, Saskatoon, SK.

McDonald, G. K. 1989. The contribution of nitrogen fertiliser to the nitrogen nutrition of rainfed wheat crops in Australia: a review. Aust. J. Exp. Agric. 29: 455-481.

McGill, W. B. 1967. Nitrogen supplying power of soils. p. 131-141. In: Proc. Manitoba Society of Soil Science Meeting. Dec 6-7, 1967. Winnipeg, MB.

McGill, W. B. 1969. A study of the quantity of nitrogen mineralized during the growing season, its effect on crop growth, and factors affecting the nitrogen mineralization-immobilization relationship. M. Sc. Thesis. University of Manitoba.

McKeague, J. A. 1976. Manual on Soil Sampling and Methods of Analysis. Prepared by Subcommittee of Canada Soil Survey Committee on Methods of Analysis. Soil Research Institute.

McNeal, F. H., Boatwright, G. O., Berg, M. A., and Watson, C. A. 1968. Nitrogen in plant parts of seven spring wheat varieties at successive stages of development. Crop Sci. 8: 535-537.

Mecham, D. K., Fullington, J. G., and Greene, F. C. 1981. Gliadin proteins in the developing wheat seed. J. Sci. Food Agric. 32: 773-780.

Miceli, F., Martin, M., and Zerbi, G. 1992. Yield, quality, and nitrogen efficiency in winter wheat fertilized with increasing N levels at different times. J. Agron. Crop Sci. 168: 337-344.

Miller, P. R., McConkey, B. G., Clayton, G. W., Brandt, S. A., Staricka, J. A., Johnston, A. M., Lafond, G. P., Schatz, B. G., Baltensperger, D. D., and Neill, K. E. 2002a. Pulse crop adaptation in the Northern Great Plains. Agron. J. 94: 261-272.

Miller, P. Ulrich, D., Entz, M., McConkey, B., Brandt, S., Cutforth, H., and Volkmar, K. 1998a. Peas are drought tolerant! p. 57-65. In: Proc. Saskatchewan Soils and Crops Workshop. February 19-20, 1998. University of Saskatchewan, Saskatoon, SK.

Miller, P. R., Waddington, J., McDonald, C. L., and Derksen, D. A. 2002b. Cropping sequence affects wheat productivity on the semiarid northern Great Plains. Can. J. Plant Sci. 82: 307-318.

Miller, P., Zentner, R., McConkey, B., Campbell, C., Derksen, D., McDonald, C., and Waddington, J. 1998b. Using pulse crops to boost wheat protein in the Brown soil zone. p. 313-316. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Miller, R. O., Jacobsen, J. S., and Skogley, E. O. 1994. Aerial accumulation and partitioning of nutrients by hard red spring wheat. Commun. Soil Sci. Plant Anal. 25: 1891-1911.

Mooleki, S. P., Slinkard, A. E., and van Kessel, C. 1997. Temporal variability of N to wheat in a lentil-wheat rotation. p. 234-241. In: Proc. Saskatchewan Soils and Crops Workshop. February 20-21, 1997. University of Saskatchewan, Saskatoon, SK.

Morris, C. F., and Paulsen, G. M. 1985. Development of hard winter wheat after anthesis as affected by nitrogen nutrition. Crop Sci. 25: 1007-1010.

Moss, H. J., Wrigley, C. W., MacRitchie, F., and Randall, P. J. 1981. Sulfur and nitrogen fertilizer effects on wheat. II. Influence on grain quality. Aust. J. Agric. Res. 32: 203-216.

Muller, M. M., and Sundman, V. 1988. The fate of nitrogen (^{15}N) released from different plant materials during decomposition under field conditions. Plant Soil 105: 133-139.

Nair, M. S., Abrol, Y. P., Nair, T. V. R., and Ramarao, C. S. 1982. Nitrate assimilation – its regulation and relationship to reduced nitrogen in higher plants. Phytochemistry 3: 495-504.

Nelson, D. W. 1982. Gaseous losses of nitrogen other than through denitrification. p. 327-363. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI., USA.

Nommik, H., and Vahtras K. 1982. Retention and fixation of ammonium and ammonia in soils. p. 123-171. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI., USA.

Nuttall, W. F., Zandstra, H. G., and Bowren, K. E. 1979. Yield and N percentage of spring wheat as affected by phosphate fertilizer, moisture use, and available soil P and N. Agron. J. 71: 385-391.

Nyborg, M., Solberg, E. D., and Zhang. M. 1993. *Reported in* Haderlein, L., Jensen, T. L., Dowbenko, R. E., and Blaylock, A. D. 2001. Controlled release urea as a nitrogen source for spring wheat in western Canada: yield, grain N content, and N use efficiency. In: Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International itrogen Conference on Science and Policy. TheScientificWorld 1.

Olson, R. A. 1984. Nitrogen use in dryland farming under semiarid conditions. p. 335-347. In: Nitrogen in Crop Production. Hauck, R. D. et al. eds. ASA-CSSA-SSSA, Madison, WI., USA.

Olson, R. A., Frank, K. D., Deibert, E. J., Dieier, A. F., Sander, D. H., and Johnson, V. A. 1976. Impact of residual mineral N in soil on grain protein yields of winter wheat and corn. Agron. J. 68: 769-772.

Olson, R. A., and Kurtz, L. T. 1982. Crop nitrogen requirements, utilization, and fertilization. p. 567-604. Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI., USA.

Olu Obi, A., Hedlin, R. A., and Cho, C. M. 1986. Crop utilization and soil retention of nitrogen from ^{15}N-labelled urea, calcium nitrate, and ammonium sulphate in several Manitoba soils. Can. J. Soil Sci. 66: 661-671.

Orth, R. A., and Bushuk, W. 1972. A comparative study of the proteins of wheats of diverse baking qualities. Cereal Chem. 49: 268-275.

Palta, J. A., Kobata, T., Turner, N. C., and Fillery, I. R. P. 1994. Remobilization of carbon and nitrogen in wheat as influenced by post-anthesis water deficits. Crop Sci. 34: 118-124.

Panozzo, J. F., and Eagles, H. A. 1998. Cultivar and environmental effects on quality characters in wheat. I. Starch. Aust. J. Agric. Res. 49: 757-766.

Panozzo, J. F., and Eagles, H. A. 1999. Rate and duration off grain filling and grain nitrogen accumulation of wheat cultivars grown in different environments. Aust. J. Ag. Res. 50: 1007-1015.

Panozzo, J. F., and Eagles, H. A. 2000. Cultivar and environmental effects on quality characters in wheat. II. Protein. Aust. J. Agric. Res. 51: 629-636.

Panozzo, J. F., Eagles, H. A., and Wootton, M. 2001. Changes in protein composition during grain development in wheat. Aust. J. Agric. Res. 52: 485-493.

Parades-López, O., Covarrubias-Alvarez, M., and Barquín-Carmona, J. 1985. Influence of nitrogen fertilization on the physiochemical and functional properties of bread wheats. Cereal Chem. 62: 427-430.

Payne, P. I., Nightingale, M. A., Krattiger, A. F., and Holt, L. M. 1987. The relationship between HMW glutenin subunit composition and the bread-making quality of British-grown wheat varieties. J. Sci. Food Agric. 40: 51-65.

Pechanek, U., Karger, A., Gröger, S., Charvat, B., Schöggl, G., and Lelley, T. 1997. Effect of nitrogen fertilization on the quantity of flour protein components, dough properties, and breadmaking quality of wheat. Cereal Chem. 74: 800-805.

Peltonen, J. 1992. Ear development stage used for timing supplemental nitrogen application to spring wheat. Crop Sci. 32: 1029-1033.

Peltonen, J., and Sontag-Strohm, T. 1992. Genotypic differences of storage proteins in four Scandinavian spring wheat cultivars during seed development. Agric. Sci. Finl. 1: 499-507.

Peltonen, J., and Virtanen, A. 1994. Effect of nitrogen fertilizers differing in release characteristics on the quantity of storage proteins in wheat. Cereal Chem. 71: 1-5.

Peoples, M. B., Beilharz, V. C., Waters, S. P., Simpson, R. J., and Dalling, M. J. 1980. Nitrogen redistribution during grain growth in wheat (*Triticum aestivum* L.) II. Chroloplast senescence and the degradation of Ribulose-1,5-bisphosphate carboxylase. Planta 149: 241-251.

Peoples, M. B., Herridge, D. F., and Ladha, J. K. 1995. Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production? Plant Soil 174: 3-28.

Perrotta, C., Treglia, A. S., Mita, G., Giangrande, E., Rampino, P., Ronga, G., Spano, G., and Marmiroli, N. 1998. Analysis of mRNAs from ripening wheat seeds: the effect of high temperature. J. Cer. Sci. 27: 127-132.

Peterson, C. J., Johnson, V. A., and Mattern, P. J. 1986. Influence of cultivar and environment on mineral and protein concentrations of wheat flour, bran, and grain. Cereal Chem. 63: 183-186.

Preston, K. R., Hucl, P., Townley-Smith, T. F., Dexter, J. E., Williams, P. C., and Stevenson, S. G. 2002. Effects of cultivar and environment on farinograph and Canadian short process mixing properties of Canada western red spring wheat. Can. J. Plant Sci. 81: 391-398.

Preston, K. R., Kilborn R. H., and Black, H. C. 1982. The GRL pilot mill. II. Physical dough and baking properties of flour streams milled from Canadian red spring wheats. Can. Inst. of Food Sci. Technol. J. 15 (1).

Preston, K. R.., Kilborn, R. H., Morgan, B. C., and Babb, J. C. 1991. Effects of frost and immaturity on the quality of Canadian hard red spring wheat. Cereal Chem. 68: 133-138.

Preston, K. R., and Tipples, K. H. 1980. Effects of acid-soluble and acid-insoluble gluten proteins on the rheological and baking properties of wheat flours. Cereal Chem. 57: 314-320.

Raczkowski, C. W., and D. E. Kissel. 1989. Fate of subsurface-banded and broadcast nitrogen applied to tall fescue. Soil Sci. Soc. Am. J. 53: 566-570.

Randall, P. J., and Moss, H. J. 1990. Some effects of temperature regime during grain filling on wheat quality. Aust. J. Agric. Res. 41: 603-617.

Randall, P. J., and Wrigley, C. W. 1986. Effects of sulfur supply on the yield, composition, and quality of grain from cereals, oilseeds, and legumes. p. 171-206. In: Advances in Cereal Science and Technology Vol. 8. Pomeranz, Y. ed. American Association of Cereal Chemists, St. Paul, MN.

Rees, R. M., Yan, L., and Ferguson, M. 1993. The release and plant uptake of nitrogen from some plant and animal manures. Biol. Fertil. Soils 15: 285-293.

Reeves, T. G., Ellington, A., and Brooke, H. D. 1984. Effects of lupin-wheat rotations on soil fertility, crop disease and crop yields. Aust. J. Exp. Agric. Anim. Husb. 24: 595-600.

Rhoads, F. M. 1984. Nitrogen or water stress: their interrelationships. p. 307-317. In: Nitrogen in Crop Production. Hauck, R. D. et al. eds. ASA-CSSA-SSSA, Madison, WI., USA.

Rousset, M., Triboi, E., Branlard, G., and Godon, B. 1985. Influence du génotype et du milieu sur les tests d'appréciation de la valeur d'utilisation du blé tendre (*Triticum aestivum* em. Thell.) dans les industries de cuisson. Agronomie 5: 653-663.

Rowland, I. C., Mason, M. G., and Hamblin, J. 1988. Effect of lupins and wheat on the yield and subsequent wheat crops grown at several rates of applied nitrogen. Aust. J. Exp. Agric. 28: 91-97.

Salisbury, F. B., and Ross, C. W. 1992. Plant Physiology 4th ed. Wadsworth Publishing Company, Belmont, CA. 682 pp.

Sanford, J. O., and Hairston, J. E. 1984. Effects of N fertilization on yield, growth, and extraction of water by wheat following soybeans and grain sorghum. Agron. J. 76: 623-627.

Sapirstein, H. D., and Fu, B. X. 1998. Intercultivar variation in the quantity of monomeric protein, soluble and insoluble glutenin and residue protein in wheat flour and relationships to breadmaking quality. Cereal Chem. 75: 500-507.

Sapirstein, H. D., and Fu, B. X. 2000. Evidence for varying interaction of gliadin and glutenin proteins as an explanation for differences in dough strength of different wheats. p. 425-429. In: Wheat Gluten. Shewry, P. R.. and Tatham, A. S. eds. Royal Society of Chemistry, Cambridge, UK.

Sapirstein, H. D., and Johnson, W. J. 2001. A rapid spectophotometric method for measuring insoluble glutenin content of flour and semolina for wheat quality screening. p. 307-312. In: Wheat Gluten. Shewry, P. R.. and Tatham, A. S. eds. Royal Society of Chemistry, Cambridge, UK.

SAS Institute Inc. 2001. SAS User's Guide: Statistics, Version 8.1, SAS Institute, Inc., Cary, NC.

Scanlon, M. G., Ng, P. K. W., Lawless, D. E., and Bushuk, W. 1990. Suitability of reversed-phase high-performance liquid chromatographic separation of wheat proteins for long-term statistical assessment of breadmaking quality. Cereal Chem. 67: 395-399.

Schoenau, J. J. 1995. Understanding the role of mineralization in supply of plant available N. p. 166-172. In: Proc. Saskatchewan Soils and Crops Workshop. February 23-24, 1995. University of Saskatchewan, Saskatoon, SK.

Schofield, J. D. 1986. Flour proteins: structure and functionality in baked products. p. 14-29. In: Chemistry and Physics of Baking: Materials, Processes, and Products. Blanshard, J. M. V., Frazier, P. J., and Galliard, T. eds. Royal Society of Chemistry.

Schofield, J. D. 1994. Wheat proteins: structure and functionality in milling and breadmaking. p. 73-106. In: Wheat: Production, Properties and Quality. Bushuk, W. and Rasper, J. D. eds. Chapman and Hall, London.

Selles, F., and Zentner, R. P. 1998. Environmental factors affecting wheat protein. p. 139-150. In: Wheat Protein Production and Marketing. Proceedings of the Wheat Protein Symposium. Fowler, D. B. et al. eds. University Extension Press, University of Saskatchewan, Saskatoon, SK.

Selles, F., Zentner, R. P., Campbell, C. A., and James, D. C. 1997. Split nitrogen applications for management of yield and protein of wheat grown in dryland conditions. p. 274-283. In: Proc. Saskatchewan Soils and Crops Workshop. February 20-21, 1997. University of Saskatchewan, Saskatoon, SK.

Senaratne, R., and Hardarson, G. 1988. Estimation of the residual N effect of faba bean and pea on two succeeding cereals using ^{15}N methodology. Plant Soil 110: 81-89.

Sharma, R. B., and Ghildyal, B. P. 1977. Soil water-root relations in wheat: water extraction rate of wheat roots that developed under dry and moist conditions. Agron. J. 69: 231-233.

Shaviv, A. 2001. Advances in Controlled-release fertilizers. Adv. Agron. 71: 2-51.

Shaviv, A., and Mikkelsen, R. L. 1993. Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation – a review. Fert. Res. 35: 1-12.

Shewry, P. R., and Miflin, B. J. 1985. Seed storage proteins of economically important cereals. p. 1-83. In: Advances in Cereal Science and Technology; Vol. 7. Pomeranz, Y. ed. American Association of Cereal Chemists, Inc., St. Paul, MN.

Shewry, P. R., and Tatham, A. S. 1997. Disulphide bonds in wheat gluten proteins. J. Cer. Sci. 25: 207-227.

Shewry, P. R., Tatham, A. S., Forde, J., Kreis, M, and Miflin, B. J. 1986. The classification and nomenclature of wheat gluten proteins; a reassessment. J. Cer. Sci. 4: 97-106.

Shoji, S., Gandeza, A. T., and Kimura, K. 1991. Simulation of crop response to polyolefin-coated urea: II. Nitrogen uptake by corn. Soil Sci. Soc. Am. J. 55: 1468-1473.

Silsbury, J. H. 1990. Grain yield of wheat in rotation with pea, vetch, or medic grown with three systems of management. Aust. J. Exp. Agric. 30: 645-649.

Singh, H., and MacRitchie, F. 2001. Application of polymer science to properties of gluten. J. Cer. Sci. 33: 231-243.

Singh, N. K., Sheperd, K. W., Gupta, R. B., Moss, J., and MacRitchie, F. 1991. Proportion of glutenin in the flour protein as a measure of dough strength. p. 129-144. In: Gluten Proteins 1990. Bushuk, W., and Tkachuk, R. eds. American Association of Cereal Chemists, St. Paul, MN.

Sinha, R. C., and Savard, M. E. 1996. Comparison od immunoassay and gas chromatography methods for the detection of the mycotoxin deoxynivalenol in grain samples. Can. J. Plant Pathol. 18: 233-236.

Skerritt, J. H., Lew, P. Y., and Castle, S. L. 1987. Accumulation of gliadin and glutenin polypeptides during development of normal and sulphur-deficient wheat seed: Analysis using specific monoclonal antibodies. J. Exp. Bot. 39: 723-737.

Smewing, J. 1995. The Measurement of Dough and Gluten Extensibility using the SMS/Kieffer Rig and the *TA.XT2* Texture Analyzer. Stable Micro Systems, Ltd., Surrey, England.

Smika, D. E., and Greb, B. W. 1973. Protein content of winter wheat grain as related to soil and climatic factors in the semiarid Central Great Plains. Agron. J. 65: 433-436.

Smith, J. H., and Peterson, J. R. 1982. *Reported in* Grenier, M. R. 1992. Effect of annual legumes on the nitrogen status of soils. M. Sc. Thesis. University of Manitoba.

Smith, J. L., and Paul, E. A. 1990. *Reported in* Bremer, E., and van Kessel, C. 1992. Plant-available nitrogen from lentil and wheat residues during a subsequent growing season. Soil Sci. Soc. Am. J. 56: 1155-1160.

Sofield, I., Wardlaw, I. F., Evans, L. T., and Zee, S. Y. 1977. Nitrogen, phosphorous and water contents during grain development and maturation in wheat. Aust. J. Plant Physiol. 4: 799-810.

Soon, Y. K., Clayton, G. W., and Rice, W. A. 2001. Tillage and previous crop effects on dynamics of nitrogen in a wheat-soil system. Agron. J. 93: 842-849.

Soper, R. J., and Huang, P. M. 1963. The effect of nitrate nitrogen in the soil profile on the response of barley to fertilizer nitrogen. Can. J. Soil Sci. 43: 350-358.

Soper, R. J., Racz, G. J., and Fehr, P. I. 1971. Nitrate nitrogen in the soil as a means of predicting the fertilizer nitrogen requirements of barley. Can. J. Soil Sci. 51: 45-49.

Southan, M., and MacRitchie, F. 1999. Molecular weight distribution of wheat proteins. Cereal Chem. 76: 827-836.

Spiertz, J. H. J., and Ellen, J. 1978. Effects of nitrogen on crop development and grain growth of winter wheat in relation to assimilation and utilization of assimilates and nutrients. Neth. J. Agric. Sci. 26: 210-231.

Spratt, E. D., and Gasser, J. K. R. 1970. Effects of fertilizer nitrogen and water supply on distribution of dry matter and nitrogen between the different parts of wheat. Can. J. Soil Sci. 50: 613-625.

Stable Micro Systems, Inc. 1995. User Guide – Texture Expert for Windows Version 1.0. Stable Micro Systems Ltd., Surrey, England.

Stanford, G. 1982. Assessment of soil nitrogen availability. p. 651-688. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI, USA.

Stanford, G., and Legg, J. O. 1984. Nitrogen and yield potential. p. 263-272. In: Nitrogen in Crop Production. Hauck, R. D. et al. eds. ASA-CSSA-SSSA, Madison, WI., USA.

Stanford, G., and Smith, S. J. 1972. Nitrogen mineralization potential of soils. Soil Sci. Soc. Am. J. Proc. 36: 465-472.

Steel, R. G. D., Torrie, J. H., and Dickey, D. A. 1997. Principles and Procedures of Statistics – A Biometrical Approach. 3rd ed. McGraw Hill, New York, NY.

Stenram, D., Heneen, W. K., and Olered, R. 1990. The effect of nitrogen fertilizers on protein accumulation in wheat (*Triticum aestivum* L.). Swed. J. Agric. Res. 20: 105-114.

Steppuhn, H., and R. P. Zentner. 1987. Water utilization and water use efficiency in relation to yield and quality of red spring wheat. p. 136-160. In: Wheat Production in Canada. Proceedings of the Canadian Wheat Production Symposium. Slinkard, A. E., and Fowler, D. B. eds. Crop Development Centre, University of Saskatchewan, Saskatoon, SK.

Stevenson, F. J. 1982. Origin and distribution of nitrogen in the soil. p. 1-42. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI, USA.

Stevenson, C., and van Kessel, C. 1995. Landscape-scale controls on the availability of pea-residue nitrogen for the subsequent cereal crop. p. 283-290. In: Proc. Saskatchewan Soils and Crops Workshop. February 23-24, 1995. University of Saskatchewan, Saskatoon, SK.

Stevenson, C., and van Kessel, C. 1996. A landscape-scale assessment of the nitrogen and non-nitrogen rotation benefits of pea. Soil Sci. Soc. Am. J. 60: 1797-1805.

Stevenson, F. C., and van Kessel, C. 1997. Nitrogen contribution of pea residue in a hummocky terrain. Soil Sci. Soc. Am J. 61: 494-503.

Stone, P. J., Gras, P. W., and Nicolas, M. E. 1997. The influence of recovery temperature on the effects of a brief heat shock on wheat. III. Grain protein composition and dough properties. J. Cer. Sci. 25: 129-141.

Stone, P. J., and Nicolas, M. E. 1996a. Varietal differences in mature protein composition of wheat resulted from different rates of polymer accumulation during grain filling. Aust. J. Agric. Res. 23: 727-737.

Stone, P. J., and Nicolas, M. E. 1996b. Effect of timing of heat stress during grain filling on two wheat varieties differing in heat tolerance. II. Fractional protein accumulation. Aust. J. Agric. Res. 23: 739-749.

Stone, P. J., and Savin, R. 1999. Grain quality and its physiological determinants. p. 85-120. In: Wheat: Ecology and Physiology of Yield Determination. Satorre, E. H. and Slafer, G. A. eds. Food Products Press. New York.

Strong, W. M., Harbison, J., Nielsen, R. G. H., Hall, B. D., and Best, E. K. 1986a. Nitrogen availability in a Darling Downs soil following cereal, oilseed, and grain legume crops. 1. Soil nitrogen accumulation. Aust. J. Exp. Agric. 26: 347-351.

Strong, W. M., Harbison, J., Nielsen, R. G. H., Hall, B. D., and Best, E. K. 1986b. Nitrogen availability in a Darling Downs soil following cereal, oilseed, and grain legume crops. 2. Effects of residual soil nitrogen and fertilizer nitrogen on subsequent cereal crops. Aust. J. Exp. Agric. 26: 353-359.

Suchy, J., Lukow, O. M., and Ingelin, M. E. 2000. Dough microextensibility method using a 2-g Mixograph and a texture analyzer. Cereal Chem. 77: 39-43.

Technicon Instrument Corporation. 1995. Technicon Autoanalyzer II Continuous Flow Instrument Manual.

Terman, G. L. 1979. Volatilization losses of nitrogen as ammonia from surface-applied fertilizers, organic amendments, and crop residues. Adv. Agron. 31: 189-223.

Terman, G. L. 1979. Yields and protein content of wheat grain as influenced by cultivar, N, and environmental growth factors. Agron. J. 71: 437-440.

Terman, G. L., Ramig, R. E., Dreier, A. F., and Olson, R. A. 1969. Yield-protein relationships in wheat grain as affected by nitrogen and water. Agron. J. 61: 755-759.

Thicke, F. E., Russelle, M. P., Hesterman, O. B., and Scheaffer, C. C. 1993. Soil nitrogen mineralization indexes and corn response in crop rotations. Plant Soil 156: 322-335.

Thiessen Martens, J. R., and Entz, M. H. 2001. Availability of late-season heat and water resources for relay and double-cropping with winter wheat in prairie Canada. Can. J. Plant Sci. 81: 273-276.

Timms, M. F., Bottomley, R. C., Richard, J. Ellis, S., and Schofield, J. D. 1981. The baking quality and protein characteristics of a winter wheat grown at different levels of nitrogen fertilization. J. Sci. Food Agric. 32: 684-698.

Tindall, T. A., and Detrick, J. 1999. Controlled release fertilizer application and use in production agriculture. p. 93-96. In: Proc. Western Canadian Agronomy Workshop. July 7-9. 1999. Brandon, MB.

Tipples, K. H., Dubetz, S., and Irvine, G. N. 1977. Effects of high rates of nitrogen on Neepawa wheat grown under irrigation. II. Milling and baking quality. Can. J. Plant Sci. 57: 337-350.

Tipples, K. H., Kilborn, R. H., and Preston, K. R. 1994. Bread-wheat quality defined. p. 25-36. In: Wheat: Production, Properties and Quality. Bushuk, W. and Rasper, J. D. eds. Chapman and Hall, London.

Tomar, J. S., and Soper, R. J. 1981. Fate of tagged urea N in the field with different methods of N and organic matter placement. Agron. J. 73: 991-995.

Tomar, J. S., and R. J. Soper. 1987. Fate of ^{15}N-labelled urea in the growth chamber as affected by added organic matter and N placement. Can. J. Soil Sci. 67: 639-646.

Tourraine, B., and Gojon, A. 2001. Integration of nitrate uptake in the whole plant. p. 95-114. In: Nitrogen Assimilation by Plants: Physiological, Biochemical, and Molecular Aspects. Morot-Gaudry, J-F. ed. Science Publishers, Inc., Enfield, NH, USA.

Tran, T. S., and Tremblay, G. 2000. Recovery of 15N-labeled fertilizer by spring bread wheat at different N rates and application times. Can. J. Soil Sci. 80: 533-539.

Triboi, E., Abad, A., Michelena, A., Lloveras, J., Ollier, J. L., and Daniel, C. 2000. Environmental effects on the quality of two wheat genotypes: 1. quantitative and qualitative variation of storage proteins. Eur. J. Agron. 13: 47-64.

Triboi, E., Branlard, G., and Landry, J. 1990. Environmental and husbandry effects on the content and composition of proteins in wheat. Asp. Appl. Biol. 25: 149-158.

Triboi, E., and Leblevenec, L. 1995. Temperature effects on grain growth and protein fraction accumulation in winter wheat. J. Exp. Bot. Supplement 46: 8.

Triboi, E., and Triboi-Blondel, A. M. 2001. Environmental effects on wheat grain growth and composition. Aspects Appl. Biol. 64: 91-101.

Unger, C. J. H. 2002. The impact of sulphur on the breadmaking quality of Canadian Western Red Spring wheat in western Canada. M. Sc. Thesis. University of Manitoba.

Uthayakumaran, S., Gras, P. W., Stoddard, F. L., and Bekes, F. 1999. Effect of varying protein content and glutenin-to-gliadin ratio on the functional properties of wheat dough. Cereal Chem. 76: 389-394.

Uthayakumaran, S., Newberry, M., Keentok, M., Stoddard, F. L., and Bekes, F. 2000. Basic rheology of wheat dough with modified protein content and glutenin-to-gliadin ratios. Cereal Chem. 77: 744-749.

van Herwaarden, A. F., Angus, J. F., Richards, R. A., and Farquhar, G. D. 1998. 'Haying-off,' the negative grain yield response of dryland wheat to nitrogen fertilizer II. Carbohydtare and protein dynamics. Aust. J. Agric. Res. 49: 1083-1093.

van Lonkhuijsen, H. J., Hamer, R. J., and Schreuder, C. 1992. Influence of specific gliadins on the breadmaking quality of wheat. Cereal Chem. 69: 174-177.

Vaughan, B., Westfall, D. G., and Barbarick, K. A. 1990. Nitrogen rate and timing effects on winter wheat grain yield, grain protein, and economics. J. Prod. Agric. 3: 324-328.

Verbruggen, I. M., Veraverbeke, W. S., and Delcour, J. A. 2001. Significance of LMW-GS and HMW-GS for dough extensibility: 'Addition' versus 'incorporation' protocols. J. Cer. Sci. 33: 253-260.

Wahab, J., and Hogg, T. 1995. Controlled-release urea, is it a viable nitrogen source for irrigated potato? p. 161-165. In: Proc. Saskatchewan Soils and Crops Workshop. February 23-24, 1995. University of Saskatchewan, Saskatoon, SK.

Waldren, R. P., and Flowerday, A. D. 1979. Growth stages and distribution of dry matter, N, P, and K in winter wheat. Agron. J. 71: 391-397.

Walker, A. E., and Walker, C. E. 1995. Data acquisition and analysis system for the Mixograph. Release 3.80. National Manufacturing Division -- TMCO. Lincoln, NE.

Wall, J. S. 1979. The role of wheat proteins in determining wheat quality. p. 275-311. In: Recent Advances in the Biochemistry of Cereals. Laidman, D. L., and Wyn Jones, R. G. eds. Academic Press, New York.

Wang, X. T., and Below, F. E. 1992. Root growth, nitrogen uptake, and tillering of wheat as influenced by mixed nitrogen source. Crop Sci. 32: 997-1002.

Waters, S. P., Peoples, M. B., Simpson, R. J., and Dalling, M. J. 1980. Nitrogen redistribution during grain growth in wheat (*Triticum aestivum* L.) I. Peptide hydrolase activity and protein breakdown in the flag leaf, glumes and stems. Planta 148: 422-428.

Weegels, P. L., Hamer, R. J., and Schofield, J. D. 1996. Critical review – functional properties of wheat glutenin. J. Cer. Sci. 23: 1-18.

Wieser, H., and Kieffer, R. 2001. Correlations of the amount of gluten protein types to the technological properties of wheat flours determined on a micro-scale. J. Cer. Sci. 34: 19-27.

Wieser, H., and Seilmeier, W. 1998. The influence of nitrogen fertilization on quantities and proportions of different protein types in wheat flour. J. Sci. Food Agric. 76: 49-55.

Wieser, H., Seilmeier, W., and Belitz, H. D. 1994. Quantitative determination of gliadin subgroups from different wheat cultivars. J. Cer. Sci. 19: 149-155.

Wooding, A. R., Savale, S., MacRitchie, F., Stoddard, F. L., and Wallace, A. 2000a. Effects of nitrogen and sulfur fertilization on commercial-scale wheat quality and mixing requirements. Cereal Chem. 77: 791-797.

Wooding, A. R., Savale, S., MacRitchie, F., Stoddard, F. L., and Wallace, A. 2000b. Effects of nitrogen and sulfur fertilizer on protein composition, mixing requirements, and dough strength of four wheat cultivars. Cereal Chem. 77: 798-807.

Wrigley, C. W. 1996. Giant proteins with flour power. Nature 381: 738-739.

Wrigley, C. W., and Bietz, J. A. 1988. Proteins and amino acids. p. 159-275. In: Wheat: Chemistry and Technology. Pomeranz Y. eds. American Association of Cereal Chemists, St. Paul, MN.

Wrigley, C. W., du Cros, D. L., Fullington, J. G., and Kasarda, D. D. 1984. Changes in polypeptide composition and grain quality due to sulfur deficiency in wheat. J. Cer. Sci. 2: 15-24.

Wright, A. T. 1990. Yield effect of pulses on subsequent cereal crops in the northern Prairies. Can. J. Plant Sci. 70: 1023-1032.

Wuest, S. B., and Cassman, K. G. 1992a. Fertilizer-nitrogen use efficiency of irrigated wheat: I. Uptake efficiency of preplant versus late-season application. Agron. J. 84: 682-688.

Yaacob, O., and Blair, G. J. 1980. Mineralization of ^{15}N-labelled legume residues in soils with different nitrogen contents and its uptake by Rhodes grass. Plant Soil 90: 237-248.

Young, J. L., and Aldag, R. W. 1982. Inorganic forms of nitrogen in soil. p. 43-66. In: Nitrogen in Agricultural Soils. Stevenson, R. J. et al. eds. Agronomy Monograph No. 22. ASA-CSSA-SSSA, Madison, WI., USA.

Zentner, R. P., Campbell, C. A., Biederbeck, V. O., Miller, R. P., Selles, F., and Fernandez, M. R. 2001. In search of a sustainable cropping system for the semiarid Canadian Prairies. J. Sustainable Agric. 18: 117-136.

Zhao, F. J., Hawkesford, M. J., and McGrath, S. P. 1999a. Sulphur assimilation and effects on yield and quality of wheat. J. Cer. Sci. 30: 1-7.

Zhao, F. J., Salmon, S. E., Withers, P. J. A., Monaghan, J. M., Evans, E. J., Shewry, P. R., and McGrath, S. P. 1999b. Variation in the breadmaking quality and rheological properties of wheat in relation to sulphur nutrition under field conditions. J. Cer. Sci. 30: 19-31.

Zhu, J., and Khan, K. 1999. Characterization of monomeric and glutenin polymeric proteins of hard red spring wheats during grain development by multistacking SDS-PAGE and capillary zone electrophoresis. Cereal Chem. 76: 261-269.

Zhu, J., and Khan, K. 2001. Effects of genotype and environment on glutenin polymers and breadmaking quality. Cereal Chem. 78: 125-130.

Zhu, J., Khan, K., Huang, S., and O'Brien, L. 1999. Allelic variation at Glu-D1 lous for high molecular weight (HMW) glutenin subunits: quantification by multistacking SDS-PAGE of wheat grown under nitrogen fertilization. Cereal Chem. 76: 915-919.

The Effect of Pulse Crop Rotation and Controlled-Release Urea on the Nitrogen Accumulation and End-Use Quality of Canada Western Red Spring Wheat

BY

DAVID WILLIAM ANDREW PRZEDNOWEK

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES
*****
COPYRIGHT PERMISSION PAGE

THE EFFECT OF PULSE CROP ROTATION AND CONTROLLED-RELEASED UREA ON THE NITROGEN ACCUMULATION AND END-USE QUALITY OF CANADA WESTERN RED SPRING WHEAT

BY

DAVID WILLIAM ANDREW PRZEDNOWEK

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

of Manitoba in partial fulfillment of the requirements of the degree

of

Master of Science

8.0 APPENDICES

8.1. APPENDIX A – METEOROLOGICAL INFORMATION AND SELECT AGRONOMIC INFORMATION FOR THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table A.1. Mean monthly air temperature for the experimental sites.

Site Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	mean temperature (°C)											
Carman	-17.1	-13.8	-6.6	3.8	11.9	17.4	20.1	18.7	11.6	5.1	-5.3	-14.6
Brandon	-18.4	-15.0	-7.5	3.3	11.0	16.2	18.7	17.5	11.4	5.0	-5.7	-15.0
Swift Current	-13.0	-9.6	-4.0	4.3	10.8	15.6	18.3	17.6	11.4	5.5	-4.0	-10.8

Source: Environment Canada Climate Center, Winnipeg, MB.

Table A.2. Mean monthly precipitation for the experimental sites.

Site Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	total monthly precipitation (mm)											
Carman	18.5	17.7	21.7	42.5	52.7	72.8	69.1	65.5	49.0	34.0	18.6	20.8
Brandon	18.4	15.6	20.5	35.4	48.4	66.9	72.1	69.3	50.5	22.2	14.9	18.9
Swift Current	20.0	16.2	19.5	24.7	45.7	66.8	48.9	38.2	33.7	17.5	14.7	21.5

Source: Environment Canada Climate Center, Winnipeg, MB.

Table A.3. Meteorological data for the Swift Current experimental sites.[a]

	Site Year	
	2000	2001
May		
Precipitation (mm)	65 (46)	23
Average Air Temperature (°C)	10.9 (10.8)	12.2
June		
Precipitation (mm)	54 (67)	32
Average Air Temperature (°C)	13.8 (15.6)	15.0
July		
Precipitation (mm)	127 (49)	63
Average Air Temperature (°C)	19.1 (18.3)	19.7
August		
Precipitation (mm)	13 (38)	3
Average Air Temperature (°C)	18.5 (17.6)	20.9

[a] Data in parentheses are 1961-1990 climatic averages (Environment Canada Climate Center, Winnipeg, MB).

Table A.4. Agronomic information for the Swift Current experimental sites.

	Site Year	
Characteristic	2000	2001
Reference Crop Residue Management	Plot combine w/o chopper; no incorporation	Plot combine w/o chopper; no incorporation
Spring Soil Sampling	----	4-May
Seeding Date	17-May	8-May
First neutron probe reading	----	14-May
Tissue Sampling at Flag Leaf	----	29-Jun
50% Anthesis Date	----	17-Jul
Last Tissue Sampling Date	----	21-Aug
Harvest Date	12-Sep	22-Aug
Soil Sampling at Harvest	----	4-Sep

Table A.5. Soil physical and chemical characteristics at the Swift Current-01 site.[a,b,c]

Characteristic[a]	Depth (cm)	Stubble Type Pea	Durum
Soil Name		Haverhill	
Soil Classification		Orthic Brown Chernozem	
Soil Texture		loam	
pH	0-15	7.3	7.5
Organic Matter (%)	0-15	2.7	3.0
Electrical Conductivity (ds/M)	0-15	0.62	0.54
Cation Exchange Capacity (meq/100 g)	0-15	20.5	22.1
Estimated NO_3-N (kg ha^{-1})[b]	0-15	10	7
	15-60	10	7
	60-120	10	12
	0-60	20 (VL)[c]	14 (VL)
Estimated NH_4-N (kg ha^{-1})	0-15	10	7
Extractable SO_4-S (mg kg^{-1})	0-60	>20	>20
Extractable P (mg kg^{-1})	0-15	13	11
Extractable K (mg kg^{-1})	0-15	303	360

[a] Particle size analysis for soil texture determination was determined by hydrometer method (Black et al. 1965), organic matter by ignition (McKeague 1976), cation exchange capacity by NH_4OAc at pH 7 (McKeague 1976), 2 N KCl extractable NO_3-N by automated Cadmium reduction method (Clesceri et al. 1998), 2 N KCl extractable NH_4-N by automated phenate method (Clesceri et al. 1998), extractable SO_4-S by turbidimetric method (Clesceri et al. 1998), extractable K by flame photometric method (Clesceri et al. 1998), and extractable P by stannous chloride method (Clesceri et al. 1998). Soil pH and electrical conductivity were determined in water using a soil to water ratio of 1:2 (McKeague 1976).

[b] Estimated assuming a bulk density of 1.33 g cm^3.

[c] Ratings for wheat production according to the Manitoba Soil Fertility Guide where VL = very low; L = low; M = medium; H = high; VH = very high (Manitoba Agriculture and Food 2001).

8.2. APPENDIX B – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SELECTED MEASUREMENTS ASSOCIATED WITH DRY MATTER AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table B.1. Dry matter yield of the stem/leaf fraction at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---------------------kg ha^{-1}---------------------		
Flax	0	4333	4569	2632
Flax	30 AN*	4682	4905	3404
Flax	30 CRU**	4676	5135	3498
Flax	90 AN	5366	5569	4569
Flax	90 CRU	4821	5438	3813
Pea	0	3585	4034	3679
Pea	30 AN	5041	4798	4273
Pea	30 CRU	5126	5192	3797
Pea	90 AN	5797	5577	4462
Pea	90 CRU	4944	5077	4630
LSD (P=0.05)		707	768	658
Stubble				
Flax		4776	5123	3529
Pea		4899	4938	4168
LSD (P=0.05)		ns	ns	296
	N Applied ($kg\ ha^{-1}$)			
	0	3959	4306	3020
	30 AN	4861	4852	3839
	30 CRU	4901	5573	3648
	90 AN	5582	5163	4515
	90 CRU	4883	5258	4222
	LSD (P=0.05)	503	557	468
ANOVA	df		Pr>F	
Stubble (S)	1	0.48	0.27	0.0206
N Applied ($kg\ ha^{-1}$)	4	<0.0001	0.0013	<0.0001
N*S	4	0.11	0.79	0.0409
Contrasts				
Pea vs Flax at 0 N		0.0391	0.17	0.0003
Pea vs Flax at 30 N		0.11	0.93	0.0157
Pea vs Flax at 90 N		0.27	0.51	0.13
AN vs CRU		0.0675	0.99	0.14
AN vs CRU - 30 N vs 90 N		0.0423	0.11	0.75
0 N vs 30 N		0.0002	0.0062	0.0012
30N vs 90 N		0.0527	0.043	0.0007
Pea vs Flax - 0 N vs 30 N		0.0116	0.3	0.0748
Pea vs Flax - 30 N vs 90 N		0.71	0.69	0.48
Pea at 30 N vs Flax 90 N		0.97	0.0655	0.5
C.V. (%)		10.1	10.7	11.8

* Ammonium nitrate

** Controlled-release urea

Table B.2. Dry matter yield of the stem/leaf fraction 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--------------------kg ha^{-1}--------------------		
Flax	0	4333	4569	2632
Flax	30 AN*	4682	4905	3404
Flax	30 CRU**	4676	5135	3498
Flax	90 AN	5366	5569	4569
Flax	90 CRU	4821	5438	3813
Pea	0	3585	4034	3679
Pea	30 AN	5041	4798	4273
Pea	30 CRU	5126	5192	3797
Pea	90 AN	5797	5577	4462
Pea	90 CRU	4944	5077	4630
LSD (P=0.05)		707	ns	658
Stubble				
Flax		4776	5123	3529
Pea		4899	4938	4168
LSD (P=0.05)		ns	ns	296
	N Applied (kg ha^{-1})			
	0	3959	4306	3020
	30 AN	4861	4852	3839
	30 CRU	4901	5573	3648
	90 AN	5582	5163	4515
	90 CRU	4883	5258	4222
	LSD (P=0.05)	503	557	468
ANOVA	df		Pr>F	
Stubble (S)	1	0.65	0.93	0.0185
N Applied (kg ha^{-1})	4	0.0132	0.0052	<0.0001
N*S	4	0.0381	0.64	0.0988
Contrasts				
Pea vs Flax at 0 N		0.42	0.82	0.0003
Pea vs Flax at 30 N		0.42	0.37	0.0002
Pea vs Flax at 90 N		0.92	0.4	0.018
AN vs CRU		0.43	0.54	0.0977
AN vs CRU - 30 N vs 90 N		0.37	0.32	0.106
0 N vs 30 N		0.0281	0.0068	0.0018
30N vs 90 N		0.09	0.13	<0.0001
Pea vs Flax - 0 N vs 30 N		0.83	0.71	0.37
Pea vs Flax - 30 N vs 90 N		0.48	0.18	0.18
Pea at 30 N vs Flax 90 N		0.45	0.34	0.58
C.V. (%)		13.2	10.1	13.5

* Ammonium nitrate

** Controlled-release urea

Table B.3. Dry matter yield of the stem/leaf fraction 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-------kg ha^{-1}-------		
Flax	0	5682	5534	2575
Flax	30 AN*	7175	6321	3765
Flax	30 CRU**	7224	6408	3609
Flax	90 AN	7503	6474	6152
Flax	90 CRU	7142	6452	4519
Pea	0	6896	5074	4667
Pea	30 AN	6814	6409	4872
Pea	30 CRU	7224	5512	4716
Pea	90 AN	7881	6212	5569
Pea	90 CRU	6552	5392	4888
LSD (P=0.05)		ns	ns	1240
Stubble				
Flax		6946	6238	4124
Pea		7074	5720	4943
LSD (P=0.05)		ns	ns	514
	N Applied (kg ha^{-1})			
	0	6289	5304	3621
	30 AN	6995	6365	4318
	30 CRU	7224	6343	4163
	90 AN	7692	5960	5860
	90 CRU	6847	5922	4704
	LSD (P=0.05)	ns	680	813
ANOVA	df		Pr>F	
Stubble (S)	1	0.68	0.26	0.001
N Applied (kg ha^{-1})	4	0.2	0.0241	0.0001
N*S	4	0.55	0.42	0.0313
Contrasts				
Pea vs Flax at 0 N		0.14	0.38	0.0018
Pea vs Flax at 30 N		0.75	0.28	0.0152
Pea vs Flax at 90 N		0.85	0.0829	0.8
AN vs CRU		0.45	0.0891	0.0271
AN vs CRU - 30 N vs 90 N		0.2	0.97	0.0852
0 N vs 30 N		0.11	0.0061	0.0822
30N vs 90 N		0.7	0.9	0.001
Pea vs Flax - 0 N vs 30 N		0.17	0.92	0.16
Pea vs Flax - 30 N vs 90 N		0.93	0.59	0.0395
Pea at 30 N vs Flax 90 N		0.59	0.18	0.21
C.V. (%)		16.3	11.0	17.4

* Ammonium nitrate

** Controlled-release urea

Table B.4. Dry matter yield of the stem/leaf fraction 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----------------------kg ha^{-1}-------------------------		
Flax	0	4206	5545	2436
Flax	30 AN*	5912	6354	3609
Flax	30 CRU**	5846	6135	3191
Flax	90 AN	6732	7185	5372
Flax	90 CRU	6765	6704	4708
Pea	0	6060	5720	4642
Pea	30 AN	6289	6441	5323
Pea	30 CRU	5961	6179	4823
Pea	90 AN	7372	6682	5709
Pea	90 CRU	6699	6365	4856
LSD (P=0.05)		1562	826	1205
Stubble				
Flax		5892	6385	3863
Pea		6476	6277	5071
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	5133	5632	3539
	30 AN	6101	6397	4466
	30 CRU	5904	6934	4007
	90 AN	7052	6157	5541
	90 CRU	6732	6534	4782
	LSD (P=0.05)	1128	481	640
ANOVA	df		Pr>F	
Stubble (S)	1	0.14	0.78	0.12
N Applied (kg ha^{-1})	4	0.0164	0.0002	<0.0001
N*S	4	0.4457	0.53	0.0091
Contrasts				
Pea vs Flax at 0 N		0.0218	0.67	0.0008
Pea vs Flax at 30 N		0.65	0.82	0.0004
Pea vs Flax at 90 N		0.6	0.15	0.56
AN vs CRU		0.51	0.0641	0.0105
AN vs CRU - 30 N vs 90 N		0.87	0.63	0.5
0 N vs 30 N		0.0786	0.0039	0.0159
30N vs 90 N		0.0302	0.0106	0.0003
Pea vs Flax - 0 N vs 30 N		0.1	0.79	0.33
Pea vs Flax - 30 N vs 90 N		0.96	0.15	0.0033
Pea at 30 N vs Flax 90 N		0.26	0.0343	0.94
C.V. (%)		17.7	7.4	13.9

* Ammonium nitrate

** Controlled-release urea

Table B.5. Dry matter yield of the stem/leaf fraction 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		------kg ha^{-1}------		
Flax	0	n.d.†	4670	2034
Flax	30 AN*	n.d.	5320	2748
Flax	30 CRU**	n.d.	5042	2813
Flax	90 AN	n.d.	5381	4429
Flax	90 CRU	n.d.	5517	4003
Pea	0	n.d.	4757	3428
Pea	30 AN	n.d.	4692	4175
Pea	30 CRU	n.d.	5320	4364
Pea	90 AN	n.d.	5616	5405
Pea	90 CRU	n.d.	5517	4593
LSD (P=0.05)		n.d.	ns	1114
Stubble				
Flax		n.d.	5186	3205
Pea		n.d.	5199	4393
LSD (P=0.05)		n.d.	ns	496
	N Applied ($kg\ ha^{-1}$)			
	0	n.d.	4713	2731
	30 AN	n.d.	5053	3461
	30 CRU	n.d.	5498	3588
	90 AN	n.d.	5181	4917
	90 CRU	n.d.	5517	4298
	LSD (P=0.05)	n.d.	ns	785
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.97	0.0198
N Applied ($kg\ ha^{-1}$)	4	n.d.	0.13	<0.0001
N*S	4	n.d.	0.76	0.7
Contrasts				
Pea vs Flax at 0 N		n.d.	0.87	0.0161
Pea vs Flax at 30 N		n.d.	0.73	0.0006
Pea vs Flax at 90 N		n.d.	0.75	0.0512
AN vs CRU		n.d.	0.76	0.37
AN vs CRU - 30 N vs 90 N		n.d.	0.82	0.18
0 N vs 30 N		n.d.	0.18	0.024
30N vs 90 N		n.d.	0.12	0.0005
Pea vs Flax - 0 N vs 30 N		n.d.	0.72	0.89
Pea vs Flax - 30 N vs 90 N		n.d.	0.61	0.2
Pea at 30 N vs Flax 90 N		n.d.	0.29	0.89
C.V. (%)		n.d.	13.1	20.0

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table B.6. Dry matter yield of the stem/leaf fraction 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------kg ha^{-1}---------		
Flax	0	4600	4440	2215
Flax	30 AN*	5322	4790	2838
Flax	30 CRU**	4829	4976	3314
Flax	90 AN	5830	5282	4733
Flax	90 CRU	5633	5381	4323
Pea	0	4715	3871	3207
Pea	30 AN	5764	4692	4011
Pea	30 CRU	4879	4976	4487
Pea	90 AN	6421	5402	4519
Pea	90 CRU	4403	5238	4232
LSD (P=0.05)		1215	569	1099
Stubble				
Flax		5243	4974	3484
Pea		5236	4836	4091
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	4657	4156	2711
	30 AN	5543	4741	3424
	30 CRU	4854	5342	3900
	90 AN	6125	4976	4626
	90 CRU	5018	5309	4277
	LSD (P=0.05)	862	408	766
ANOVA	df		Pr>F	
Stubble (S)	1	0.98	0.31	0.11
N Applied (kg ha^{-1})	4	0.0119	<0.0001	0.0003
N*S	4	0.2375	0.5	0.17
Contrasts				
Pea vs Flax at 0 N		0.85	0.0501	0.075
Pea vs Flax at 30 N		0.56	0.8	0.0045
Pea vs Flax at 90 N		0.45	0.96	0.69
AN vs CRU		0.0056	0.48	0.81
AN vs CRU - 30 N vs 90 N		0.15	0.35	0.13
0 N vs 30 N		0.86	0.0004	0.0068
30N vs 90 N		0.35	0.0027	0.0061
Pea vs Flax - 0 N vs 30 N		0.86	0.14	0.78
Pea vs Flax - 30 N vs 90 N		0.35	0.89	0.0186
Pea at 30 N vs Flax 90 N		0.34	0.0172	0.47
C.V. (%)		15.9	8.1	19.6

* Ammonium nitrate

** Controlled-release urea

Table B.7. Dry matter yield of the stem/leaf fraction at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date					
Stubble	N Applied (kg ha^{-1})	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		kg ha^{-1}					
Durum	34	1663	2224	1607	1380	1534	1724
Durum	50	1627	2176	1777	1625	1267	2006
Durum	78	1993	2361	1755	2028	1828	2376
Pea	34	1096	1203	1268	1325	1183	1346
Pea	50	1311	1463	1178	1153	1540	1191
Pea	78	1925	1791	2252	1549	1496	2143
LSD (P=0.05)		ns	ns	911	ns	ns	ns
Stubble							
Durum		1761	2254	1713	1678	1543	2035
Pea		1444	1486	1566	1343	1407	1560
LSD (P=0.05)		ns	712	ns	ns	ns	ns
N Applied (kg ha^{-1})							
	34	1379	1714	1437	1352	1358	1535
	50	1469	1819	1478	1389	1404	1598
	78	1959	2076	2003	1789	1662	2260
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F					
Stubble (S)	1	0.15	0.0367	0.55	0.16	0.54	0.16
N Applied (kg ha^{-1})	2	0.0866	0.66	0.15	0.25	0.49	0.17
N*S	2	0.63	0.85	0.2	0.68	0.44	0.75
Contrasts							
34 N vs 50 N		0.73	0.8	0.89	0.89	0.87	0.88
50 N vs 78 N		0.0774	0.53	0.1	0.17	0.35	0.12
Pea vs Durum - 34 N vs 50 N		0.63	0.71	0.67	0.46	0.26	0.59
Pea vs Durum - 50 N vs 78 N		0.63	0.86	0.0886	0.99	0.28	0.47
Durum at 50 N vs Pea at 34 N		0.17	0.11	0.25	0.45	0.83	0.26
Durum at 78 N vs Pea at 50 N		0.0818	0.14	0.19	0.0421	0.46	0.0545
C.V. (%)		27.4	37.1	31.2	31.2	31.3	37.9

*Days after anthesis

Table B.8. Dry matter yield of the head fraction at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		------------------------kg ha^{-1}------------------------		
Flax	0	810	919	484
Flax	30 AN*	854	901	668
Flax	30 CRU**	885	955	681
Flax	90 AN	810	980	796
Flax	90 CRU	806	994	656
Pea	0	598	746	709
Pea	30 AN	807	883	742
Pea	30 CRU	771	916	685
Pea	90 AN	781	1001	722
Pea	90 CRU	879	834	664
LSD (P=0.05)		ns	ns	156
Stubble				
Flax		833	950	657
Pea		767	876	705
LSD (P=0.05)		59	ns	ns
	N Applied (kg ha^{-1})			
	0	704	832	597
	30 AN	831	892	705
	30 CRU	828	991	683
	90 AN	796	935	759
	90 CRU	842	914	660
	LSD (P=0.05)	93	ns	87
ANOVA	df		Pr>F	
Stubble (S)	1	0.0266	0.2	0.54
N Applied (kg ha^{-1})	4	0.0324	0.0926	0.0132
N*S	4	0.0511	0.31	0.0211
Contrasts				
Pea vs Flax at 0 N		0.0018	0.0403	0.0061
Pea vs Flax at 30 N		0.0732	0.62	0.47
Pea vs Flax at 90 N		0.61	0.23	0.55
AN vs CRU		0.49	0.67	0.0545
AN vs CRU - 30 N vs 90 N		0.45	0.13	0.22
0 N vs 30 N		0.0037	0.0971	0.0137
30N vs 90 N		0.74	0.33	0.61
Pea vs Flax - 0 N vs 30 N		0.11	0.14	0.0177
Pea vs Flax - 30 N vs 90 N		0.12	0.6	0.24
Pea at 30 N vs Flax 90 N		0.67	0.14	0.82
C.V. (%)		11.3	12.0	12.4

* Ammonium nitrate

** Controlled-release urea

Table B.9. Dry matter yield of the head fraction 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment			Site	
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
			kg ha^{-1}	
Flax	0	1296	1442	632
Flax	30 AN*	1421	1628	714
Flax	30 CRU**	1394	1616	910
Flax	90 AN	1141	1716	1140
Flax	90 CRU	1461	1702	943
Pea	0	1184	1453	968
Pea	30 AN	1320	1517	1025
Pea	30 CRU	1141	1657	992
Pea	90 AN	1337	1619	1230
Pea	90 CRU	1293	1576	1124
LSD (P=0.05)		ns	ns	218
Stubble				
Flax		1343	1621	868
Pea		1255	1564	1068
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	1240	1448	800
	30 AN	1371	1573	869
	30 CRU	1267	1637	951
	90 AN	1239	1667	1185
	90 CRU	1377	1639	1033
	LSD (P=0.05)	ns	145	124
ANOVA	df		Pr>F	
Stubble (S)	1	0.53	0.0446	0.12
N Applied (kg ha^{-1})	4	0.42	0.0322	<0.0001
N*S	4	0.23	0.67	0.13
Contrasts				
Pea vs Flax at 0 N		0.49	0.91	0.0038
Pea vs Flax at 30 N		0.13	0.6	0.0141
Pea vs Flax at 90 N		0.9	0.11	0.0823
AN vs CRU		0.81	0.72	0.42
AN vs CRU - 30 N vs 90 N		0.0943	0.36	0.0113
0 N vs 30 N		0.36	0.0163	0.0442
30N vs 90 N		0.87	0.34	<0.0001
Pea vs Flax - 0 N vs 30 N		0.7	0.7	0.19
Pea vs Flax - 30 N vs 90 N		0.18	0.45	0.48
Pea at 30 N vs Flax 90 N		0.54	0.0783	0.67
C.V. (%)		15.0	8.8	12.4

* Ammonium nitrate

** Controlled-release urea

Table B.10. Dry matter yield of the head fraction 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---------kg ha^{-1}---------		
Flax	0	2293	3096	1222
Flax	30 AN*	2672	3687	1435
Flax	30 CRU**	2666	3600	1550
Flax	90 AN	2298	3454	2075
Flax	90 CRU	2318	3466	1804
Pea	0	2367	2756	1796
Pea	30 AN	2113	3364	1706
Pea	30 CRU	2201	2941	1706
Pea	90 AN	2293	3130	1944
Pea	90 CRU	2457	2743	1558
LSD (P=0.05)		ns	611	364
Stubble				
Flax		2449	3460	1617
Pea		2286	2987	1742
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	2330	2926	1509
	30 AN	2393	3525	1571
	30 CRU	2434	3270	1628
	90 AN	2296	3292	2010
	90 CRU	2388	3104	1681
	LSD (P=0.05)	ns	ns	249
ANOVA	df		Pr>F	
Stubble (S)	1	0.0889	0.0775	0.3
N Applied ($kg\ ha^{-1}$)	4	0.98	0.0677	0.0035
N*S	4	0.52	0.73	0.018
Contrasts				
Pea vs Flax at 0 N		0.83	0.26	0.0032
Pea vs Flax at 30 N		0.0425	0.0274	0.1
Pea vs Flax at 90 N		0.78	0.0194	0.14
AN vs CRU		0.71	0.13	0.13
AN vs CRU - 30 N vs 90 N		0.89	0.81	0.0331
0 N vs 30 N		0.71	0.0117	0.4
30N vs 90 N		0.69	0.17	0.0081
Pea vs Flax - 0 N vs 30 N		0.19	0.67	0.0968
Pea vs Flax - 30 N vs 90 N		0.12	0.91	0.0269
Pea at 30 N vs Flax 90 N		0.54	0.16	0.073
C.V. (%)		21.3	12.4	14.4

* Ammonium nitrate

** Controlled-release urea

Table B.11. Dry matter yield of the head fraction 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg ha^{-1}---		
Flax	0	2756	4987	1788
Flax	30 AN*	3691	5337	2338
Flax	30 CRU**	3691	5151	2190
Flax	90 AN	3248	5654	2846
Flax	90 CRU	3675	5435	2748
Pea	0	3625	5009	2871
Pea	30 AN	3297	5151	3018
Pea	30 CRU	3461	5304	2781
Pea	90 AN	3478	5184	2912
Pea	90 CRU	3986	4954	2731
LSD (P=0.05)		ns	ns	663
Stubble				
Flax		3412	5321	2382
Pea		3570	5120	2863
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	3191	4998	2329
	30 AN	3494	5244	2678
	30 CRU	3576	5227	2485
	90 AN	3363	5419	2879
	90 CRU	3830	5195	2740
	LSD (P=0.05)	ns	ns	324
ANOVA	df		Pr>F	
Stubble (S)	1	0.56	0.54	0.24
N Applied (kg ha^{-1})	4	0.74	0.42	0.0156
N*S	4	0.71	0.47	0.0099
Contrasts				
Pea vs Flax at 0 N		0.2	0.95	0.0024
Pea vs Flax at 30 N		0.52	0.95	0.0097
Pea vs Flax at 90 N		0.57	0.065	0.92
AN vs CRU		0.43	0.43	0.15
AN vs CRU - 30 N vs 90 N		0.58	0.49	0.82
0 N vs 30 N		0.42	0.2	0.0758
30N vs 90 N		0.86	0.64	0.0513
Pea vs Flax - 0 N vs 30 N		0.17	0.92	0.11
Pea vs Flax - 30 N vs 90 N		0.4	0.14	0.0111
Pea at 30 N vs Flax 90 N		0.86	0.21	0.66
C.V. (%)		27.7	8.1	12.0

* Ammonium nitrate

** Controlled-release urea

Table B.12. Dry matter yield of the head fraction 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		kg ha^{-1}		
Flax	0	n.d.†	5173	2124
Flax	30 AN*	n.d.	5069	2748
Flax	30 CRU**	n.d.	4965	2740
Flax	90 AN	n.d.	5140	3494
Flax	90 CRU	n.d.	5091	3305
Pea	0	n.d.	4768	3330
Pea	30 AN	n.d.	4681	3830
Pea	30 CRU	n.d.	4998	3428
Pea	90 AN	n.d.	5594	4126
Pea	90 CRU	n.d.	4779	3527
LSD (P=0.05)		n.d.	ns	937
Stubble				
Flax		n.d.	5087	2882
Pea		n.d.	4964	3648
LSD (P=0.05)		n.d.	ns	ns
	N Applied (kg ha^{-1})			
	0	n.d.	4970	2727
	30 AN	n.d.	4875	3289
	30 CRU	n.d.	4981	3084
	90 AN	n.d.	5367	3810
	90 CRU	n.d.	4935	3416
	LSD (P=0.05)	n.d.	ns	511
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.83	0.17
N Applied (kg ha^{-1})	4	n.d.	0.63	0.0035
N*S	4	n.d.	0.68	0.32
Contrasts				
Pea vs Flax at 0 N		n.d.	0.51	0.0136
Pea vs Flax at 30 N		n.d.	0.68	0.0106
Pea vs Flax at 90 N		n.d.	0.87	0.2
AN vs CRU		n.d.	0.51	0.1
AN vs CRU - 30 N vs 90 N		n.d.	0.28	0.6
0 N vs 30 N		n.d.	0.89	0.0425
30N vs 90 N		n.d.	0.37	0.0226
Pea vs Flax - 0 N vs 30 N		n.d.	0.71	0.46
Pea vs Flax - 30 N vs 90 N		n.d.	0.61	0.2
Pea at 30 N vs Flax 90 N		n.d.	0.52	0.48
C.V. (%)		n.d.	13.7	15.2

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table B.13. Dry matter yield of the head fraction 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg ha^{-1}---		
Flax	0	4610	5227	2772
Flax	30 AN*	4724	5206	3191
Flax	30 CRU**	4577	5173	3560
Flax	90 AN	3970	5162	4314
Flax	90 CRU	4741	5402	4076
Pea	0	4938	4506	3519
Pea	30 AN	4708	4888	4175
Pea	30 CRU	4528	5107	3978
Pea	90 AN	5135	5337	3420
Pea	90 CRU	3822	4834	3945
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		4524	5234	3583
Pea		4626	4934	3807
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	4774	4867	3146
	30 AN	4716	5047	3683
	30 CRU	4552	5140	3769
	90 AN	4552	5249	3867
	90 CRU	4281	5118	4011
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.7	0.49	0.49
N Applied (kg ha^{-1})	4	0.8	0.64	0.1
N*S	4	0.21	0.4	0.0474
Contrasts				
Pea vs Flax at 0 N		0.58	0.11	0.13
Pea vs Flax at 30 N		0.94	0.54	0.0454
Pea vs Flax at 90 N		0.77	0.53	0.14
AN vs CRU		0.47	0.92	0.61
AN vs CRU - 30 N vs 90 N		0.86	0.53	0.9
0 N vs 30 N		0.71	0.31	0.045
30N vs 90 N		0.47	0.62	0.35
Pea vs Flax - 0 N vs 30 N		0.63	0.24	0.94
Pea vs Flax - 30 N vs 90 N		0.8	0.99	0.0122
Pea at 30 N vs Flax 90 N		0.54	0.37	0.72
C.V. (%)		18.5	9.9	17.1

* Ammonium nitrate

** Controlled-release urea

Table B.14. Dry matter yield of the stem/leaf fraction at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date					
Stubble	N Applied (kg ha^{-1})	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		kg ha^{-1}					
Durum	34	710	1802	2063	2710	2660	3210
Durum	50	755	1798	2282	2758	2488	3312
Durum	78	769	1581	2009	3118	3113	3704
Pea	34	556	1067	1798	2282	2098	3035
Pea	50	578	1064	1320	2287	2493	2391
Pea	78	748	1410	2470	2511	3000	4025
LSD (P=0.05)		ns	ns	ns	ns	ns	ns
Stubble							
Durum		745	1727	2118	2862	2754	3409
Pea		627	1180	1863	2360	2530	3150
LSD (P=0.05)		ns	385	ns	ns	ns	ns
	N Applied (kg ha^{-1})						
	34	633	1434	1930	2496	2379	3122
	50	666	1431	1801	2522	2490	2852
	78	758	1496	2239	2814	3057	3865
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F					
Stubble (S)	1	0.28	0.0093	0.29	0.23	0.48	0.53
N Applied (kg ha^{-1})	2	0.6	0.95	0.31	0.77	0.19	0.14
N*S	2	0.8	0.36	0.0775	0.98	0.73	0.47
Contrasts							
34 N vs 50 N		0.8	0.99	0.66	0.96	0.77	0.59
50 N vs 78 N		0.48	0.78	0.15	0.56	0.16	0.0612
Pea vs Durum - 34 N vs 50 N		0.93	1	0.24	0.97	0.46	0.46
Pea vs Durum - 50 N vs 78 N		0.55	0.22	0.0266	0.89	0.88	0.23
Durum at 50 N vs Pea at 34 N		0.29	0.0343	0.25	0.5	0.48	0.7
Durum at 78 N vs Pea at 50 N		0.3	0.12	0.11	0.25	0.26	0.0827
C.V. (%)		31.8	25.8	24.5	32.0	24.5	25.9

*Days after anthesis

Table B.15. Aboveground plant dry matter yield at the flag leaf stage at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg ha^{-1}---		
Flax	0	n.d.†	3642	1952
Flax	30 AN*	n.d.	4659	2822
Flax	30 CRU**	n.d.	4199	2797
Flax	90 AN	n.d.	5326	3937
Flax	90 CRU	n.d.	4538	3100
Pea	0	n.d.	2876	3133
Pea	30 AN	n.d.	3521	3412
Pea	30 CRU	n.d.	4276	3502
Pea	90 AN	n.d.	4713	3921
Pea	90 CRU	n.d.	4232	3986
LSD (P=0.05)		n.d.	928	660
Stubble				
Flax		n.d.	4473	2922
Pea		n.d.	3924	3591
LSD (P=0.05)		n.d.	ns	312
	N Applied (kg ha^{-1})			
	0	n.d.	3259	2543
	30 AN	n.d.	4090	3117
	30 CRU	n.d.	4238	3150
	90 AN	n.d.	5020	3929
	90 CRU	n.d.	4385	3543
	LSD (P=0.05)	n.d.	572	494
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.21	0.0013
N Applied (kg ha^{-1})	4	n.d.	<0.0001	0.0001
N*S	4	n.d.	0.27	0.18
Contrasts				
Pea vs Flax at 0 N		n.d.	0.1	0.001
Pea vs Flax at 30 N		n.d.	0.11	0.0083
Pea vs Flax at 90 N		n.d.	0.16	0.0666
AN vs CRU		n.d.	0.23	0.31
AN vs CRU - 30 N vs 90 N		n.d.	0.0576	0.23
0 N vs 30 N		n.d.	0.0009	0.0088
30N vs 90 N		n.d.	0.0112	0.0016
Pea vs Flax - 0 N vs 30 N		n.d.	0.63	0.21
Pea vs Flax - 30 N vs 90 N		n.d.	0.86	0.53
Pea at 30 N vs Flax 90 N		n.d.	0.0032	0.79
C.V. (%)		n.d.		

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table B.16. Aboveground plant dry matter yield at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--------------------kg ha^{-1}--------------------		
Flax	0	5143	5487	2846
Flax	30 AN*	5536	5806	4072
Flax	30 CRU**	5561	6089	4179
Flax	90 AN	6176	6549	5364
Flax	90 CRU	5627	6432	4470
Pea	0	4183	4789	4388
Pea	30 AN	5848	5682	5016
Pea	30 CRU	5897	6108	4482
Pea	90 AN	6578	6579	5184
Pea	90 CRU	5823	5911	5294
LSD (P=0.05)		786	ns	770
Stubble				
Flax		5609	6073	4186
Pea		5666	5814	4873
LSD (P=0.05)		ns	ns	337
	N Applied (kg ha^{-1})			
	0	4663	5138	3617
	30 AN	5692	5744	4544
	30 CRU	5729	6099	4331
	90 AN	6377	6564	5274
	90 CRU	5725	6172	4882
	LSD (P=0.05)	560	662	533
ANOVA	df		Pr>F	
Stubble (S)	1	0.76	0.24	0.042
N Applied (kg ha^{-1})	4	<0.0001	0.0025	<0.0001
N*S	4	0.0959	0.71	0.03
Contrasts				
Pea vs Flax at 0 N		0.0186	0.13	0.0003
Pea vs Flax at 30 N		0.24	0.87	0.0264
Pea vs Flax at 90 N		0.28	0.44	0.24
AN vs CRU		0.12	0.93	0.11
AN vs CRU - 30 N vs 90 N		0.0854	0.11	0.63
0 N vs 30 N		0.0002	0.0095	0.0012
30N vs 90 N		0.0889	0.0605	0.0018
Pea vs Flax - 0 N vs 30 N		0.0117	0.26	0.0509
Pea vs Flax - 30 N vs 90 N		0.95	0.67	0.42
Pea at 30 N vs Flax 90 N		0.92	0.0707	0.53
C.V. (%)		9.6	10.8	11.4

* Ammonium nitrate

** Controlled-release urea

Table B.17. Aboveground plant dry matter yield 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----kg ha^{-1}-----		
Flax	0	6519	6506	2871
Flax	30 AN*	7711	7250	3707
Flax	30 CRU**	7421	7456	4634
Flax	90 AN	7332	8201	6644
Flax	90 CRU	9079	7913	5184
Pea	0	6949	6626	5011
Pea	30 AN	8249	7313	5873
Pea	30 CRU	7299	7923	5545
Pea	90 AN	8873	7633	7177
Pea	90 CRU	7467	7700	6471
LSD (P=0.05)		ns	ns	1085
Stubble				
Flax		7612	7465	4608
Pea		7768	7439	6015
LSD (P=0.05)		ns	ns	453
	N Applied (kg ha^{-1})			
	0	6734	6566	3941
	30 AN	7980	7281	4790
	30 CRU	7360	7690	5089
	90 AN	8103	7917	6910
	90 CRU	8273	7807	5828
	LSD (P=0.05)	1028	734	716
ANOVA	df		Pr>F	
Stubble (S)	1	0.81	0.94	0.0263
N Applied (kg ha^{-1})	4	0.0286	0.0055	<0.0001
N*S	4	0.0552	0.67	0.0973
Contrasts				
Pea vs Flax at 0 N		0.59	0.82	0.0004
Pea vs Flax at 30 N		0.71	0.49	0.0003
Pea vs Flax at 90 N		0.95	0.31	0.0218
AN vs CRU		0.53	0.56	0.12
AN vs CRU - 30 N vs 90 N		0.27	0.31	0.0096
0 N vs 30 N		0.0401	0.0064	0.0029
30N vs 90 N		0.15	0.15	<0.0001
Pea vs Flax - 0 N vs 30 N		0.8	0.82	0.33
Pea vs Flax - 30 N vs 90 N		0.73	0.21	0.21
Pea at 30 N vs Flax 90 N		0.45	0.26	0.59
C.V. (%)		12.9	9.5	13.1

* Ammonium nitrate

** Controlled-release urea

Table B.18. Aboveground plant dry matter yield 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----kg ha^{-1}-----		
Flax	0	7976	8630	3798
Flax	30 AN*	9847	10008	5200
Flax	30 CRU**	9890	10009	5159
Flax	90 AN	9802	9928	8227
Flax	90 CRU	9460	9918	6324
Pea	0	9263	7830	6463
Pea	30 AN	8927	9773	6578
Pea	30 CRU	9426	8453	6422
Pea	90 AN	10174	9342	7513
Pea	90 CRU	9009	8134	6447
LSD (P=0.05)		ns	1517	1567
Stubble				
Flax		9395	6998	5741
Pea		9360	8706	6685
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	8620	8230	5130
	30 AN	9387	9890	5889
	30 CRU	9658	9231	5791
	90 AN	9988	9635	7870
	90 CRU	9235	9026	6385
	LSD (P=0.05)	ns	1064	1038
ANOVA	df		Pr>F	
Stubble (S)	1	0.92	0.0727	0.15
N Applied (kg ha^{-1})	4	0.52	0.0351	0.0002
N*S	4	0.67	0.53	0.0274
Contrasts				
Pea vs Flax at 0 N		0.25	0.29	0.0017
Pea vs Flax at 30 N		0.38	0.0981	0.0213
Pea vs Flax at 90 N		0.96	0.0316	0.59
AN vs CRU		0.67	0.0948	0.0357
AN vs CRU - 30 N vs 90 N		0.37	0.95	0.0631
0 N vs 30 N		0.2	0.0065	0.12
30N vs 90 N		0.88	0.53	0.0014
Pea vs Flax - 0 N vs 30 N		0.16	0.92	0.14
Pea vs Flax - 30 N vs 90 N		0.57	0.7	0.0324
Pea at 30 N vs Flax 90 N		0.56	0.13	0.16
C.V. (%)		17.0	11.2	16.2

* Ammonium nitrate

** Controlled-release urea

Table B.19. Aboveground plant dry matter yield 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg ha^{-1}----------		
Flax	0	6962	10531	4224
Flax	30 AN*	9603	11691	5947
Flax	30 CRU**	9537	11286	5381
Flax	90 AN	9980	12839	8219
Flax	90 CRU	10440	12139	7456
Pea	0	9685	10728	7513
Pea	30 AN	9587	11592	8342
Pea	30 CRU	9423	11483	7603
Pea	90 AN	10850	11866	8620
Pea	90 CRU	10686	11319	7587
LSD (P=0.05)		ns	ns	1771
Stubble				
Flax		9304	11697	6245
Pea		10046	11398	7933
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	8323	10630	5869
	30 AN	9595	11642	7144
	30 CRU	9480	11385	6492
	90 AN	10415	12352	8419
	90 CRU	10563	11729	7521
	LSD (P=0.05)	ns	870	897
ANOVA	df		Pr>F	
Stubble (S)	1	0.25	0.54	0.14
N Applied (kg ha^{-1})	4	0.18	0.0084	<0.0001
N*S	4	0.58	0.49	0.0049
Contrasts				
Pea vs Flax at 0 N		0.0537	0.76	0.0007
Pea vs Flax at 30 N		0.95	0.92	0.0008
Pea vs Flax at 90 N		0.56	0.0614	0.67
AN vs CRU		0.98	0.15	0.0187
AN vs CRU - 30 N vs 90 N		0.85	0.54	0.69
0 N vs 30 N		0.16	0.0235	0.0187
30N vs 90 N		0.18	0.0893	0.001
Pea vs Flax - 0 N vs 30 N		0.11	0.84	0.21
Pea vs Flax - 30 N vs 90 N		0.65	0.13	0.0028
Pea at 30 N vs Flax 90 N		0.47	0.0481	0.83
C.V. (%)		20.0	7.3	12.3

* Ammonium nitrate

** Controlled-release urea

Table B.20. Aboveground plant dry matter yield 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg ha^{-1}----------		
Flax	0	n.d.†	9843	4158
Flax	30 AN*	n.d.	10389	5495
Flax	30 CRU**	n.d.	10007	5553
Flax	90 AN	n.d.	10521	7923
Flax	90 CRU	n.d.	10608	7308
Pea	0	n.d.	9525	6759
Pea	30 AN	n.d.	9465	8005
Pea	30 CRU	n.d.	10318	7792
Pea	90 AN	n.d.	11210	9531
Pea	90 CRU	n.d.	10296	8120
LSD (P=0.05)		n.d.	ns	1933
Stubble				
Flax		n.d.	10273	6088
Pea		n.d.	10163	8041
LSD (P=0.05)		n.d.	ns	ns
	N Applied (kg ha^{-1})			
	0	n.d.	9684	5458
	30 AN	n.d.	9927	6750
	30 CRU	n.d.	10162	6672
	90 AN	n.d.	10865	8727
	90 CRU	n.d.	10452	7714
	LSD (P=0.05)	n.d.	ns	1244
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.9	0.0594
N Applied (kg ha^{-1})	4	n.d.	0.35	0.0002
N*S	4	n.d.	0.71	0.56
Contrasts				
Pea vs Flax at 0 N		n.d.	0.76	0.0103
Pea vs Flax at 30 N		n.d.	0.67	0.0014
Pea vs Flax at 90 N		n.d.	0.79	0.0805
AN vs CRU		n.d.	0.84	0.21
AN vs CRU - 30 N vs 90 N		n.d.	0.45	0.28
0 N vs 30 N		n.d.	0.49	0.0245
30N vs 90 N		n.d.	0.16	0.0017
Pea vs Flax - 0 N vs 30 N		n.d.	0.99	0.83
Pea vs Flax - 30 N vs 90 N		n.d.	0.56	0.18
Pea at 30 N vs Flax 90 N		n.d.	0.36	0.67
C.V. (%)		n.d.	11.7	17.1

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table B.21. Aboveground plant dry matter yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------------------kg ha^{-1}---------------------		
Flax	0	9209	9668	4987
Flax	30 AN*	10046	9996	6029
Flax	30 CRU**	9406	10149	6873
Flax	90 AN	9800	10444	9047
Flax	90 CRU	10374	10783	8399
Pea	0	9652	8377	6726
Pea	30 AN	10472	9580	8186
Pea	30 CRU	9406	10083	8465
Pea	90 AN	11555	10739	7940
Pea	90 CRU	8225	10072	8177
LSD (P=0.05)		ns	ns	1777
Stubble				
Flax		9767	10208	7067
Pea		9862	9770	7899
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	9431	9022	5856
	30 AN	10259	9788	7107
	30 CRU	9406	10116	7669
	90 AN	10677	10592	8493
	90 CRU	9300	10428	8288
	LSD (P=0.05)	ns	863	1251
ANOVA	df		Pr>F	
Stubble (S)	1	0.86	0.42	0.14
N Applied (kg ha^{-1})	4	0.3	0.0081	0.0015
N*S	4	0.18	0.4	0.0528
Contrasts				
Pea vs Flax at 0 N		0.69	0.0608	0.0548
Pea vs Flax at 30 N		0.78	0.61	0.005
Pea vs Flax at 90 N		0.8	0.66	0.29
AN vs CRU		0.0502	0.78	0.68
AN vs CRU - 30 N vs 90 N		0.63	0.41	0.38
0 N vs 30 N		0.55	0.0169	0.0075
30N vs 90 N		0.78	0.0714	0.028
Pea vs Flax - 0 N vs 30 N		0.86	0.16	0.9
Pea vs Flax - 30 N vs 90 N		0.71	0.96	0.0068
Pea at 30 N vs Flax 90 N		0.85	0.11	0.52
C.V. (%)		15.9	8.4	16.2

* Ammonium nitrate

** Controlled-release urea

Table B.22. Aboveground plant dry matter yield at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date						
Stubble	N Applied (kg ha^{-1})	Flag Leaf	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		kg ha^{-1}						
Durum	34	586	2373	4026	3670	4090	4194	4935
Durum	50	643	2382	3973	4059	4383	3755	5318
Durum	78	687	2762	3942	3763	5146	4941	6080
Pea	34	471	1653	2270	3066	3608	3280	4381
Pea	50	239	1889	2527	2498	3440	4033	3582
Pea	78	438	2673	3201	4722	4061	4497	6168
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns
Stubble								
Durum		638	2506	3980	3831	4540	4297	5444
Pea		383	2071	2666	3428	3703	3937	4710
LSD (P=0.05)		ns	ns	1009	ns	ns	ns	ns
N Applied (kg ha^{-1})								
	34	528	2013	3148	3368	3849	3737	4658
	50	441	2135	3250	3279	3912	3894	4450
	78	562	2717	3571	4242	4603	4719	6124
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F						
Stubble (S)	1	0.0814	0.17	0.0149	0.38	0.19	0.48	0.32
N Applied (kg ha^{-1})	2	0.75	0.16	0.74	0.19	0.54	0.25	0.16
N*S	2	0.69	0.69	0.67	0.1	0.91	0.62	0.59
Contrasts								
34 N vs 50 N		0.6	0.74	0.86	0.87	0.93	0.8	0.82
50 N vs 78 N		0.47	0.14	0.58	0.1	0.36	0.19	0.0799
Pea vs Durum - 34 N vs 50 N		0.4	0.76	0.79	0.39	0.76	0.34	0.51
Pea vs Durum - 50 N vs 78 N		0.65	0.59	0.55	0.0379	0.92	0.56	0.32
Durum at 50 N vs Pea at 34 N		0.48	0.18	0.0552	0.22	0.47	0.59	0.46
Durum at 78 N vs Pea at 50 N		0.0784	0.12	0.1	0.12	0.13	0.31	0.0665
C.V. (%)		55.8	27.7	29.6	25.8	30.8	25.2	29.9

*Days after anthesis

Table B.23. Aboveground dry matter accumulation between anthesis and 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg ha^{-1}---		
Flax	0	4067	4180	2141
Flax	30 AN*	4510	4189	1956
Flax	30 CRU**	3845	4059	2694
Flax	90 AN	3624	3895	3683
Flax	90 CRU	4747	4351	3929
Pea	0	5469	3588	2338
Pea	30 AN	4624	3898	3170
Pea	30 CRU	3509	3975	3982
Pea	90 AN	4977	4160	2756
Pea	90 CRU	2402	4161	2883
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		4158	4135	2881
Pea		4196	3957	3026
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	4768	3884	2239
	30 AN	4567	4044	2563
	30 CRU	3677	4017	3338
	90 AN	4300	4028	3219
	90 CRU	3574	4256	3406
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.93	0.62	0.69
N Applied (kg ha^{-1})	4	0.5	0.96	0.23
N*S	4	0.16	0.93	0.17
Contrasts				
Pea vs Flax at 0 N		0.22	0.4	0.82
Pea vs Flax at 30 N		0.89	0.7	0.0434
Pea vs Flax at 90 N		0.54	0.94	0.1
AN vs CRU		0.17	0.77	0.27
AN vs CRU - 30 N vs 90 N		0.89	0.71	0.49
0 N vs 30 N		0.37	0.73	0.18
30N vs 90 N		0.75	0.75	0.4
Pea vs Flax - 0 N vs 30 N		0.29	0.64	0.32
Pea vs Flax - 30 N vs 90 N		0.74	0.75	0.0143
Pea at 30 N vs Flax 90 N		0.88	0.71	0.7
C.V. (%)		38.9	24.1	40.5

* Ammonium nitrate

** Controlled-release urea

Table B.24. Post-anthesis aboveground dry matter accumulation as a percentage of aboveground plant dry matter yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	43.5	42.6	42.1
Flax	30 AN*	41.3	41.8	32.1
Flax	30 CRU**	40.4	39.8	38.5
Flax	90 AN	36.9	36.4	39.1
Flax	90 CRU	44.1	40.2	46.7
Pea	0	55.4	42.8	34.0
Pea	30 AN	43.8	39.9	38.3
Pea	30 CRU	35.3	39.0	45.7
Pea	90 AN	41.6	38.0	33.7
Pea	90 CRU	28.0	41.1	33.8
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		41.2	40.2	39.7
Pea		40.8	40.2	37.1
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	49.4	42.7	38.1
	30 AN	42.5	40.8	35.2
	30 CRU	37.9	39.4	42.1
	90 AN	39.2	37.2	36.4
	90 CRU	36.1	40.7	40.3
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.89	1	0.27
N Applied (kg ha^{-1})	4	0.18	0.73	0.63
N*S	4	0.17	0.99	0.2
Contrasts				
Pea vs Flax at 0 N		0.14	0.97	0.24
Pea vs Flax at 30 N		0.82	0.74	0.17
Pea vs Flax at 90 N		0.31	0.75	0.0646
AN vs CRU		0.34	0.72	0.14
AN vs CRU - 30 N vs 90 N		0.86	0.4	0.67
0 N vs 30 N		0.072	0.46	0.89
30N vs 90 N		0.53	0.69	0.92
Pea vs Flax - 0 N vs 30 N		0.19	0.83	0.1
Pea vs Flax - 30 N vs 90 N		0.59	0.66	0.0322
Pea at 30 N vs Flax 90 N		0.87	0.78	0.85
C.V. (%)		27.7	20.1	25.7

* Ammonium nitrate

** Controlled-release urea

Table B.25. Ratio of head dry matter yield to total aboveground plant dry matter yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
Flax	0	0.50	0.54	0.56
Flax	30 AN*	0.47	0.52	0.53
Flax	30 CRU**	0.49	0.51	0.52
Flax	90 AN	0.40	0.49	0.48
Flax	90 CRU	0.46	0.50	0.48
Pea	0	0.51	0.54	0.52
Pea	30 AN	0.45	0.51	0.51
Pea	30 CRU	0.48	0.50	0.48
Pea	90 AN	0.44	0.50	0.42
Pea	90 CRU	0.47	0.48	0.49
LSD (P=0.05)		0.05	0.04	ns
Stubble				
Flax		0.46	0.51	0.51
Pea		0.47	0.51	0.48
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	0.51	0.54	0.54
	30 AN	0.46	0.51	0.52
	30 CRU	0.48	0.51	0.50
	90 AN	0.42	0.49	0.45
	90 CRU	0.46	0.49	0.49
	LSD (P=0.05)	0.04	0.02	0.05
ANOVA	df		Pr>F	
Stubble (S)	1	0.35	0.66	0.29
N Applied ($kg\ ha^{-1}$)	4	0.0013	0.0001	0.0097
N*S	4	0.52	0.69	0.74
Contrasts				
Pea vs Flax at 0 N		0.49	0.77	0.34
Pea vs Flax at 30 N		0.48	0.54	0.27
Pea vs Flax at 90 N		0.17	0.42	0.29
AN vs CRU		0.0225	0.26	0.69
AN vs CRU - 30 N vs 90 N		0.63	1	0.0814
0 N vs 30 N		0.0251	0.0009	0.14
30N vs 90 N		0.0278	0.0121	0.0238
Pea vs Flax - 0 N vs 30 N		0.35	0.88	0.88
Pea vs Flax - 30 N vs 90 N		0.16	0.85	0.97
Pea at 30 N vs Flax 90 N		0.0487	0.48	0.63
C.V. (%)		7.8	3.6	9.6

* Ammonium nitrate

** Controlled-release urea

Table B.26. Ratio of head dry matter yield to stem/leaf dry matter yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	1.00	1.18	1.25
Flax	30 AN*	0.90	1.09	1.13
Flax	30 CRU**	0.95	1.04	1.08
Flax	90 AN	0.69	0.97	0.92
Flax	90 CRU	0.85	1.01	0.95
Pea	0	1.06	1.17	1.10
Pea	30 AN	0.83	1.04	1.05
Pea	30 CRU	0.94	1.03	0.92
Pea	90 AN	0.79	0.98	0.79
Pea	90 CRU	0.89	0.92	0.96
LSD (P=0.05)		0.16	0.14	0.21
Stubble				
Flax		0.87	1.06	1.07
Pea		0.90	1.03	0.97
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	1.03	1.17	1.18
	30 AN	0.86	1.06	1.09
	30 CRU	0.94	1.03	1.00
	90 AN	0.74	0.98	0.86
	90 CRU	0.87	0.96	0.95
	LSD (P=0.05)	0.12	0.08	0.14
ANOVA	df		Pr>F	
Stubble (S)	1	0.35	0.67	0.25
N Applied (kg ha^{-1})	4	0.0008	<0.0001	0.0009
N*S	4	0.61	0.69	0.68
Contrasts				
Pea vs Flax at 0 N		0.4	0.85	0.17
Pea vs Flax at 30 N		0.52	0.55	0.11
Pea vs Flax at 90 N		0.19	0.44	0.44
AN vs CRU		0.0185	0.38	0.97
AN vs CRU - 30 N vs 90 N		0.56	0.75	0.0576
0 N vs 30 N		0.0191	0.0006	0.0327
30N vs 90 N		0.0243	0.0057	0.0073
Pea vs Flax - 0 N vs 30 N		0.31	0.8	0.83
Pea vs Flax - 30 N vs 90 N		0.19	0.87	0.51
Pea at 30 N vs Flax 90 N		0.0458	0.35	0.49
C.V. (%)		13.0	7.0	13.3

* Ammonium nitrate

** Controlled-release urea

Table B.27. Average head mass 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---------- $g\ head^{-1}$ ----------		
Flax	0	0.93	0.86	0.77
Flax	30 AN*	0.89	0.84	0.82
Flax	30 CRU**	0.87	0.80	0.83
Flax	90 AN	0.80	0.83	0.79
Flax	90 CRU	0.88	0.78	0.81
Pea	0	0.96	0.85	0.85
Pea	30 AN	0.90	0.78	0.89
Pea	30 CRU	0.90	0.75	0.83
Pea	90 AN	0.87	0.82	0.73
Pea	90 CRU	0.92	0.71	0.77
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		0.88	0.82	0.80
Pea		0.91	0.78	0.81
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	0.95	0.86	0.81
	30 AN	0.90	0.81	0.85
	30 CRU	0.88	0.78	0.83
	90 AN	0.84	0.82	0.76
	90 CRU	0.90	0.74	0.79
	LSD (P=0.05)	ns	ns	ns
ANOVA	**df**		**Pr>F**	
Stubble (S)	1	0.12	0.28	0.76
N Applied ($kg\ ha^{-1}$)	4	0.37	0.12	0.26
N*S	4	0.99	0.95	0.23
Contrasts				
Pea vs Flax at 0 N		0.71	1	0.12
Pea vs Flax at 30 N		0.7	0.2	0.41
Pea vs Flax at 90 N		0.33	0.33	0.27
AN vs CRU		0.51	0.11	0.51
AN vs CRU - 30 N vs 90 N		0.3	0.48	0.28
0 N vs 30 N		0.24	0.0653	0.38
30N vs 90 N		0.53	0.82	0.0578
Pea vs Flax - 0 N vs 30 N		0.94	0.45	0.38
Pea vs Flax - 30 N vs 90 N		0.69	0.82	0.13
Pea at 30 N vs Flax 90 N		0.26	0.33	0.27
C.V. (%)		12.2	9.4	9.9

* Ammonium nitrate

** Controlled-release urea

Table B.28. Average number of heads per m^2 at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------------------heads m^2----------------------		
Flax	0	448	575	301
Flax	30 AN*	521	606	348
Flax	30 CRU**	522	619	352
Flax	90 AN	542	616	494
Flax	90 CRU	563	641	420
Pea	0	521	550	406
Pea	30 AN	543	601	445
Pea	30 CRU	540	625	418
Pea	90 AN	590	617	488
Pea	90 CRU	509	611	457
LSD (P=0.05)		ns	37	59
Stubble				
Flax		519	612	383
Pea		540	601	443
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	484	563	354
	30 AN	532	604	396
	30 CRU	531	622	385
	90 AN	566	617	491
	90 CRU	536	626	439
	LSD (P=0.05)	ns	27	36
ANOVA	df		Pr>F	
Stubble (S)	1	0.41	0.11	0.0837
N Applied (kg ha^{-1})	4	0.0525	0.0004	<0.0001
N*S	4	0.15	0.57	0.0215
Contrasts				
Pea vs Flax at 0 N		0.059	0.17	0.0011
Pea vs Flax at 30 N		0.46	0.97	0.0004
Pea vs Flax at 90 N		0.89	0.26	0.46
AN vs CRU		0.39	0.14	0.0156
AN vs CRU - 30 N vs 90 N		0.42	0.63	0.1
0 N vs 30 N		0.0394	0.0002	0.0204
30N vs 90 N		0.28	0.37	<0.0001
Pea vs Flax - 0 N vs 30 N		0.23	0.28	0.44
Pea vs Flax - 30 N vs 90 N		0.52	0.43	0.0119
Pea at 30 N vs Flax 90 N		0.66	0.23	0.22
C.V. (%)		9.4	4.4	8.4

* Ammonium nitrate

** Controlled-release urea

Table B.29. Lodging score (0-9) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--------------------kg ha^{-1}--------------------		
Flax	0	0.1	3.6	0.0
Flax	30 AN*	0.4	5.0	0.0
Flax	30 CRU**	0.3	5.1	0.0
Flax	90 AN	3.4	6.5	0.3
Flax	90 CRU	1.5	6.5	0.8
Pea	0	1.1	2.5	0.0
Pea	30 AN	3.5	4.1	0.3
Pea	30 CRU	1.6	6.6	0.5
Pea	90 AN	2.5	7.3	4.5
Pea	90 CRU	2.6	6.9	3.0
LSD (P=0.05)		2.6	2.2	1.2
Stubble				
Flax		1.1	5.4	0.2
Pea		2.3	5.5	1.7
LSD (P=0.05)		ns	ns	0.5
N Applied (kg ha^{-1})				
	0	0.6	3.1	0.0
	30 AN	1.9	4.6	0.1
	30 CRU	0.9	5.9	0.3
	90 AN	3.0	6.9	2.4
	90 CRU	2.1	6.7	1.9
	LSD (P=0.05)	ns	1.6	0.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.1081	0.66	0.0485
N Applied (kg ha^{-1})	4	0.1042	0.0003	<0.0001
N*S	4	0.31	0.44	<0.0001
Contrasts				
Pea vs Flax at 0 N		0.43	0.3	1
Pea vs Flax at 30 N		0.0179	0.68	0.38
Pea vs Flax at 90 N		0.92	0.47	<0.0001
AN vs CRU		0.15	0.32	0.48
AN vs CRU - 30 N vs 90 N		0.94	0.19	0.25
0 N vs 30 N		0.31	0.0045	0.57
30N vs 90 N		0.1	0.01	<0.0001
Pea vs Flax - 0 N vs 30 N		0.43	0.31	0.57
Pea vs Flax - 30 N vs 90 N		0.1	0.83	<0.0001
Pea at 30 N vs Flax 90 N		0.92	0.15	0.77
C.V. (%)		106.0	29.3	80.5

* Ammonium nitrate

** Controlled-release urea

Table B.30. Select agronomic data for the Swift Current-01 site..

Treatment: Stubble	Treatment: N Applied ($kg\ ha^{-1}$)	Post-anthesis DM accumulation[a]	% DM accumulated post-anthesis[a]	Ratio of head DM to whole plant Dm[b]	Ratio of head DM to stem/leaf DM[b]	Average heads per m^2	Average mass per head[b]
		---kg ha^{-1}---					---g $head^{-1}$---
Durum	34	2562	52.1	0.65	1.88	220	0.85
Durum	50	2937	55.0	0.62	1.65	221	0.78
Durum	78	3318	50.1	0.62	1.65	242	0.86
Pea	34	2728	62.2	0.69	2.25	202	0.97
Pea	50	1693	45.6	0.67	2.04	191	0.94
Pea	78	3495	55.2	0.66	1.93	233	0.73
LSD (P=0.05)		ns	ns	0.04	0.32	ns	0.19
Stubble							
Durum		2939	52.4	0.63	1.73	228	0.83
Pea		2639	54.3	0.67	2.07	209	0.88
LSD (P=0.05)		ns	ns	0.02	0.18	ns	ns
	N Applied ($kg\ ha^{-1}$)						
	34	2645	57.1	0.67	2.06	211	0.91
	50	2315	50.3	0.65	1.85	206	0.86
	78	3407	52.7	0.64	1.79	238	0.80
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F					
Stubble (S)	1	0.65	0.76	0.002	0.0015	0.3	0.35
N Applied ($kg\ ha^{-1}$)	2	0.4	0.66	0.097	0.0562	0.31	0.23
N*S	2	0.6	0.43	0.96	0.85	0.88	0.0656
Contrasts							
34 N vs 50 N		0.69	0.38	0.1	0.0636	0.81	0.43
50 N vs 78 N		0.2	0.76	0.62	0.61	0.16	0.33
Pea vs Durum - 34 N vs 50 N		0.39	0.22	0.8	0.94	0.79	0.63
Pea vs Durum - 50 N vs 78 N		0.39	0.35	0.8	0.61	0.63	0.029
Durum at 50 N vs Pea at 34 N		0.86	0.51	0.0038	0.0017	0.54	0.0485
Durum at 78 N vs Pea at 50 N		0.17	0.68	0.02	0.0216	0.11	0.37
C.V. (%)		49.5	24.5	3.5	9.4	16.8	12.4

*Days after anthesis

[a] 'Post-anthesis' refers to the period between anthesis and 35 DAA.

[b] Based on dry matter samples collcted 35 DAA.

8.3. APPENDIX C – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON TISSUE N CONCENTRATION AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table C.1. Whole plant tissue N concentration at the flag leaf stage at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------g N kg^{-1}----------		
Flax	0	n.d.†	29.4	19.8
Flax	30 AN*	n.d.	28.4	20.6
Flax	30 CRU**	n.d.	28.7	20.7
Flax	90 AN	n.d.	31.0	28.1
Flax	90 CRU	n.d.	32.7	27.1
Pea	0	n.d.	29.0	20.3
Pea	30 AN	n.d.	28.3	25.7
Pea	30 CRU	n.d.	29.5	22.8
Pea	90 AN	n.d.	31.2	30.3
Pea	90 CRU	n.d.	32.6	30.9
LSD (P=0.05)		n.d.	3.6	3.6
Stubble				
Flax		n.d.	30.0	23.3
Pea		n.d.	30.0	26.0
LSD (P=0.05)		n.d.	ns	1.7
	N Applied (kg ha^{-1})			
	0	n.d.	29.2	20.0
	30 AN	n.d.	28.4	23.1
	30 CRU	n.d.	29.1	21.7
	90 AN	n.d.	31.1	29.2
	90 CRU	n.d.	32.6	29.0
	LSD (P=0.05)	n.d.	2.3	3.0
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.95	0.0076
N Applied (kg ha^{-1})	4	n.d.	0.0052	<0.0001
N*S	4	n.d.	0.99	0.47
Contrasts				
Pea vs Flax at 0 N		n.d.	0.83	0.81
Pea vs Flax at 30 N		n.d.	0.79	0.0076
Pea vs Flax at 90 N		n.d.	0.97	0.0231
AN vs CRU		n.d.	0.16	0.4
AN vs CRU - 30 N vs 90 N		n.d.	0.61	0.54
0 N vs 30 N		n.d.	0.67	0.0461
30N vs 90 N		n.d.	0.0006	<0.0001
Pea vs Flax - 0 N vs 30 N		n.d.	0.71	0.17
Pea vs Flax - 30 N vs 90 N		n.d.	0.86	0.75
Pea at 30 N vs Flax 90 N		n.d.	0.0285	0.0125
C.V. (%)		n.d.	10.6	7.4

* Ammonium nitrate

** Controlled-release urea

† Data were not collected.

Table C.2. Tissue N concentration of the stem/leaf fraction at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------g N kg^{-1}	----------	
Flax	0	16.4	26.0	14.5
Flax	30 AN*	17.7	24.3	15.9
Flax	30 CRU**	17.6	25.2	14.9
Flax	90 AN	22.2	22.9	21.5
Flax	90 CRU	21.5	25.9	20.5
Pea	0	25.2	22.8	16.0
Pea	30 AN	24.2	23.6	20.3
Pea	30 CRU	25.2	24.0	17.3
Pea	90 AN	28.6	26.5	23.5
Pea	90 CRU	25.7	27.1	22.9
LSD (P=0.05)		2.7	ns	3.3
Stubble				
Flax		19.1	24.8	17.5
Pea		25.8	24.8	20.0
LSD (P=0.05)		0.9	ns	ns
N Applied (kg ha^{-1})				
	0	20.8	24.4	15.2
	30 AN	20.9	23.9	18.1
	30 CRU	21.4	24.6	16.1
	90 AN	25.4	24.7	22.5
	90 CRU	23.6	26.5	21.7
	LSD (P=0.05)	1.4	ns	2.2
ANOVA	df		Pr>F	
Stubble (S)	1	0.0042	0.96	0.1
N Applied (kg ha^{-1})	4	<0.0001	0.26	<0.0001
N*S	4	0.0238	0.0815	0.71
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.0632	0.38
Pea vs Flax at 30 N		<0.0001	0.44	0.007
Pea vs Flax at 90 N		<0.0001	0.0469	0.0718
AN vs CRU		0.14	0.16	0.0787
AN vs CRU - 30 N vs 90 N		0.0229	0.5	0.43
0 N vs 30 N		0.52	0.87	0.052
30N vs 90 N		<0.0001	0.11	<0.0001
Pea vs Flax - 0 N vs 30 N		0.13	0.28	0.31
Pea vs Flax - 30 N vs 90 N		0.0741	0.0584	0.43
Pea at 30 N vs Flax 90 N		0.0011	0.6	0.0616
C.V. (%)		5.9	9.4	17.4

* Ammonium nitrate

** Controlled-release urea

Table C.3. Tissue N concentration of the stem/leaf fraction 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---g N kg^{-1}---		
Flax	0	11.8	22.4	14.4
Flax	30 AN*	12.7	18.9	13.4
Flax	30 CRU**	12.6	23.1	11.8
Flax	90 AN	17.9	20.4	18.9
Flax	90 CRU	15.4	20.5	18.7
Pea	0	19.3	18.1	16.3
Pea	30 AN	19.5	20.7	15.8
Pea	30 CRU	18.7	21.4	15.2
Pea	90 AN	21.9	22.9	20.8
Pea	90 CRU	19.4	22.1	21.1
LSD (P=0.05)		2.7	2.2	2.2
Stubble				
Flax		14.1	21.0	15.4
Pea		19.7	21.0	17.8
LSD (P=0.05)		0.8	ns	1.0
	N Applied (kg ha^{-1})			
	0	15.5	20.2	15.4
	30 AN	16.1	19.8	14.6
	30 CRU	15.6	22.3	13.5
	90 AN	19.9	21.6	19.8
	90 CRU	17.4	21.3	19.9
	LSD (P=0.05)	1.3	ns	1.6
ANOVA	df		Pr>F	
Stubble (S)	1	0.0099	0.98	0.003
N Applied (kg ha^{-1})	4	<0.0001	0.17	<0.0001
N*S	4	0.019	0.0207	0.89
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.0114	0.0927
Pea vs Flax at 30 N		<0.0001	0.93	0.0007
Pea vs Flax at 90 N		<0.0001	0.0718	0.0074
AN vs CRU		0.0022	0.17	0.35
AN vs CRU - 30 N vs 90 N		0.0275	0.078	0.3
0 N vs 30 N		0.53	0.41	0.0656
30N vs 90 N		<0.0001	0.59	<0.0001
Pea vs Flax - 0 N vs 30 N		0.34	0.0297	0.45
Pea vs Flax - 30 N vs 90 N		0.0073	0.21	0.53
Pea at 30 N vs Flax 90 N		0.0038	0.55	0.0002
C.V. (%)		7.2	10.3	19.5

* Ammonium nitrate

** Controlled-release urea

Table C.4. Tissue N concentration of the stem/leaf fraction 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------g N kg^{-1}----------		
Flax	0	10.0	18.0	11.2
Flax	30 AN*	11.1	16.7	10.0
Flax	30 CRU**	10.7	18.2	9.7
Flax	90 AN	14.9	19.6	14.6
Flax	90 CRU	14.5	18.4	9.9
Pea	0	16.4	18.0	11.2
Pea	30 AN	17.7	17.6	11.8
Pea	30 CRU	16.1	18.9	12.0
Pea	90 AN	19.6	19.9	15.1
Pea	90 CRU	17.1	20.1	14.0
LSD (P=0.05)		3.6	ns	2.4
Stubble				
Flax		12.2	18.2	11.1
Pea		17.4	18.9	12.8
LSD (P=0.05)		1.4	ns	1.1
	N Applied (kg ha^{-1})			
	0	13.2	18.0	11.2
	30 AN	14.4	17.2	10.9
	30 CRU	13.4	18.6	10.8
	90 AN	17.2	19.8	14.9
	90 CRU	15.8	19.2	11.9
	LSD (P=0.05)	2.2	1.1	1.7
ANOVA	df		Pr>F	
Stubble (S)	1	0.0038	0.28	0.0272
N Applied (kg ha^{-1})	4	0.0032	0.0004	0.0003
N*S	4	0.34	0.59	0.15
Contrasts				
Pea vs Flax at 0 N		0.0002	1	1
Pea vs Flax at 30 N		<0.0001	0.18	0.02
Pea vs Flax at 90 N		0.0015	0.0972	0.0082
AN vs CRU		0.1	0.24	0.0162
AN vs CRU - 30 N vs 90 N		0.76	0.0145	0.0226
0 N vs 30 N		0.42	0.72	0.67
30N vs 90 N		0.0019	0.0002	0.0003
Pea vs Flax - 0 N vs 30 N		0.81	0.4	0.17
Pea vs Flax - 30 N vs 90 N		0.13	0.79	0.79
Pea at 30 N vs Flax 90 N		0.0403	0.2	0.68
C.V. (%)		14.1	5.6	24.5

* Ammonium nitrate

** Controlled-release urea

Table C.5. Tissue N concentration of the stem/leaf fraction 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---g N kg^{-1}---		
Flax	0	9.3	14.4	9.1
Flax	30 AN*	8.9	14.3	9.1
Flax	30 CRU**	9.1	14.7	9.1
Flax	90 AN	14.7	14.4	10.9
Flax	90 CRU	13.0	15.5	10.3
Pea	0	14.0	14.1	9.6
Pea	30 AN	16.3	13.6	9.5
Pea	30 CRU	14.9	15.1	9.6
Pea	90 AN	17.9	17.2	13.0
Pea	90 CRU	14.7	15.7	12.3
LSD (P=0.05)		3.8	3.2	2.0
Stubble				
Flax		11.0	14.6	9.7
Pea		15.5	15.1	10.8
LSD (P=0.05)		1.4	ns	ns
	N Applied (kg ha^{-1})			
	0	11.7	14.2	9.3
	30 AN	12.6	13.9	9.3
	30 CRU	12.0	14.9	9.3
	90 AN	16.3	15.8	11.9
	90 CRU	13.8	15.6	11.3
	LSD (P=0.05)	2.3	1.3	1.4
ANOVA	df		Pr>F	
Stubble (S)	1	0.0085	0.16	0.14
N Applied (kg ha^{-1})	4	0.002	0.0309	0.0005
N*S	4	0.12	0.0787	0.49
Contrasts				
Pea vs Flax at 0 N		0.0051	0.73	0.65
Pea vs Flax at 30 N		<0.0001	0.79	0.57
Pea vs Flax at 90 N		0.0385	0.0203	0.0065
AN vs CRU		0.0628	0.43	0.52
AN vs CRU - 30 N vs 90 N		0.25	0.21	0.46
0 N vs 30 N		0.51	0.76	0.98
30N vs 90 N		0.0016	0.0096	18
Pea vs Flax - 0 N vs 30 N		0.35	0.9	0.97
Pea vs Flax - 30 N vs 90 N		0.0132	0.0741	0.0961
Pea at 30 N vs Flax 90 N		0.13	0.35	0.13
C.V. (%)		16.5	8.5	22.4

* Ammonium nitrate

** Controlled-release urea

Table C.6. Tissue N concentration of the stem/leaf fraction 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		----------g N kg^{-1}	----------	
Flax	0	7.0	11.2	7.4
Flax	30 AN*	7.5	11.6	7.5
Flax	30 CRU**	7.6	11.6	7.0
Flax	90 AN	12.7	13.1	9.5
Flax	90 CRU	10.2	13.3	9.5
Pea	0	11.2	10.4	8.5
Pea	30 AN	12.9	11.9	8.3
Pea	30 CRU	11.6	12.5	8.4
Pea	90 AN	14.9	12.3	11.2
Pea	90 CRU	12.5	14.2	11.1
LSD (P=0.05)		3.4	2.8	1.5
Stubble				
Flax		9.0	12.2	8.2
Pea		12.6	12.2	9.5
LSD (P=0.05)		1.3	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	9.1	10.8	7.9
	30 AN	10.2	11.7	7.9
	30 CRU	9.6	12.1	7.7
	90 AN	13.8	12.7	10.3
	90 CRU	11.3	13.7	10.3
	LSD (P=0.05)	2.0	1.3	1.0
ANOVA	df		Pr>F	
Stubble (S)	1	0.0076	0.92	0.0532
N Applied ($kg\ ha^{-1}$)	4	0.0006	0.0023	<0.0001
N*S	4	0.47	0.51	0.89
Contrasts				
Pea vs Flax at 0 N		0.0054	0.43	0.13
Pea vs Flax at 30 N		<0.0001	0.43	0.0471
Pea vs Flax at 90 N		0.0291	0.96	0.0041
AN vs CRU		0.037	0.15	0.76
AN vs CRU - 30 N vs 90 N		0.19	0.44	0.86
0 N vs 30 N		0.37	0.0616	0.76
30N vs 90 N		0.0009	0.0088	<0.0001
Pea vs Flax - 0 N vs 30 N		0.78	0.22	0.93
Pea vs Flax - 30 N vs 90 N		0.0973	0.56	0.44
Pea at 30 N vs Flax 90 N		0.42	0.18	0.0395
C.V. (%)		18.3	10.6	21.3

* Ammonium nitrate

** Controlled-release urea

Table C.7. Tissue N concentration of the stem/leaf fraction 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------------------g N kg^{-1}	----------------------	
Flax	0	7.3	9.6	6.7
Flax	30 AN*	6.7	10.0	6.3
Flax	30 CRU**	7.5	10.4	6.7
Flax	90 AN	10.8	11.0	7.1
Flax	90 CRU	9.2	11.7	8.2
Pea	0	7.7	8.7	6.5
Pea	30 AN	10.1	10.9	7.2
Pea	30 CRU	9.3	11.4	7.0
Pea	90 AN	11.2	11.9	10.0
Pea	90 CRU	11.5	12.2	9.2
LSD (P=0.05)		3.2	2.7	1.8
Stubble				
Flax		8.3	10.5	7.0
Pea		10.0	11.0	8.0
LSD (P=0.05)		1.3	ns	0.8
	N Applied (kg ha^{-1})			
	0	7.5	9.1	6.6
	30 AN	8.4	10.5	6.8
	30 CRU	8.4	10.9	6.8
	90 AN	11.0	11.4	8.5
	90 CRU	10.4	11.9	8.7
	LSD (P=0.05)	2.0	1.1	1.3
ANOVA	df		Pr>F	
Stubble (S)	1	0.0048	0.44	0.0347
N Applied (kg ha^{-1})	4	0.0066	0.0004	0.0027
N*S	4	0.52	0.4	0.19
Contrasts				
Pea vs Flax at 0 N		0.72	0.3	0.82
Pea vs Flax at 30 N		0.0092	0.12	0.32
Pea vs Flax at 90 N		0.16	0.23	0.0039
AN vs CRU		0.63	0.24	0.76
AN vs CRU - 30 N vs 90 N		0.65	0.91	0.91
0 N vs 30 N		0.29	0.003	0.69
30N vs 90 N		0.0029	0.0184	0.0004
Pea vs Flax - 0 N vs 30 N		0.22	0.0632	0.47
Pea vs Flax - 30 N vs 90 N		0.37	0.77	0.15
Pea at 30 N vs Flax 90 N		0.74	0.82	0.37
C.V. (%)		21.4	10.3	29.1

* Ammonium nitrate

** Controlled-release urea

Table C.8. Tissue N concentration of the stem/leaf fraction at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date						
Stubble	N Applied ($kg\ ha^{-1}$)	Flag Leaf[a]	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		$g\ N\ kg^{-1}$						
Durum	34	45.0	25.2	19.1	14.4	9.9	8.2	9.0
Durum	50	44.9	24.7	22.6	19.5	11.4	8.6	8.7
Durum	78	46.2	26.2	24.3	21.7	13.7	9.2	11.8
Pea	34	43.0	26.7	25.5	21.0	16.2	10.6	9.2
Pea	50	41.9	27.7	27.1	23.6	14.1	11.2	9.8
Pea	78	51.2	28.5	25.1	20.6	16.9	9.2	7.8
LSD (P=0.05)		ns	ns	ns	ns	ns	1.4	2.3
Stubble								
Durum		45.4	25.3	22.0	18.5	11.7	8.7	9.8
Pea		45.4	27.6	25.9	21.7	15.7	10.4	8.9
LSD (P=0.05)		ns	ns	2.7	ns	3.5	0.8	ns
	N Applied ($kg\ ha^{-1}$)							
	34	44.0	25.9	22.3	17.7	13.1	9.4	9.1
	50	43.4	26.2	24.9	21.6	12.8	9.9	9.3
	78	48.7	27.3	24.7	21.2	15.3	9.2	9.8
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F						
Stubble (S)	1	0.99	0.4	0.0086	0.15	0.027	0.0007	0.17
N Applied ($kg\ ha^{-1}$)	2	0.26	0.9	0.22	0.29	0.41	0.36	0.65
N*S	2	0.46	0.97	0.22	0.34	0.62	0.0253	0.0092
Contrasts								
34 N vs 50 N		0.86	0.93	0.12	0.16	0.88	0.32	0.86
50 N vs 78 N		0.14	0.73	0.92	0.88	0.22	0.18	0.49
Pea vs Durum- 34 N vs 50 N		0.89	0.81	0.53	0.63	0.38	0.81	0.53
Pea vs Durum- 50 N vs 78 N		0.26	0.91	0.26	0.33	0.91	0.0139	0.0041
Durum at 50 N vs Pea at 34 N		0.7	0.67	0.2	0.67	0.11	0.0083	0.59
Durum at 78 N vs Pea at 50 N		0.38	0.73	0.22	0.61	0.89	0.0101	0.0857
C.V. (%)		12.8	20.9	11.1	22.0	25.0	8.4	13.5

*Days after anthesis

a Tissue N concentration is based on whole aboveground plant sample.

Table C.9. Tissue N concentration of the head fraction at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		g N kg^{-1}		
Flax	0	24.4	23.4	22.4
Flax	30 AN*	25.4	23.2	23.7
Flax	30 CRU**	25.4	23.4	23.1
Flax	90 AN	29.2	23.5	28.5
Flax	90 CRU	27.9	24.1	26.7
Pea	0	27.1	23.3	23.3
Pea	30 AN	29.2	22.8	26.5
Pea	30 CRU	29.4	23.3	25.6
Pea	90 AN	30.6	24.5	26.5
Pea	90 CRU	29.7	24.4	26.7
LSD (P=0.05)		2.4	ns	2.4
Stubble				
Flax		26.4	23.5	24.9
Pea		29.2	23.6	25.7
LSD (P=0.05)		0.9	ns	ns
	N Applied (kg ha^{-1})			
	0	25.8	23.3	22.9
	30 AN	27.3	23.0	25.1
	30 CRU	27.4	23.3	24.4
	90 AN	29.9	24.0	27.5
	90 CRU	28.8	24.2	26.7
	LSD (P=0.05)	1.4	0.9	1.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0079	0.82	0.12
N Applied (kg ha^{-1})	4	<0.0001	0.0408	0.0001
N*S	4	0.26	0.47	0.0643
Contrasts				
Pea vs Flax at 0 N		0.0113	0.94	0.47
Pea vs Flax at 30 N		<0.0001	0.56	0.0044
Pea vs Flax at 90 N		0.0258	0.19	0.24
AN vs CRU		0.32	0.33	0.23
AN vs CRU - 30 N vs 90 N		0.21	0.87	0.98
0 N vs 30 N		0.0144	0.64	0.0206
30N vs 90 N		0.0004	0.0042	0.0007
Pea vs Flax - 0 N vs 30 N		0.3	0.74	0.26
Pea vs Flax - 30 N vs 90 N		0.0268	0.12	0.0067
Pea at 30 N vs Flax 90 N		0.27	0.14	0.0716
C.V. (%)		5.0	3.6	12.9

* Ammonium nitrate

** Controlled-release urea

Table C.10. Tissue N concentration of the head fraction 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---g N kg^{-1}---		
Flax	0	21.6	23.1	20.4
Flax	30 AN*	20.6	23.9	20.9
Flax	30 CRU**	21.1	23.5	19.8
Flax	90 AN	22.2	24.0	22.2
Flax	90 CRU	21.6	23.7	21.4
Pea	0	24.1	22.1	20.9
Pea	30 AN	23.4	23.6	21.1
Pea	30 CRU	22.8	22.9	20.6
Pea	90 AN	25.5	23.7	22.2
Pea	90 CRU	23.6	23.2	21.7
LSD (P=0.05)		2.4	ns	ns
Stubble				
Flax		21.4	23.6	20.9
Pea		23.9	23.1	21.3
LSD (P=0.05)		0.9	ns	ns
	N Applied (kg ha^{-1})			
	0	22.8	22.6	20.6
	30 AN	22.0	23.8	21.0
	30 CRU	21.9	23.2	20.2
	90 AN	23.8	23.8	22.2
	90 CRU	22.6	23.4	21.5
	LSD (P=0.05)	ns	ns	0.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0251	0.4	0.4
N Applied (kg ha^{-1})	4	0.0553	0.21	0.0003
N*S	4	0.79	0.97	0.85
Contrasts				
Pea vs Flax at 0 N		0.0172	0.26	0.35
Pea vs Flax at 30 N		0.0037	0.47	0.24
Pea vs Flax at 90 N		0.0008	0.51	0.73
AN vs CRU		0.17	0.24	0.0105
AN vs CRU - 30 N vs 90 N		0.21	0.89	0.81
0 N vs 30 N		0.15	0.0778	0.93
30N vs 90 N		0.0151	0.72	0.0002
Pea vs Flax - 0 N vs 30 N		0.81	0.58	0.93
Pea vs Flax - 30 N vs 90 N		0.66	0.96	0.52
Pea at 30 N vs Flax 90 N		0.0962	0.36	0.0401
C.V. (%)		5.9	4.8	11.8

* Ammonium nitrate

** Controlled-release urea

Table C.11. Tissue N concentration of the head fraction 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------g N kg^{-1} ----------		
Flax	0	19.8	22.7	20.0
Flax	30 AN*	20.2	22.7	19.9
Flax	30 CRU**	20.3	22.9	18.9
Flax	90 AN	23.2	22.9	21.5
Flax	90 CRU	22.5	23.1	21.3
Pea	0	23.5	22.2	20.0
Pea	30 AN	24.9	22.5	20.8
Pea	30 CRU	24.4	22.3	20.4
Pea	90 AN	24.4	23.1	22.9
Pea	90 CRU	23.9	23.1	22.3
LSD (P=0.05)		2.7	ns	2.0
Stubble				
Flax		21.2	22.8	20.3
Pea		24.2	22.6	21.3
LSD (P=0.05)		1.0	ns	ns
	N Applied (kg ha^{-1})			
	0	21.6	22.4	20.0
	30 AN	22.6	22.6	20.3
	30 CRU	22.3	22.6	19.7
	90 AN	23.8	23.0	22.2
	90 CRU	23.2	23.1	21.8
	LSD (P=0.05)	ns	ns	1.4
ANOVA	df		Pr>F	
Stubble (S)	1	0.0137	0.65	0.17
N Applied (kg ha^{-1})	4	0.0734	0.28	0.0026
N*S	4	0.0866	0.78	0.79
Contrasts				
Pea vs Flax at 0 N		0.002	0.41	0.94
Pea vs Flax at 30 N		<0.0001	0.35	0.0943
Pea vs Flax at 90 N		0.11	0.83	0.0943
AN vs CRU		0.43	0.8	0.27
AN vs CRU - 30 N vs 90 N		0.73	1	0.82
0 N vs 30 N		0.23	0.56	0.98
30N vs 90 N		0.0562	0.0846	0.0003
Pea vs Flax - 0 N vs 30 N		0.61	0.89	0.29
Pea vs Flax - 30 N vs 90 N		0.0074	0.35	1
Pea at 30 N vs Flax 90 N		0.0289	0.15	0.27
C.V. (%)		6.6	3.1	12.4

* Ammonium nitrate

** Controlled-release urea

Table C.12. Tissue N concentration of the head fraction 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------g N kg^{-1}	----------	----------
Flax	0	20.0	24.5	18.3
Flax	30 AN*	20.6	24.2	19.2
Flax	30 CRU**	20.8	24.2	18.8
Flax	90 AN	25.6	23.8	20.9
Flax	90 CRU	22.5	25.9	19.7
Pea	0	22.4	24.4	18.5
Pea	30 AN	24.4	24.8	19.8
Pea	30 CRU	24.2	23.9	19.2
Pea	90 AN	27.2	24.8	20.5
Pea	90 CRU	24.0	25.9	20.5
LSD (P=0.05)		5.3	ns	ns
Stubble				
Flax		21.9	24.5	19.4
Pea		24.4	24.7	19.7
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	21.2	24.4	18.4
	30 AN	22.5	24.5	19.5
	30 CRU	22.5	24.0	19.0
	90 AN	26.4	24.3	20.7
	90 CRU	23.2	25.9	20.1
	LSD (P=0.05)	3.0	ns	1.4
ANOVA	df		Pr>F	
Stubble (S)	1	0.1246	0.54	0.43
N Applied (kg ha^{-1})	4	0.0191	0.1	0.0213
N*S	4	0.9	0.86	0.93
Contrasts				
Pea vs Flax at 0 N		0.26	0.9	0.77
Pea vs Flax at 30 N		0.0238	0.83	0.42
Pea vs Flax at 90 N		0.32	0.46	0.75
AN vs CRU		0.13	0.26	0.29
AN vs CRU - 30 N vs 90 N		0.13	0.0488	0.92
0 N vs 30 N		0.3	0.79	0.16
30N vs 90 N		0.0345	0.1	0.0239
Pea vs Flax - 0 N vs 30 N		0.65	0.82	0.82
Pea vs Flax - 30 N vs 90 N		0.32	0.72	0.73
Pea at 30 N vs Flax 90 N		0.86	0.47	0.26
C.V. (%)		12.5	5.6	13.4

* Ammonium nitrate

** Controlled-release urea

Table C.13. Tissue N concentration of the head fraction 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		g N kg^{-1}		
Flax	0	20.8	26.4	21.2
Flax	30 AN*	22.1	28.5	19.3
Flax	30 CRU**	21.9	26.8	18.9
Flax	90 AN	27.2	27.5	22.5
Flax	90 CRU	24.7	28.6	20.9
Pea	0	24.0	25.4	20.9
Pea	30 AN	25.5	27.1	20.7
Pea	30 CRU	24.9	28.8	20.2
Pea	90 AN	28.0	27.4	23.2
Pea	90 CRU	27.2	28.6	22.9
LSD (P=0.05)		3.9	ns	ns
Stubble				
Flax		23.3	27.5	20.6
Pea		25.9	27.4	21.6
LSD (P=0.05)		1.5	ns	ns
	N Applied (kg ha^{-1})			
	0	22.4	25.9	21.0
	30 AN	23.8	27.8	20.0
	30 CRU	23.4	27.8	19.6
	90 AN	27.6	27.4	22.8
	90 CRU	25.9	28.6	21.9
	LSD (P=0.05)	2.3	1.3	2.1
ANOVA	df		Pr>F	
Stubble (S)	1	0.0252	0.95	0.15
N Applied (kg ha^{-1})	4	0.0008	0.0032	0.0241
N*S	4	0.79	0.0839	0.84
Contrasts				
Pea vs Flax at 0 N		0.0534	0.38	0.82
Pea vs Flax at 30 N		0.0083	0.68	0.19
Pea vs Flax at 90 N		0.16	1	0.19
AN vs CRU		0.23	0.18	0.37
AN vs CRU - 30 N vs 90 N		0.42	0.19	0.73
0 N vs 30 N		0.24	0.0016	0.17
30N vs 90 N		0.0006	0.58	0.0016
Pea vs Flax - 0 N vs 30 N		1	0.24	0.36
Pea vs Flax - 30 N vs 90 N		0.34	0.72	0.99
Pea at 30 N vs Flax 90 N		0.5	0.91	0.23
C.V. (%)		9.2	4.4	17.0

* Ammonium nitrate

** Controlled-release urea

Table C.14. Tissue N concentration of the head fraction 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---g N kg^{-1}---		
Flax	0	23.2	26.5	21.7
Flax	30 AN*	23.9	25.3	20.5
Flax	30 CRU**	23.6	29.0	21.3
Flax	90 AN	28.8	29.6	24.2
Flax	90 CRU	27.6	29.0	23.6
Pea	0	25.9	28.2	21.8
Pea	30 AN	27.6	28.0	22.4
Pea	30 CRU	27.6	29.1	24.9
Pea	90 AN	29.8	28.1	26.4
Pea	90 CRU	30.4	29.7	26.6
LSD (P=0.05)		3.2	ns	2.5
Stubble				
Flax		25.4	27.9	22.2
Pea		28.3	28.6	24.4
LSD (P=0.05)		1.1	ns	1.1
	N Applied (kg ha^{-1})			
	0	24.5	27.4	21.7
	30 AN	25.8	26.6	21.4
	30 CRU	25.6	29.1	23.1
	90 AN	29.3	28.8	25.3
	90 CRU	29.0	29.3	25.1
	LSD (P=0.05)	1.8	ns	1.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0497	0.13	0.0383
N Applied (kg ha^{-1})	4	<0.0001	0.0504	0.0001
N*S	4	0.47	0.3	0.34
Contrasts				
Pea vs Flax at 0 N		0.0561	0.22	0.94
Pea vs Flax at 30 N		0.0003	0.16	0.0035
Pea vs Flax at 90 N		0.0495	0.66	0.0063
AN vs CRU		0.74	0.0489	0.26
AN vs CRU - 30 N vs 90 N		0.92	0.17	0.13
0 N vs 30 N		0.13	0.6	0.48
30N vs 90 N		<0.0001	0.0978	<0.0001
Pea vs Flax - 0 N vs 30 N		0.42	0.86	0.0827
Pea vs Flax - 30 N vs 90 N		0.12	0.21	0.86
Pea at 30 N vs Flax 90 N		0.53	0.45	0.77
C.V. (%)		6.4	7.1	19.7

* Ammonium nitrate

** Controlled-release urea

Table C.15. Tissue N concentration of the head fraction at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date					
Stubble	N Applied (kg ha^{-1})	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		g N kg^{-1}					
Durum	34	22.4	20.7	21.1	18.6	17.1	15.2
Durum	50	22.5	22.7	23.2	19.4	20.9	17.1
Durum	78	22.6	23.6	23.1	21.5	20.1	15.1
Pea	34	24.1	23.8	23.0	22.2	24.3	16.5
Pea	50	23.7	24.6	25.9	22.6	23.5	18.9
Pea	78	23.5	23.0	22.1	22.8	20.5	15.6
LSD (P=0.05)		1.2	ns	ns	ns	4.0	ns
Stubble							
Durum		22.5	22.3	22.5	19.8	19.4	15.8
Pea		23.8	23.8	23.7	22.6	22.8	17.0
LSD (P=0.05)		0.7	ns	ns	ns	2.3	ns
	N Applied (kg ha^{-1})						
	34	23.1	23.7	24.6	21.0	22.2	18.0
	50	23.1	23.3	22.6	22.2	20.3	15.4
	78	48.7	24.7	21.2	15.3	9.2	9.8
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F					
Stubble (S)	1	0.0018	0.0753	0.29	0.1	0.0073	0.33
N Applied (kg ha^{-1})	2	0.92	0.32	0.18	0.64	0.33	0.17
N*S	2	0.56	0.18	0.38	0.81	0.063	0.89
Contrasts							
34 N vs 50 N		0.8	0.15	0.0818	0.74	0.26	0.14
50 N vs 78 N		0.9	0.7	0.17	0.55	0.16	0.0792
Pea vs Durum- 34 N vs 50 N		0.5	0.56	0.76	0.91	0.1	0.86
Pea vs Durum- 50 N vs 78 N		0.7	0.2	0.19	0.62	0.43	0.64
Durum at 50 N vs Pea at 34 N		0.0152	0.43	0.9	0.3	0.0918	0.74
Durum at 78 N vs Pea at 50 N		0.0726	0.44	0.16	0.67	0.0835	0.0795
C.V. (%)		2.9	6.9	10.1	15.0	10.6	14.7

*Days after anthesis

8.4. APPENDIX D – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SELECTED MEASUREMENTS ASSOCIATED WITH PLANT N YIELD AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table D.1. N yield of the stem/leaf fraction at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------------------kg N ha^{-1}---------------------		
Flax	0	71	121	34
Flax	30 AN*	83	119	54
Flax	30 CRU**	82	130	52
Flax	90 AN	119	127	98
Flax	90 CRU	103	141	79
Pea	0	90	94	59
Pea	30 AN	122	114	86
Pea	30 CRU	129	125	66
Pea	90 AN	166	148	105
Pea	90 CRU	127	138	106
LSD (P=0.05)		17	27	19
Stubble				
Flax		92	128	63
Pea		127	124	84
LSD (P=0.05)		8	ns	8
	N Applied (kg ha^{-1})			
	0	81	108	47
	30 AN	102	116	70
	30 CRU	105	127	59
	90 AN	143	138	101
	90 CRU	115	139	92
	LSD (P=0.05)	12	19	13
ANOVA	df		Pr>F	
Stubble (S)	1	0.0029	0.54	0.0187
N Applied (kg ha^{-1})	4	<0.0001	0.0097	<0.0001
N*S	4	0.0697	0.2	0.32
Contrasts				
Pea vs Flax at 0 N		0.0321	0.048	0.0122
Pea vs Flax at 30 N		<0.0001	0.62	0.0014
Pea vs Flax at 90 N		<0.0001	0.34	0.0161
AN vs CRU		0.0061	0.34	0.0383
AN vs CRU - 30 N vs 90 N		0.0011	0.47	0.83
0 N vs 30 N		0.0001	0.1	0.0037
30N vs 90 N		<0.0001	0.0181	<0.0001
Pea vs Flax - 0 N vs 30 N		0.0263	0.18	0.89
Pea vs Flax - 30 N vs 90 N		0.3701	0.31	0.48
Pea at 30 N vs Flax 90 N		0.0265	0.13	0.0642
C.V. (%)		10.6	14.8	17.4

* Ammonium nitrate

** Controlled-release urea

Table D.2. N yield of the stem/leaf fraction 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg N ha^{-1}---		
Flax	0	63	113	32
Flax	30 AN*	80	106	40
Flax	30 CRU**	76	134	44
Flax	90 AN	110	131	103
Flax	90 CRU	117	128	79
Pea	0	110	93	66
Pea	30 AN	134	120	77
Pea	30 CRU	115	134	69
Pea	90 AN	163	139	124
Pea	90 CRU	119	134	113
LSD (P=0.05)		21	26	21
Stubble				
Flax		89	122	60
Pea		128	124	90
LSD (P=0.05)		9	ns	10
	N Applied (kg ha^{-1})			
	0	86	103	49
	30 AN	107	113	59
	30 CRU	95	134	57
	90 AN	136	135	114
	90 CRU	118	131	96
	LSD (P=0.05)	15	19	15
ANOVA	df		Pr>F	
Stubble (S)	1	0.0044	0.64	0.0035
N Applied (kg ha^{-1})	4	<0.0001	0.0051	<0.0001
N*S	4	0.0068	0.43	0.77
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.12	0.0023
Pea vs Flax at 30 N		<0.0001	0.45	0.0002
Pea vs Flax at 90 N		0.0006	0.44	0.0007
AN vs CRU		0.0062	0.22	0.0685
AN vs CRU - 30 N vs 90 N		0.52	0.0625	0.15
0 N vs 30 N		0.0249	0.0184	0.2
30N vs 90 N		<0.0001	0.15	<0.0001
Pea vs Flax - 0 N vs 30 N		0.94	0.11	0.8
Pea vs Flax - 30 N vs 90 N		0.0809	1	0.74
Pea at 30 N vs Flax 90 N		0.14	0.75	0.0161
C.V. (%)		13.1	15.0	19.5

* Ammonium nitrate

** Controlled-release urea

Table D.3. N yield of the stem/leaf fraction 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--------------------kg N ha^{-1}--------------------		
Flax	0	57	99	29
Flax	30 AN*	79	106	38
Flax	30 CRU**	78	117	35
Flax	90 AN	113	127	89
Flax	90 CRU	103	119	41
Pea	0	114	91	52
Pea	30 AN	120	113	58
Pea	30 CRU	114	104	57
Pea	90 AN	151	124	85
Pea	90 CRU	111	108	67
LSD (P=0.05)		26	21	22
Stubble				
Flax		86	114	46
Pea		122	108	64
LSD (P=0.05)		12	ns	ns
	N Applied (kg ha^{-1})			
	0	85	95	40
	30 AN	100	110	48
	30 CRU	96	110	46
	90 AN	132	125	87
	90 CRU	107	113	54
	LSD (P=0.05)	18	14	14
ANOVA	df		Pr>F	
Stubble (S)	1	0.0116	0.46	0.1
N Applied (kg ha^{-1})	4	0.0004	0.0042	<0.0001
N*S	4	0.13	0.63	0.19
Contrasts				
Pea vs Flax at 0 N		0.0001	0.43	0.0343
Pea vs Flax at 30 N		0.0002	0.71	0.0099
Pea vs Flax at 90 N		0.0159	0.34	0.16
AN vs CRU		0.034	0.26	0.001
AN vs CRU - 30 N vs 90 N		0.11	0.19	0.0031
0 N vs 30 N		0.12	0.019	0.28
30N vs 90 N		0.0019	0.0598	<0.0001
Pea vs Flax - 0 N vs 30 N		0.24	0.64	0.81
Pea vs Flax - 30 N vs 90 N		0.24	0.66	0.31
Pea at 30 N vs Flax 90 N		0.34	0.0585	0.31
C.V. (%)		17.0	12.2	24.5

* Ammonium nitrate

** Controlled-release urea

Table D.4. N yield of the stem/leaf fraction 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--kg N ha^{-1}--		
Flax	0	39	80	22
Flax	30 AN*	54	91	34
Flax	30 CRU**	53	89	30
Flax	90 AN	98	103	59
Flax	90 CRU	88	103	48
Pea	0	86	81	45
Pea	30 AN	99	88	50
Pea	30 CRU	89	93	46
Pea	90 AN	130	115	74
Pea	90 CRU	98	100	62
LSD (P=0.05)		24	17	19
Stubble				
Flax		66	93	39
Pea		100	95	55
LSD (P=0.05)		10	ns	ns
N Applied (kg ha^{-1})				
	0	63	80	34
	30 AN	76	89	42
	30 CRU	71	91	38
	90 AN	114	109	67
	90 CRU	93	102	55
	LSD (P=0.05)	16	11	11
ANOVA	df		Pr>F	
Stubble (S)	1	0.0139	0.72	0.14
N Applied (kg ha^{-1})	4	<0.0001	0.0003	<0.0001
N*S	4	0.18	0.65	0.92
Contrasts				
Pea vs Flax at 0 N		0.0004	0.9	0.0227
Pea vs Flax at 30 N		<0.0001	0.95	0.0204
Pea vs Flax at 90 N		0.0156	0.5	0.0433
AN vs CRU		0.0271	0.53	0.036
AN vs CRU - 30 N vs 90 N		0.17	0.24	0.34
0 N vs 30 N		0.11	0.0478	0.17
30N vs 90 N		<0.0001	0.0008	<0.0001
Pea vs Flax - 0 N vs 30 N		0.65	0.95	0.5
Pea vs Flax - 30 N vs 90 N		0.093	0.65	0.76
Pea at 30 N vs Flax 90 N		0.9	0.0364	0.39
C.V. (%)		18.8	11.7	22.4

* Ammonium nitrate

** Controlled-release urea

Table D.5. N yield of the stem/leaf fraction 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg N ha^{-1}---		
Flax	0	n.d.†	52	14
Flax	30 AN*	n.d.	62	21
Flax	30 CRU**	n.d.	59	20
Flax	90 AN	n.d.	71	43
Flax	90 CRU	n.d.	74	38
Pea	0	n.d.	49	29
Pea	30 AN	n.d.	57	34
Pea	30 CRU	n.d.	66	37
Pea	90 AN	n.d.	69	60
Pea	90 CRU	n.d.	78	49
LSD (P=0.05)		n.d.	20	11
Stubble				
Flax		n.d.	64	27
Pea		n.d.	64	42
LSD (P=0.05)		n.d.	ns	5
	N Applied (kg ha^{-1})			
	0	n.d.	51	22
	30 AN	n.d.	59	28
	30 CRU	n.d.	63	28
	90 AN	n.d.	70	51
	90 CRU	n.d.	76	44
	LSD (P=0.05)	n.d.	15	8
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.99	0.0254
N Applied (kg ha^{-1})	4	n.d.	0.0159	<0.0001
N*S	4	n.d.	0.89	0.89
Contrasts				
Pea vs Flax at 0 N		n.d.	0.76	0.0151
Pea vs Flax at 30 N		n.d.	0.92	0.0006
Pea vs Flax at 90 N		n.d.	0.92	0.0011
AN vs CRU		n.d.	0.37	0.21
AN vs CRU - 30 N vs 90 N		n.d.	0.78	0.12
0 N vs 30 N		n.d.	0.11	0.0556
30N vs 90 N		n.d.	0.0238	<0.0001
Pea vs Flax - 0 N vs 30 N		n.d.	0.76	0.89
Pea vs Flax - 30 N vs 90 N		n.d.	1	0.85
Pea at 30 N vs Flax 90 N		n.d.	0.12	0.23
C.V. (%)		n.d.	22.3	21.3

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table D.6. N yield of the stem/leaf fraction 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--kg N ha^{-1}--		
Flax	0	33	43	15
Flax	30 AN*	37	48	18
Flax	30 CRU**	36	52	22
Flax	90 AN	64	58	34
Flax	90 CRU	53	63	35
Pea	0	36	33	21
Pea	30 AN	59	52	29
Pea	30 CRU	47	57	32
Pea	90 AN	71	64	46
Pea	90 CRU	52	64	38
LSD (P=0.05)		21	11	12
Stubble				
Flax		45	53	25
Pea		53	54	33
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	34	38	18
	30 AN	48	50	23
	30 CRU	41	54	27
	90 AN	67	61	40
	90 CRU	53	63	37
	LSD (P=0.05)	15	8	
ANOVA	df		Pr>F	
Stubble (S)	1	0.0675	0.67	0.064
N Applied (kg ha^{-1})	4	0.0025	<0.0001	<0.0001
N*S	4	0.6	0.26	0.82
Contrasts				
Pea vs Flax at 0 N		0.76	0.0953	0.31
Pea vs Flax at 30 N		0.031	0.24	0.0201
Pea vs Flax at 90 N		0.64	0.37	0.093
AN vs CRU		0.0528	0.23	0.88
AN vs CRU - 30 N vs 90 N		0.45	0.67	0.28
0 N vs 30 N		0.12	0.0002	0.0471
30N vs 90 N		0.008	0.0007	0.0002
Pea vs Flax - 0 N vs 30 N		0.32	0.041	0.56
Pea vs Flax - 30 N vs 90 N		0.23	0.83	0.61
Pea at 30 N vs Flax 90 N		0.47	0.11	0.35
C.V. (%)		30.5	13.7	29.1

* Ammonium nitrate

** Controlled-release urea

Table D.7. N yield of the stem/leaf fraction at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date					
Stubble	N Applied (kg ha^{-1})	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		kg N ha^{-1}					
Durum	34	40	44	22	13	13	16
Durum	50	40	49	34	18	11	18
Durum	78	51	57	38	28	17	28
Pea	34	30	31	26	21	13	12
Pea	50	36	39	28	16	17	12
Pea	78	55	45	48	25	14	16
LSD (P=0.05)		24	ns	26	11	ns	12
Stubble							
Durum		44	50	31	20	13	20
Pea		40	38	34	20	15	14
LSD (P=0.05)		ns	ns	ns	ns	ns	ns
N Applied (kg ha^{-1})							
	34	35	37	24	17	13	14
	50	38	44	31	17	14	15
	78	53	51	43	26	15	22
	LSD (P=0.05)	ns	ns	ns	7	ns	ns
ANOVA	df	Pr>F					
Stubble (S)	1	0.55	0.19	0.69	0.81	0.55	0.0654
N Applied (kg ha^{-1})	2	0.0727	0.44	0.11	0.0354	0.64	0.13
N*S	2	0.65	0.99	0.62	0.28	0.24	0.6
Contrasts							
34 N vs 50 N		0.69	0.53	0.42	0.98	0.63	0.86
50 N vs 78 N		0.0701	0.51	0.18	0.0242	0.66	0.092
Pea vs Durum - 34 N vs 50 N		0.68	0.87	0.55	0.19	0.27	0.76
Pea vs Durum - 50 N vs 78 N		0.62	0.94	0.34	0.9	0.1	0.5
Durum at 50 N vs Pea at 34 N		0.34	0.23	0.51	0.62	0.59	0.39
Durum at 78 N vs Pea at 50 N		0.18	0.25	0.42	0.0353	0.88	0.0167
C.V. (%)		31.5	40.9	44.1	29.3	33.3	40.9

*Days after anthesis

Table D.8. N yield of the head fraction at anthesis at the Carman-00, Carman-01, and Carman-01, Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg N ha^{-1}----------		
Flax	0	20	22	11
Flax	30 AN*	22	21	16
Flax	30 CRU**	22	22	16
Flax	90 AN	24	23	23
Flax	90 CRU	22	24	17
Pea	0	16	17	17
Pea	30 AN	24	20	19
Pea	30 CRU	23	21	17
Pea	90 AN	24	25	19
Pea	90 CRU	26	20	18
LSD (P=0.05)		4	4	4
Stubble				
Flax		22	22	17
Pea		22	21	18
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	18	19	14
	30 AN	23	20	18
	30 CRU	23	22	17
	90 AN	24	24	21
	90 CRU	24	22	18
	LSD (P=0.05)	3	3	2
ANOVA	df		Pr>F	
Stubble (S)	1	0.45	0.36	0.48
N Applied (kg ha^{-1})	4	0.0004	0.0346	<0.0001
N*S	4	0.0944	0.24	0.0054
Contrasts				
Pea vs Flax at 0 N		0.0458	0.0576	0.0105
Pea vs Flax at 30 N		0.4	0.54	0.0752
Pea vs Flax at 90 N		0.12	0.51	0.26
AN vs CRU		0.79	0.87	0.0089
AN vs CRU - 30 N vs 90 N		0.75	0.13	0.14
0 N vs 30 N		0.0003	0.15	0.0017
30N vs 90 N		0.14	0.0684	0.0129
Pea vs Flax - 0 N vs 30 N		0.0432	0.17	0.14
Pea vs Flax - 30 N vs 90 N		0.62	0.97	0.0107
Pea at 30 N vs Flax 90 N		0.92	0.0744	0.27
C.V. (%)		11.4	12.2	12.9

* Ammonium nitrate

** Controlled-release urea

Table D.9. N yield of the head fraction 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------------------kg N ha^{-1}	-------------------------	
Flax	0	28	33	13
Flax	30 AN*	29	39	15
Flax	30 CRU**	29	38	18
Flax	90 AN	25	41	25
Flax	90 CRU	32	40	20
Pea	0	28	32	20
Pea	30 AN	31	36	22
Pea	30 CRU	26	38	20
Pea	90 AN	34	38	27
Pea	90 CRU	31	36	24
LSD (P=0.05)		7	6	4
Stubble				
Flax		29	38	18
Pea		30	36	23
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	28	33	16
	30 AN	30	37	18
	30 CRU	27	38	19
	90 AN	30	40	26
	90 CRU	31	38	22
	LSD (P=0.05)	ns	4	3
ANOVA	df		Pr>F	
Stubble (S)	1	0.62	0.12	0.1
N Applied (kg ha^{-1})	4	0.52	0.0208	<0.0001
N*S	4	0.1	0.87	0.13
Contrasts				
Pea vs Flax at 0 N		0.84	0.63	0.0023
Pea vs Flax at 30 N		0.65	0.45	0.0054
Pea vs Flax at 90 N		0.11	0.0916	0.0476
AN vs CRU		0.76	0.75	0.1
AN vs CRU - 30 N vs 90 N		0.24	0.45	0.0072
0 N vs 30 N		0.77	0.0092	0.0399
30N vs 90 N		0.3	0.34	<0.0001
Pea vs Flax - 0 N vs 30 N		0.64	0.96	0.22
Pea vs Flax - 30 N vs 90 N		0.12	0.5	0.41
Pea at 30 N vs Flax 90 N		0.91	0.0602	0.29
C.V. (%)		15.2	10.6	11.8

*.Ammonium nitrate

** Controlled-release urea

Table D.10. N yield of the head fraction 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg N ha^{-1}----------		
Flax	0	45	70	25
Flax	30 AN*	54	84	29
Flax	30 CRU**	54	83	29
Flax	90 AN	53	79	44
Flax	90 CRU	52	80	36
Pea	0	55	61	36
Pea	30 AN	52	76	35
Pea	30 CRU	53	66	35
Pea	90 AN	56	72	44
Pea	90 CRU	58	63	32
LSD (P=0.05)		ns	14	7
Stubble				
Flax		52	79	33
Pea		55	68	37
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	50	65	30
	30 AN	53	80	32
	30 CRU	53	74	32
	90 AN	55	76	44
	90 CRU	55	72	34
	LSD (P=0.05)	ns	9	4
ANOVA	df		Pr>F	
Stubble (S)	1	0.26	0.12	0.17
N Applied (kg ha^{-1})	4	0.89	0.0371	<0.0001
N*S	4	0.75	0.64	0.0163
Contrasts				
Pea vs Flax at 0 N		0.17	0.21	0.0024
Pea vs Flax at 30 N		0.76	0.018	0.0124
Pea vs Flax at 90 N		0.39	0.0241	0.46
AN vs CRU		0.86	0.12	0.0035
AN vs CRU - 30 N vs 90 N		0.98	0.81	0.0039
0 N vs 30 N		0.55	0.0051	0.36
30N vs 90 N		0.61	0.3	<0.0001
Pea vs Flax - 0 N vs 30 N		0.2	0.64	0.21
Pea vs Flax - 30 N vs 90 N		0.42	0.92	0.0139
Pea at 30 N vs Flax 90 N		0.92	0.0832	0.039
C.V. (%)		19.0	11.8	12.4

* Ammonium nitrate

** Controlled-release urea

Table D.11. N yield of the head fraction 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg N ha^{-1}---		
Flax	0	55	122	33
Flax	30 AN*	77	129	45
Flax	30 CRU**	77	124	41
Flax	90 AN	81	134	59
Flax	90 CRU	82	140	54
Pea	0	81	122	53
Pea	30 AN	78	127	60
Pea	30 CRU	82	127	54
Pea	90 AN	88	129	60
Pea	90 CRU	95	128	56
LSD (P=0.05)		27	18	14
Stubble				
Flax		74	130	46
Pea		85	127	57
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	68	122	43
	30 AN	77	128	52
	30 CRU	80	125	47
	90 AN	84	132	59
	90 CRU	89	134	55
	LSD (P=0.05)	ns	ns	7
ANOVA	df		Pr>F	
Stubble (S)	1	0.14	0.62	0.23
N Applied (kg ha^{-1})	4	0.28	0.25	0.0008
N*S	4	0.71	0.73	0.0308
Contrasts				
Pea vs Flax at 0 N		0.0554	0.97	0.0051
Pea vs Flax at 30 N		0.72	0.93	0.0074
Pea vs Flax at 90 N		0.29	0.18	0.78
AN vs CRU		0.61	0.95	0.0815
AN vs CRU - 30 N vs 90 N		0.87	0.51	0.87
0 N vs 30 N		0.22	0.34	0.0313
30N vs 90 N		0.24	0.15	0.0056
Pea vs Flax - 0 N vs 30 N		0.17	0.99	0.26
Pea vs Flax - 30 N vs 90 N		0.62	0.28	0.0161
Pea at 30 N vs Flax 90 N		0.89	0.11	0.96
C.V. (%)		23.6	8.9	13.4

* Ammonium nitrate

** Controlled-release urea

Table D.12. N yield of the head fraction 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----------------------kg N ha^{-1}-----------------------		
Flax	0	n.d.†	136	44
Flax	30 AN*	n.d.	144	53
Flax	30 CRU**	n.d.	133	52
Flax	90 AN	n.d.	141	78
Flax	90 CRU	n.d.	145	70
Pea	0	n.d.	122	69
Pea	30 AN	n.d.	126	79
Pea	30 CRU	n.d.	143	69
Pea	90 AN	n.d.	152	95
Pea	90 CRU	n.d.	136	79
LSD (P=0.05)		n.d.	ns	20
Stubble				
Flax		n.d.	140	59
Pea		n.d.	136	78
LSD (P=0.05)		n.d.	ns	ns
	N Applied (kg ha^{-1})			
	0	n.d.	129	56
	30 AN	n.d.	135	66
	30 CRU	n.d.	138	60
	90 AN	n.d.	146	86
	90 CRU	n.d.	141	75
	LSD (P=0.05)	n.d.	ns	12
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.73	0.0858
N Applied (kg ha^{-1})	4	n.d.	0.43	0.0002
N*S	4	n.d.	0.37	0.6
Contrasts				
Pea vs Flax at 0 N		n.d.	0.33	0.0166
Pea vs Flax at 30 N		n.d.	0.7	0.0032
Pea vs Flax at 90 N		n.d.	0.92	0.0689
AN vs CRU		n.d.	0.84	0.0474
AN vs CRU - 30 N vs 90 N		n.d.	0.52	0.49
0 N vs 30 N		n.d.	0.38	0.18
30N vs 90 N		n.d.	0.27	0.0003
Pea vs Flax - 0 N vs 30 N		n.d.	0.52	0.81
Pea vs Flax - 30 N vs 90 N		n.d.	0.7	0.28
Pea at 30 N vs Flax 90 N		n.d.	0.4	0.99
C.V. (%)		n.d.	13.5	17.0

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table D.13. N yield of the head fraction 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----------------------kg N ha^{-1}-----------------------		
Flax	0	108	138	60
Flax	30 AN*	113	132	65
Flax	30 CRU**	109	150	76
Flax	90 AN	113	152	106
Flax	90 CRU	132	156	96
Pea	0	127	127	76
Pea	30 AN	129	136	93
Pea	30 CRU	125	149	99
Pea	90 AN	152	149	88
Pea	90 CRU	116	143	104
LSD (P=0.05)		32	26	25
Stubble				
Flax		115	146	81
Pea		130	141	92
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	117	133	68
	30 AN	121	134	79
	30 CRU	117	149	88
	90 AN	132	151	97
	90 CRU	124	150	100
	LSD (P=0.05)	ns	ns	18
ANOVA	df		Pr>F	
Stubble (S)	1	0.2	0.65	0.11
N Applied (kg ha^{-1})	4	0.6	0.0647	0.0062
N*S	4	0.17	0.79	0.0954
Contrasts				
Pea vs Flax at 0 N		0.23	0.39	0.19
Pea vs Flax at 30 N		0.16	0.84	0.0052
Pea vs Flax at 90 N		0.3	0.37	0.57
AN vs CRU		0.4	0.22	0.36
AN vs CRU - 30 N vs 90 N		0.81	0.16	0.67
0 N vs 30 N		0.87	0.21	0.0463
30N vs 90 N		0.23	0.15	0.0212
Pea vs Flax - 0 N vs 30 N		0.86	0.35	0.52
Pea vs Flax - 30 N vs 90 N		0.78	0.38	0.0174
Pea at 30 N vs Flax 90 N		0.67	0.21	0.61
C.V. (%)		17.4	11.1	19.7

* Ammonium nitrate

** Controlled-release urea

Table D.14. N yield of the head fraction at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date					
Stubble	N Applied (kg ha^{-1})	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		kg N ha^{-1}					
Durum	34	16	38	42	50	45	49
Durum	50	17	41	52	52	50	57
Durum	78	17	37	46	66	62	56
Pea	34	13	25	41	49	51	49
Pea	50	14	26	34	51	57	43
Pea	78	18	32	55	53	62	63
LSD (P=0.05)		ns	ns	16	ns	ns	ns
Stubble							
Durum		17	39	47	56	53	54
Pea		15	28	43	51	57	52
LSD (P=0.05)		ns	9	ns	ns	ns	ns
N Applied (kg ha^{-1})							
	34	15	31	42	50	48	49
	50	15	34	43	52	54	50
	78	17	35	50	60	62	59
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F					
Stubble (S)	1	0.48	0.0262	0.43	0.41	0.43	0.73
N Applied (kg ha^{-1})	2	0.6	0.77	0.26	0.39	0.12	0.39
N*S	2	0.82	0.63	0.0825	0.63	0.84	0.4
Contrasts							
34 N vs 50 N		0.8	0.67	0.77	0.8	0.39	0.9
50 N vs 78 N		0.47	0.79	0.22	0.3	0.21	0.26
Pea vs Durum - 34 N vs 50 N		0.89	0.88	0.16	0.99	0.96	0.35
Pea vs Durum - 50 N vs 78 N		0.55	0.38	0.0296	0.42	0.59	0.19
Durum at 50 N vs Pea at 34 N		0.39	0.0508	0.16	0.78	0.94	0.49
Durum at 78 N vs Pea at 50 N		0.39	0.16	0.15	0.17	0.58	0.27
C.V. (%)		31.1	26.8	20.5	23.4	19.3	25.2

*Days after anthesis

Table D.15. Aboveground plant N yield at the flag leaf stage at the Carman-00, Carman-01. and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg N ha^{-1}----------		
Flax	0	n.d.†	109	39
Flax	30 AN*	n.d.	134	59
Flax	30 CRU**	n.d.	123	57
Flax	90 AN	n.d.	168	111
Flax	90 CRU	n.d.	149	83
Pea	0	n.d.	84	63
Pea	30 AN	n.d.	101	88
Pea	30 CRU	n.d.	128	80
Pea	90 AN	n.d.	146	119
Pea	90 CRU	n.d.	138	124
LSD (P=0.05)		n.d.	38	22
Stubble				
Flax		n.d.	136	70
Pea		n.d.	119	95
LSD (P=0.05)		n.d.	ns	10
	N Applied (kg ha^{-1})			
	0	n.d.	97	51
	30 AN	n.d.	117	73
	30 CRU	n.d.	125	69
	90 AN	n.d.	157	115
	90 CRU	n.d.	143	103
	LSD (P=0.05)	n.d.	22	17
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.35	0.0002
N Applied (kg ha^{-1})	4	n.d.	<0.0001	<0.0001
N*S	4	n.d.	0.44	0.39
Contrasts				
Pea vs Flax at 0 N		n.d.	0.18	0.0322
Pea vs Flax at 30 N		n.d.	0.29	0.0021
Pea vs Flax at 90 N		n.d.	0.22	0.0039
AN vs CRU		n.d.	0.72	0.16
AN vs CRU - 30 N vs 90 N		n.d.	0.17	0.54
0 N vs 30 N		n.d.	0.0138	0.0083
30N vs 90 N		n.d.	0.0009	<0.0001
Pea vs Flax - 0 N vs 30 N		n.d.	0.56	0.91
Pea vs Flax - 30 N vs 90 N		n.d.	0.89	0.87
Pea at 30 N vs Flax 90 N		n.d.	0.0021	0.0855
C.V. (%)		n.d.	16.8	19.4

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table D.16. Aboveground plant N yield at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------------------kg N ha^{-1}	-------------------------	
Flax	0	91	143	45
Flax	30 AN*	105	139	70
Flax	30 CRU**	104	152	68
Flax	90 AN	143	150	120
Flax	90 CRU	126	164	97
Pea	0	106	112	75
Pea	30 AN	145	134	105
Pea	30 CRU	151	146	83
Pea	90 AN	190	173	124
Pea	90 CRU	153	158	123
LSD (P=0.05)		19	30	20
Stubble				
Flax		114	150	80
Pea		149	145	102
LSD (P=0.05)		9	ns	9
	N Applied (kg ha^{-1})			
	0	99	127	60
	30 AN	125	137	87
	30 CRU	128	149	76
	90 AN	166	161	122
	90 CRU	139	161	110
	LSD (P=0.05)	13	21	14
ANOVA	df		Pr>F	
Stubble (S)	1	0.0034	0.49	0.0145
N Applied (kg ha^{-1})	4	<0.0001	0.0098	<0.0001
N*S	4	0.0933	0.19	0.18
Contrasts				
Pea vs Flax at 0 N		0.115	0.0438	0.0044
Pea vs Flax at 30 N		<0.0001	0.6	0.0009
Pea vs Flax at 90 N		<0.0001	0.45	0.0382
AN vs CRU		0.0147	0.4	0.0198
AN vs CRU - 30 N vs 90 N		0.0034	0.39	0.97
0 N vs 30 N		<0.0001	0.0975	0.0016
30N vs 90 N		<0.0001	0.0186	<0.0001
Pea vs Flax - 0 N vs 30 N		0.0184	0.17	0.71
Pea vs Flax - 30 N vs 90 N		0.48	0.37	0.28
Pea at 30 N vs Flax 90 N		0.0432	0.11	0.0498
C.V. (%)		9.9	14.1	15.1

* Ammonium nitrate

** Controlled-release urea

Table D.17. Aboveground plant N yield 7 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--kg N ha^{-1}--		
Flax	0	90	147	45
Flax	30 AN*	110	145	55
Flax	30 CRU**	105	172	62
Flax	90 AN	135	172	129
Flax	90 CRU	149	168	99
Pea	0	138	125	86
Pea	30 AN	164	156	99
Pea	30 CRU	140	172	89
Pea	90 AN	197	178	151
Pea	90 CRU	150	170	138
LSD (P=0.05)		25	29	24
Stubble				
Flax		118	161	78
Pea		158	160	112
LSD (P=0.05)		11	ns	11
	N Applied (kg ha^{-1})			
	0	114	136	66
	30 AN	137	150	77
	30 CRU	123	172	76
	90 AN	166	175	140
	90 CRU	149	169	118
	LSD (P=0.05)	17	21	17
ANOVA	df		Pr>F	
Stubble (S)	1	0.01	0.8	0.0072
N Applied (kg ha^{-1})	4	<0.0001	0.0039	<0.0001
N*S	4	0.0112	0.61	0.65
Contrasts				
Pea vs Flax at 0 N		0.0006	0.14	0.0013
Pea vs Flax at 30 N		<0.0001	0.6	0.0002
Pea vs Flax at 90 N		0.0011	0.73	0.0009
AN vs CRU		0.015	0.3	0.0606
AN vs CRU - 30 N vs 90 N		0.82	0.0736	0.0863
0 N vs 30 N		0.0464	0.0106	0.14
30N vs 90 N		<0.0001	0.15	<0.0001
Pea vs Flax - 0 N vs 30 N		0.85	0.15	0.68
Pea vs Flax - 30 N vs 90 N		0.28	0.9	0.67
Pea at 30 N vs Flax 90 N		0.24	0.51	0.021
C.V. (%)		12.2	13.0	17.0

* Ammonium nitrate

** Controlled-release urea

Table D.18. Aboveground plant N yield 14 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg N ha^{-1}----------		
Flax	0	102	169	53
Flax	30 AN*	133	190	67
Flax	30 CRU**	132	199	64
Flax	90 AN	166	206	133
Flax	90 CRU	155	199	77
Pea	0	169	152	88
Pea	30 AN	172	189	93
Pea	30 CRU	167	170	91
Pea	90 AN	207	196	129
Pea	90 CRU	170	171	99
LSD (P=0.05)		36	29	26
Stubble				
Flax		138	193	79
Pea		177	176	100
LSD (P=0.05)		16	13	ns
N Applied (kg ha^{-1})				
	0	136	161	71
	30 AN	152	189	80
	30 CRU	149	185	78
	90 AN	186	201	131
	90 CRU	163	185	88
	LSD (P=0.05)	25	21	17
ANOVA	df		Pr>F	
Stubble (S)	1	0.0197	0.0235	0.0979
N Applied (kg ha^{-1})	4	0.0056	0.011	<0.0001
N*S	4	0.35	0.63	0.2
Contrasts				
Pea vs Flax at 0 N		0.0008	0.23	0.012
Pea vs Flax at 30 N		0.0064	0.14	0.0063
Pea vs Flax at 90 N		0.0348	0.0677	0.32
AN vs CRU		0.13	0.16	0.0007
AN vs CRU - 30 N vs 90 N		0.24	0.44	0.0018
0 N vs 30 N		0.16	0.0068	0.27
30N vs 90 N		0.0116	0.4	<0.0001
Pea vs Flax - 0 N vs 30 N		0.17	0.92	0.59
Pea vs Flax - 30 N vs 90 N		0.61	0.81	0.14
Pea at 30 N vs Flax 90 N		0.5	0.0265	0.17
C.V. (%)		15.5	11.2	18.4

* Ammonium nitrate

** Controlled-release urea

Table D.19. Aboveground plant N yield 21 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------------------kg N ha^{-1}---------------------		
Flax	0	94	202	55
Flax	30 AN*	130	220	79
Flax	30 CRU**	130	213	71
Flax	90 AN	179	237	118
Flax	90 CRU	170	244	103
Pea	0	167	203	98
Pea	30 AN	177	215	110
Pea	30 CRU	171	220	100
Pea	90 AN	217	244	134
Pea	90 CRU	193	228	118
LSD (P=0.05)		42	30	31
Stubble				
Flax		141	223	85
Pea		185	222	112
LSD (P=0.05)		18	ns	ns
	N Applied (kg ha^{-1})			
	0	131	202	77
	30 AN	154	217	95
	30 CRU	151	217	85
	90 AN	198	241	126
	90 CRU	182	236	110
	LSD (P=0.05)	29	21	16
ANOVA	df		Pr>F	
Stubble (S)	1	0.0324	0.89	0.17
N Applied (kg ha^{-1})	4	0.0005	0.0049	<0.0001
N*S	4	0.5	0.78	0.34
Contrasts				
Pea vs Flax at 0 N		0.0013	0.92	0.0078
Pea vs Flax at 30 N		0.0054	0.93	0.0087
Pea vs Flax at 90 N		0.0408	0.66	0.16
AN vs CRU		0.33	0.7	0.0286
AN vs CRU - 30 N vs 90 N		0.49	0.78	0.56
0 N vs 30 N		0.0857	0.0985	0.0581
30N vs 90 N		0.0008	0.0062	<0.0001
Pea vs Flax - 0 N vs 30 N		0.23	0.98	0.33
Pea vs Flax - 30 N vs 90 N		0.52	0.7	0.19
Pea at 30 N vs Flax 90 N		0.99	0.0335	0.61
C.V. (%)		17.0	9.0	15.7

* Ammonium nitrate

** Controlled-release urea

Table D.20. Aboveground plant N yield 28 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg N ha^{-1}---		
Flax	0	n.d.†	189	58
Flax	30 AN*	n.d.	206	74
Flax	30 CRU**	n.d.	192	72
Flax	90 AN	n.d.	212	121
Flax	90 CRU	n.d.	220	109
Pea	0	n.d.	171	97
Pea	30 AN	n.d.	182	114
Pea	30 CRU	n.d.	209	106
Pea	90 AN	n.d.	221	155
Pea	90 CRU	n.d.	214	129
LSD (P=0.05)		n.d.	44	29
Stubble				
Flax		n.d.	204	87
Pea		n.d.	199	120
LSD (P=0.05)		n.d.	ns	ns
	N Applied (kg ha^{-1})			
	0	n.d.	180	78
	30 AN	n.d.	194	94
	30 CRU	n.d.	200	89
	90 AN	n.d.	217	138
	90 CRU	n.d.	217	119
	LSD (P=0.05)	n.d.	ns	18
ANOVA	df		Pr>F	
Stubble (S)	1	n.d.	0.77	0.0548
N Applied (kg ha^{-1})	4	n.d.	0.0697	<0.0001
N*S	4	n.d.	0.56	0.78
Contrasts				
Pea vs Flax at 0 N		n.d.	0.41	0.0104
Pea vs Flax at 30 N		n.d.	0.82	0.0009
Pea vs Flax at 90 N		n.d.	0.91	0.0112
AN vs CRU		n.d.	0.75	0.0616
AN vs CRU - 30 N vs 90 N		n.d.	0.78	0.26
0 N vs 30 N		n.d.	0.17	0.0851
30N vs 90 N		n.d.	0.062	<0.0001
Pea vs Flax - 0 N vs 30 N		n.d.	0.56	0.92
Pea vs Flax - 30 N vs 90 N		n.d.	0.8	0.42
Pea at 30 N vs Flax 90 N		n.d.	0.19	0.63
C.V. (%)		n.d.	14.0	16.8

* Ammonium nitrate

** Controlled-release urea

† No data were collected.

Table D.21. Aboveground plant N yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--kg N ha^{-1}--		
Flax	0	141	181	74
Flax	30 AN*	150	180	83
Flax	30 CRU**	145	201	98
Flax	90 AN	176	210	139
Flax	90 CRU	185	219	131
Pea	0	163	161	97
Pea	30 AN	188	188	122
Pea	30 CRU	171	206	132
Pea	90 AN	223	213	134
Pea	90 CRU	168	207	142
LSD (P=0.05)		42	30	29
Stubble				
Flax		159	198	105
Pea		183	195	125
LSD (P=0.05)		ns	ns	13
	N Applied (kg ha^{-1})			
	0	152	171	86
	30 AN	169	184	103
	30 CRU	158	204	115
	90 AN	200	212	137
	90 CRU	177	213	137
	LSD (P=0.05)	29	20	21
ANOVA	df		Pr>F	
Stubble (S)	1	0.14	0.73	0.031
N Applied (kg ha^{-1})	4	0.0218	0.0006	<0.0001
N*S	4	0.23	0.54	0.21
Contrasts				
Pea vs Flax at 0 N		0.29	0.18	0.12
Pea vs Flax at 30 N		0.0347	0.54	0.001
Pea vs Flax at 90 N		0.31	0.65	0.8
AN vs CRU		0.0976	0.15	0.4
AN vs CRU - 30 N vs 90 N		0.56	0.19	0.42
0 N vs 30 N		0.34	0.0119	0.014
30N vs 90 N		0.0218	0.0136	0.0006
Pea vs Flax - 0 N vs 30 N		0.68	0.13	0.43
Pea vs Flax - 30 N vs 90 N		0.39	0.42	0.0256
Pea at 30 N vs Flax 90 N		0.97	0.1	0.4
C.V. (%)		16.4	9.9	17.5

* Ammonium nitrate

** Controlled-release urea

Table D.22. Aboveground plant N yield at various sampling dates at the Swift Current-01 site.

Treatment		Sampling Date						
Stubble	N Applied (kg ha^{-1})	Flag Leaf	Anthesis	7DAA*	14DAA	21DAA	28DAA	35DAA
		kg N ha^{-1}						
Durum	34	25	56	82	64	64	58	64
Durum	50	28	57	90	71	86	61	75
Durum	78	30	69	94	94	84	79	83
Pea	34	20	43	55	70	67	64	62
Pea	50	10	50	65	67	62	74	55
Pea	78	21	72	78	78	103	76	79
LSD (P=0.05)		19	27	ns	38	28	ns	ns
Stubble								
Durum		28	61	89	76	78	66	74
Pea		17	55	66	72	77	71	65
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns
N Applied (kg ha^{-1})								
	34	23	50	69	67	66	61	63
	50	19	53	78	69	74	68	65
	78	26	71	86	86	93	77	81
	LSD (P=0.05)	ns	ns	ns	ns	27	ns	ns
ANOVA	df	Pr>F						
Stubble (S)	1	0.058	0.45	0.0843	0.94	0.56	0.43	0.35
N Applied (kg ha^{-1})	2	0.58	0.074	0.5	0.11	0.11	0.18	0.24
N*S	2	0.58	0.63	0.94	0.25	0.46	0.62	0.69
Contrasts								
34 N vs 50 N		0.58	0.67	0.54	0.5	0.83	0.42	0.88
50 N vs 78 N		0.31	0.0736	0.57	0.15	0.0862	0.28	0.16
Pea vs Durum - 34 N vs 50 N		0.32	0.75	0.95	0.3	0.59	0.68	0.45
Pea vs Durum - 50 N vs 78 N		0.47	0.54	0.79	0.11	0.48	0.34	0.49
Durum at 50 N vs Pea at 34 N		0.38	0.28	0.12	0.29	0.97	0.81	0.43
Durum at 78 N vs Pea at 50 N		0.0426	0.15	0.18	0.24	0.0573	0.72	0.0946
C.V. (%)		48.5	26.4	32.5	27.3	20.9	20.5	27.4

*Days after anthesis

Table D.23. Aboveground plant N accumulated between 0 and 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		------kg N ha^{-1}------		
Flax	0	49	34	29
Flax	30 AN*	45	35	14
Flax	30 CRU**	40	30	30
Flax	90 AN	33	38	19
Flax	90 CRU	59	51	35
Pea	0	57	35	21
Pea	30 AN	43	33	17
Pea	30 CRU	20	41	48
Pea	90 AN	33	35	10
Pea	90 CRU	15	37	19
LSD (P=0.05)		40	ns	31
Stubble				
Flax		45	38	25
Pea		34	36	23
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	53	35	25
	30 AN	44	34	15
	30 CRU	30	35	39
	90 AN	33	37	14
	90 CRU	37	44	27
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.24	0.92	0.42
N Applied ($kg\ ha^{-1}$)	4	0.49	0.95	0.2
N*S	4	0.38	0.91	0.61
Contrasts				
Pea vs Flax at 0 N		0.71	0.96	0.6
Pea vs Flax at 30 N		0.43	0.74	0.33
Pea vs Flax at 90 N		0.13	0.56	0.25
AN vs CRU		0.62	0.65	0.0304
AN vs CRU - 30 N vs 90 N		0.37	0.77	0.48
0 N vs 30 N		0.2	0.98	0.85
30N vs 90 N		0.83	0.57	0.41
Pea vs Flax - 0 N vs 30 N		0.45	0.87	0.35
Pea vs Flax - 30 N vs 90 N		0.6	0.5	0.16
Pea at 30 N vs Flax 90 N		0.31	0.61	0.6

* Ammonium nitrate

** Controlled-release urea

Table D.24. Post-anthesis aboveground N accumulation as a percentage of aboveground plant N yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	34.3	19.7	39.1
Flax	30 AN*	25.2	22.3	15.6
Flax	30 CRU**	26.6	24.2	30.2
Flax	90 AN	18.5	28.2	9.6
Flax	90 CRU	29.1	24.7	26.5
Pea	0	34.3	31.1	22.6
Pea	30 AN	22.5	28.3	13.0
Pea	30 CRU	8.2	27.9	34.4
Pea	90 AN	13.5	18.3	4.7
Pea	90 CRU	6.4	23.4	13.3
LSD (P=0.05)		22.2	ns	21.1
Stubble				
Flax		26.8	23.8	24.2
Pea		17.0	25.8	17.6
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	34.3	25.4	30.9
	30 AN	23.9	25.3	14.3
	30 CRU	17.4	26.0	32.3
	90 AN	16.0	23.3	7.2
	90 CRU	17.8	24.0	19.9
	LSD (P=0.05)	ns	ns	15.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0337	0.12	0.0334
N Applied (kg ha^{-1})	4	0.16	0.99	0.0135
N*S	4	0.54	0.55	0.68
Contrasts				
Pea vs Flax at 0 N		0.99	0.2	0.12
Pea vs Flax at 30 N		0.18	0.43	0.92
Pea vs Flax at 90 N		0.0813	0.37	0.23
AN vs CRU		0.68	0.87	0.0091
AN vs CRU - 30 N vs 90 N		0.47	1	0.63
0 N vs 30 N		0.0598	0.96	0.27
30N vs 90 N		0.51	0.67	0.0839
Pea vs Flax - 0 N vs 30 N		0.45	0.56	0.21
Pea vs Flax - 30 N vs 90 N		0.77	0.26	0.38
Pea at 30 N vs Flax 90 N		0.28	0.79	0.45

* Ammonium nitrate

** Controlled-release urea

Table D.25. N yield of head fraction as a percentage of total aboveground plant N yield 35 days after anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
Flax	0	76.1	76.6	80.3
Flax	30 AN*	76.1	73.1	78.5
Flax	30 CRU**	75.1	74.4	77.4
Flax	90 AN	64.2	72.6	75.8
Flax	90 CRU	71.9	71.3	73.0
Pea	0	78.0	79.1	78.7
Pea	30 AN	69.2	72.5	76.4
Pea	30 CRU	73.5	72.2	76.2
Pea	90 AN	67.8	69.7	64.2
Pea	90 CRU	69.5	68.9	73.3
LSD (P=0.05)		8.2	4.8	9.3
Stubble				
Flax		72.7	73.6	77.0
Pea		71.6	72.5	73.7
LSD (P=0.05)		ns	ns	ns
N Applied ($kg\ ha^{-1}$)				
	0	77.0	77.8	79.5
	30 AN	72.6	72.8	77.5
	30 CRU	74.3	73.3	76.8
	90 AN	66.0	71.2	70.0
	90 CRU	70.7	70.1	73.1
	LSD (P=0.05)	6.0	2.9	6.5
ANOVA	df		Pr>F	
Stubble (S)	1	0.36	0.61	0.24
N Applied ($kg\ ha^{-1}$)	4	0.0124	0.0001	0.0444
N*S	4	0.44	0.33	0.3656
Contrasts				
Pea vs Flax at 0 N		0.63	0.29	0.71
Pea vs Flax at 30 N		0.14	0.42	0.6
Pea vs Flax at 90 N		0.83	0.13	0.0857
AN vs CRU		0.14	0.77	0.58
AN vs CRU - 30 N vs 90 N		0.47	0.45	0.41
0 N vs 30 N		0.17	0.0007	0.4
30N vs 90 N		0.0206	0.022	0.0196
Pea vs Flax - 0 N vs 30 N		0.24	0.12	1
Pea vs Flax - 30 N vs 90 N		0.25	0.55	0.38
Pea at 30 N vs Flax 90 N		0.25	0.79	0.56
C.V. (%)		8.1	3.8	8.4

* Ammonium nitrate

** Controlled-release urea

Table D.26. Selected N uptake parameters measured at the Swift Current-01 site.[a,b]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	Post-anthesis N accumulation[a]	% N accumulation post-anthesis[a]	NHI 35 days after anthesis[b]
		----kg N ha^{-1}----		---- % ----
Durum	34	8.2	13.5	75.7
Durum	50	17.5	21.3	76.3
Durum	78	14.5	14.9	67.7
Pea	34	19.0	31.6	79.9
Pea	50	5.3	10.2	79.3
Pea	78	6.6	3.2	79.4
LSD (P=0.05)		ns	ns	8.2
Stubble				
Durum		13.4	16.6	73.2
Pea		10.3	15.0	79.5
LSD (P=0.05)		ns	ns	4.8
	N Applied (kg ha^{-1})			
	34	13.6	22.5	77.8
	50	11.4	15.8	77.8
	78	10.5	9.1	73.6
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.68	0.87	0.013
N Applied (kg ha^{-1})	2	0.94	0.53	0.23
N*S	2	0.43	0.38	0.25
Contrasts				
34 N vs 50 N		0.81	0.58	0.99
50 N vs 78 N		0.93	0.58	0.14
Pea vs Durum - 34 N vs 50 N		0.23	0.24	0.8
Pea vs Durum - 50 N vs 78 N		0.82	0.98	0.13
Durum at 50 N vs Pea at 34 N		0.91	0.55	0.34
Durum at 78 N vs Pea at 50 N		0.48	0.78	0.01

*Days after anthesis

[a] 'Post-anthesis' refers to the period between anthesis and 35 DAA.

[b] NHI refers to N yield of the head fraction as a percentrage of total aboveground N yield 35 DAA.

8.5. APPENDIX E – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SOIL NH_4-N AND NO_3-N AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table E.1. Distribution of estimated NH4-N (kg ha^{-1}) in the soil profile prior to planting as affected by previous crop at the Carman-00, Carman-01, Brandon-01, and Swift Current-01 sites.[a]

	Depth (cm)			
	0-15 cm	15-60 cm	60-120 cm	0-120 cm
Carman-00				
Pea	30	71	110	211
Flax	37	91	95	223
Significance (P)	0.56	0.45	0.6	0.84
CV (%)	9.4	8.1	6.2	5.6
	Depth (cm)			
	0-15 cm	15-60 cm	60-120 cm	0-120 cm
Carman-01				
Pea	15	28	37	80
Flax	17	31	46	94
Significance (P)	0.33	0.40	0.12	0.0488
CV (%)	8.2	3.9	4.5	2.0
	Depth (cm)			
	0-15 cm	15-60 cm	60-120 cm	0-120 cm
Brandon-01				
Pea	49	52	83	184
Flax	57	49	54	160
Significance (P)	0.84	0.95	0.65	0.81
CV (%)	9.2	23.2	20.4	10.1
	Depth (cm)			
	0-15 cm	15-60 cm	60-120 cm	0-120 cm
Swift-Current-01				
Pea	10	29	40	78
Durum	7	26	36	68
Significance (P)	0.29	0.3	0.26	0.24
CV (%)	22.4	8.4	6.7	6.0

[a] Means are presented as non-transformed data, otherwise statistics are shown as log-transformed data.

Table E.2. Estimated quantity of NH4-N in the 0-10 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---------kg NH4-N ha^{-1}---------		
Flax	0	10.3	12.1	6.1
Flax	30 AN*	11.8	13.8	7.6
Flax	30 CRU**	10.4	13.4	6.1
Flax	90 AN	11.1	12.7	6.2
Flax	90 CRU	7.8	14.9	6.2
Pea	0	11.9	14.8	5.9
Pea	30 AN	10.5	13.2	6.7
Pea	30 CRU	9.1	17.0	6.0
Pea	90 AN	12.2	14.3	6.2
Pea	90 CRU	11.0	17.5	6.8
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		10.3	13.4	6.4
Pea		10.9	15.4	6.3
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	11.1	13.5	6.0
	30 AN	11.1	13.5	7.2
	30 CRU	9.7	15.2	6.1
	90 AN	11.5	13.5	6.2
	90 CRU	9.4	16.2	6.5
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.28	0.38	0.086
N Applied ($kg\ ha^{-1}$)	4	0.5	0.73	0.3
N*S	4	0.51	0.93	0.81
Contrasts				
Pea vs Flax at 0 N		0.42	0.46	0.77
Pea vs Flax at 30 N		0.38	0.55	0.41
Pea vs Flax at 90 N		0.16	0.42	0.59
AN vs CRU		0.0964	0.23	0.38
AN vs CRU - 30 N vs 90 N		0.69	0.77	0.1
0 N vs 30 N		0.61	0.69	0.24
30N vs 90 N		0.92	0.78	0.53
Pea vs Flax - 0 N vs 30 N		0.27	0.78	0.82
Pea vs Flax - 30 N vs 90 N		0.12	0.87	0.36
Pea at 30 N vs Flax 90 N		0.81	0.61	0.74
C.V. (%)		36.4	34.6	18.6

* Ammonium nitrate

** Controlled-release urea

Table E.3. Estimated quantity of NH4-N in the 10-30 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---------kg NH4-N ha^{-1}---------		
Flax	0	16.7	35.8	11.6
Flax	30 AN*	11.7	25.5	11.0
Flax	30 CRU**	11.5	24.3	10.4
Flax	90 AN	11.7	19.9	10.0
Flax	90 CRU	16.8	23.5	9.5
Pea	0	12.0	23.4	10.0
Pea	30 AN	12.2	21.8	9.8
Pea	30 CRU	15.4	25.6	9.3
Pea	90 AN	11.4	27.0	9.4
Pea	90 CRU	18.6	22.4	10.6
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		13.7	25.8	10.5
Pea		14.0	24.1	9.8
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	14.4	29.6	10.8
	30 AN	12.0	23.7	10.4
	30 CRU	13.4	25.0	9.9
	90 AN	11.6	23.5	9.7
	90 CRU	17.7	23.0	10.1
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.96	0.68	0.19
N Applied ($kg\ ha^{-1}$)	4	0.11	0.59	0.68
N*S	4	0.47	0.33	0.54
Contrasts				
Pea vs Flax at 0 N		0.23	0.0777	0.18
Pea vs Flax at 30 N		0.43	0.8	0.16
Pea vs Flax at 90 N		0.69	0.53	0.8
AN vs CRU		0.0337	0.9	0.89
AN vs CRU - 30 N vs 90 N		0.17	0.78	0.44
0 N vs 30 N		0.43	0.19	0.37
30N vs 90 N		0.3	0.74	0.65
Pea vs Flax - 0 N vs 30 N		0.1	0.17	0.78
Pea vs Flax - 30 N vs 90 N		0.64	0.51	0.25
Pea at 30 N vs Flax 90 N		0.88	0.68	0.79
C.V. (%)		34.2	36.7	16.1

* Ammonium nitrate

** Controlled-release urea

Table E.4. Estimated quantity of NH4-N in the 30-50 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NH4-N ha^{-1}----------		
Flax	0	15.1	23.4	11.6
Flax	30 AN*	10.0	25.4	11.0
Flax	30 CRU**	11.0	19.3	10.4
Flax	90 AN	10.9	22.7	10.0
Flax	90 CRU	11.9	26.7	9.5
Pea	0	10.6	25.8	10.0
Pea	30 AN	10.9	25.6	9.8
Pea	30 CRU	10.3	22.5	9.3
Pea	90 AN	11.3	31.4	9.4
Pea	90 CRU	9.6	20.6	10.6
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		11.8	23.5	12.3
Pea		10.5	25.2	12.6
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	12.9	24.6	11.8
	30 AN	10.4	25.5	12.6
	30 CRU	10.6	20.9	12.4
	90 AN	11.0	27.0	13.0
	90 CRU	10.7	23.6	12.7
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0895	0.14	0.7
N Applied (kg ha^{-1})	4	0.52	0.26	0.92
N*S	4	0.36	0.13	0.85
Contrasts				
Pea vs Flax at 0 N		0.0411	0.51	0.58
Pea vs Flax at 30 N		0.97	0.51	0.58
Pea vs Flax at 90 N		0.76	0.63	0.71
AN vs CRU		0.78	0.0479	0.8
AN vs CRU - 30 N vs 90 N		0.65	0.77	0.97
0 N vs 30 N		0.0979	0.55	0.56
30N vs 90 N		0.59	0.27	0.71
Pea vs Flax - 0 N vs 30 N		0.1	0.88	0.45
Pea vs Flax - 30 N vs 90 N		0.83	0.91	0.9
Pea at 30 N vs Flax 90 N		0.59	0.8	0.84
C.V. (%)		27.9	22.1	21.7

* Ammonium nitrate

** Controlled-release urea

Table E.5. Estimated quantity of NH4-N in the 50-70 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---kg NH4-N ha^{-1}---		
Flax	0	12.4	30.5	13.5
Flax	30 AN*	11.8	29.4	13.5
Flax	30 CRU**	12.3	27.4	12.4
Flax	90 AN	11.4	25.0	12.8
Flax	90 CRU	10.2	23.2	11.7
Pea	0	8.1	22.6	10.3
Pea	30 AN	11.5	31.9	12.1
Pea	30 CRU	12.1	27.9	10.4
Pea	90 AN	13.1	26.6	10.9
Pea	90 CRU	11.4	26.8	9.7
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		11.6	27.1	12.8
Pea		11.1	27.1	10.7
LSD (P=0.05)		ns	ns	ns
N Applied ($kg\ ha^{-1}$)				
	0	10.2	26.5	11.9
	30 AN	11.6	30.7	12.8
	30 CRU	12.2	27.7	11.4
	90 AN	12.1	25.8	11.9
	90 CRU	10.8	25.0	10.7
	LSD (P=0.05)		ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.92	0.99	0.0664
N Applied ($kg\ ha^{-1}$)	4	0.67	0.82	0.6
N*S	4	0.36	0.8	0.97
Contrasts				
Pea vs Flax at 0 N		0.0958	0.3	0.0915
Pea vs Flax at 30 N		0.89	0.79	0.18
Pea vs Flax at 90 N		0.3	0.63	0.15
AN vs CRU		0.56	0.59	0.18
AN vs CRU - 30 N vs 90 N		0.31	0.77	0.9
0 N vs 30 N		0.27	0.55	0.84
30N vs 90 N		0.92	0.3	0.38
Pea vs Flax - 0 N vs 30 N		0.18	0.3	0.53
Pea vs Flax - 30 N vs 90 N		0.36	0.87	0.94
Pea at 30 N vs Flax 90 N		0.57	0.29	0.45
C.V. (%)		30.1	37.1	22.3

* Ammonium nitrate

** Controlled-release urea

Table E.6. Estimated quantity of NH4-N in the 70-90 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----kg NH4-N ha^{-1}-----		
Flax	0	10.6	22.9	12.5
Flax	30 AN*	13.4	19.2	9.8
Flax	30 CRU**	10.5	24.5	10.3
Flax	90 AN	10.1	21.3	10.8
Flax	90 CRU	12.7	17.3	11.8
Pea	0	10.2	25.6	10.6
Pea	30 AN	11.8	26.9	11.2
Pea	30 CRU	9.3	23.6	9.7
Pea	90 AN	7.8	20.2	10.3
Pea	90 CRU	9.7	26.5	10.8
LSD (P=0.05)		ns	6.2	ns
Stubble				
Flax		11.4	21.0	11.1
Pea		9.9	24.5	10.5
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	10.4	24.3	11.6
	30 AN	12.6	23.1	10.5
	30 CRU	9.9	24.1	10.0
	90 AN	9.1	20.8	10.6
	90 CRU	11.2	21.9	11.3
	LSD (P=0.05)	ns	ns	ns
ANOVA	**df**		**Pr>F**	
Stubble (S)	1	0.12	0.0627	0.74
N Applied (kg ha^{-1})	4	0.19	0.45	0.58
N*S	4	0.91	0.077	0.65
Contrasts				
Pea vs Flax at 0 N		0.83	0.38	0.29
Pea vs Flax at 30 N		0.29	0.13	0.76
Pea vs Flax at 90 N		0.11	0.07	0.54
AN vs CRU		0.62	0.5	0.85
AN vs CRU - 30 N vs 90 N		0.0306	0.97	0.41
0 N vs 30 N		0.45	0.72	0.17
30N vs 90 N		0.35	0.15	0.36
Pea vs Flax - 0 N vs 30 N		0.67	0.86	0.22
Pea vs Flax - 30 N vs 90 N		0.73	0.83	0.45
Pea at 30 N vs Flax 90 N		0.54	0.0095	0.49
C.V. (%)		25.1	19.1	19.5

* Ammonium nitrate

** Controlled-release urea

Table E.7. Estimated quantity of NH4-N in the 90-110 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		----------kg NH4-N ha^{-1}----------		
Flax	0	15.1	17.4	11.2
Flax	30 AN*	11.2	18.4	11.2
Flax	30 CRU**	9.1	23.0	12.6
Flax	90 AN	9.4	23.4	10.7
Flax	90 CRU	11.3	20.0	13.1
Pea	0	8.0	23.0	9.5
Pea	30 AN	11.9	33.7	10.3
Pea	30 CRU	15.5	20.1	15.1
Pea	90 AN	8.3	19.1	11.9
Pea	90 CRU	10.1	30.2	11.6
LSD (P=0.05)		ns	9.4	ns
Stubble				
Flax		11.2	25.2	11.8
Pea		10.9	20.4	11.7
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	11.6	20.2	10.3
	30 AN	11.5	26.0	10.7
	30 CRU	12.3	21.5	13.8
	90 AN	8.9	21.2	11.3
	90 CRU	10.7	25.1	12.3
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.76	0.2	0.96
N Applied ($kg\ ha^{-1}$)	4	0.73	0.24	0.38
N*S	4	0.18	0.0148	0.75
Contrasts				
Pea vs Flax at 0 N		0.0666	0.24	0.55
Pea vs Flax at 30 N		0.18	0.0669	0.69
Pea vs Flax at 90 N		0.65	0.36	0.93
AN vs CRU		0.47	0.88	0.14
AN vs CRU - 30 N vs 90 N		0.75	0.0613	0.44
0 N vs 30 N		0.89	0.19	0.25
30N vs 90 N		0.25	0.78	0.74
Pea vs Flax - 0 N vs 30 N		0.0279	0.9	0.46
Pea vs Flax - 30 N vs 90 N		0.2	0.46	0.72
Pea at 30 N vs Flax 90 N		0.22	0.12	0.7
C.V. (%)		47.4	26.5	32.5

* Ammonium nitrate

** Controlled-release urea

Table E.8. Estimated quantity of NH4-N in the 0-110 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NH4-N ha^{-1}----------		
Flax	0	106	142	67
Flax	30 AN*	94	132	66
Flax	30 CRU**	90	132	63
Flax	90 AN	93	125	64
Flax	90 CRU	100	125	64
Pea	0	102	135	57
Pea	30 AN	108	153	62
Pea	30 CRU	119	137	64
Pea	90 AN	131	139	62
Pea	90 CRU	140	144	63
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		70	142	65
Pea		67	131	62
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	104	139	62
	30 AN	101	142	64
	30 CRU	105	134	64
	90 AN	109	132	63
	90 CRU	120	135	64
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.6	0.38	0.44
N Applied (kg ha^{-1})	4	0.82	0.77	0.99
N*S	4	0.11	0.51	0.78
Contrasts				
Pea vs Flax at 0 N		0.0107	0.63	0.13
Pea vs Flax at 30 N		0.57	0.2	0.73
Pea vs Flax at 90 N		0.82	0.11	0.68
AN vs CRU		0.6	0.68	0.95
AN vs CRU - 30 N vs 90 N		0.39	0.38	0.78
0 N vs 30 N		0.67	0.96	0.67
30N vs 90 N		0.83	0.42	0.79
Pea vs Flax - 0 N vs 30 N		0.0135	0.21	0.26
Pea vs Flax - 30 N vs 90 N		0.78	0.81	0.95
Pea at 30 N vs Flax 90 N		0.6	0.0553	0.84
C.V. (%)		14.0	15.6	12.7

* Ammonium nitrate

** Controlled-release urea

Table E.9. Estimated quantity of NH4-N at anthesis at various sampling depths at the Swift Current-01 site.

Treatment		Sampling Depth						
Stubble	N Applied (kg ha^{-1})	0-10 cm	10-30 cm	30-50 cm	50-70 cm	70-90 cm	90-110 cm	0-110 cm
		kg NH4-N ha^{-1}						
Durum	34	8.9	17.3	12.7	10.2	9.3	11.1	69.5
Durum	50	9.5	12.5	12.3	13.2	11.2	11.8	70.5
Durum	78	7.9	15.6	15.4	14.0	15.0	18.5	86.5
Pea	34	8.2	16.0	14.0	12.8	12.0	13.1	76.1
Pea	50	9.8	18.5	15.0	13.4	12.6	16.4	85.6
Pea	78	7.4	14.7	15.7	13.6	16.2	16.9	84.5
LSD (P=0.05)		ns	5.9	ns	ns	3.8	4.6	ns
Stubble								
Durum		8.8	15.1	13.5	12.5	11.8	13.8	75.5
Pea		8.5	16.4	14.9	13.2	13.6	15.5	82.0
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns
	N Applied (kg ha^{-1})							
	34	8.5	16.6	13.3	11.5	10.6	12.1	72.8
	50	9.7	15.5	13.6	13.3	11.9	14.1	78.1
	78	7.6	15.2	15.5	13.8	15.6	17.7	85.5
	LSD (P=0.05)	ns	ns	ns	ns	2.7	3.2	ns
ANOVA	df				Pr>F			
Stubble (S)	1	0.82	0.44	0.4	0.57	0.1	0.19	0.23
N Applied (kg ha^{-1})	2	0.49	0.72	0.51	0.35	0.0045	0.0086	0.17
N*S	2	0.94	0.14	0.83	0.62	0.8	0.15	0.43
Contrasts								
34 N vs 50 N		0.51	0.55	0.88	0.29	0.32	0.21	0.42
50 N vs 78 N		0.24	0.87	0.36	0.75	0.0112	0.0316	0.26
Pea vs Durum - 34 N vs 50 N		0.75	0.0799	0.74	0.46	0.59	0.4	0.51
Pea vs Durum - 50 N vs 78 N		0.82	0.0941	0.55	0.87	0.96	0.0567	0.2
Durum at 50 N vs Pea at 34 N		0.57	0.22	0.55	0.85	0.67	0.53	0.55
Durum at 78 N vs Pea at 50 N		0.42	0.32	0.88	0.78	0.2	0.34	0.93
C.V. (%)		33.0	20.9	24.4	21.4	16.8	17.6	13.9

*Days after anthesis

Table E.10. Estimated quantity of NO_3-N in the 0-10 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----kg NO_3-N ha^{-1}-----		
Flax	0	7.8	2.0	8.2
Flax	30 AN*	8.5	2.0	5.1
Flax	30 CRU**	7.7	2.9	5.8
Flax	90 AN	9.7	3.5	11.9
Flax	90 CRU	10.6	3.6	11.1
Pea	0	9.5	2.0	8.7
Pea	30 AN	9.5	1.5	7.9
Pea	30 CRU	9.8	1.7	8.4
Pea	90 AN	15.0	3.1	8.8
Pea	90 CRU	17.1	3.2	13.9
LSD (P=0.05)		5.2	1.7	3.9
Stubble				
Flax		8.8	2.8	8.4
Pea		12.0	2.3	9.5
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	8.6	2.0	8.5
	30 AN	9.0	1.7	6.5
	30 CRU	8.8	2.3	7.1
	90 AN	12.0	3.3	10.4
	90 CRU	13.8	3.4	12.5
	LSD (P=0.05)	3.3	ns	2.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0684	0.65	0.1
N Applied (kg ha^{-1})	4	0.0093	0.81	0.0002
N*S	4	0.59	0.88	0.0911
Contrasts				
Pea vs Flax at 0 N		0.29	0.98	0.96
Pea vs Flax at 30 N		0.4	0.14	0.0047
Pea vs Flax at 90 N		0.0083	0.99	0.84
AN vs CRU		0.64	0.13	0.12
AN vs CRU - 30 N vs 90 N		0.36	0.55	0.64
0 N vs 30 N		0.97	0.89	0.0602
30N vs 90 N		0.0014	<0.0001	<0.0001
Pea vs Flax - 0 N vs 30 N		0.7	0.31	0.1
Pea vs Flax - 30 N vs 90 N		0.13	0.51	0.0327
Pea at 30 N vs Flax 90 N		0.53	0.0018	0.0141
C.V. (%)		12.2	27.2	12.1

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.11. Estimated quantity of NO_3-N in the 10-30 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------------------kg NO_3-N ha^{-1}	----------------------	----------------------
Flax	0	5.6	4.2	7.0
Flax	30 AN*	4.6	4.6	6.0
Flax	30 CRU**	5.1	4.4	5.7
Flax	90 AN	6.0	5.9	10.3
Flax	90 CRU	6.3	5.0	8.2
Pea	0	6.6	3.3	7.1
Pea	30 AN	7.4	3.6	8.0
Pea	30 CRU	11.0	3.7	7.9
Pea	90 AN	8.9	5.7	10.6
Pea	90 CRU	9.7	5.0	11.9
LSD (P=0.05)		5.0	1.6	3.1
Stubble				
Flax		5.5	4.8	7.5
Pea		8.7	4.3	9.1
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	6.1	3.7	7.1
	30 AN	6.0	4.1	7.0
	30 CRU	8.1	4.1	6.8
	90 AN	7.3	5.8	10.5
	90 CRU	8.0	5.0	10.1
	LSD (P=0.05)	ns	ns	2.2
ANOVA	df		Pr>F	
Stubble (S)	1	0.12	0.56	0.12
N Applied (kg ha^{-1})	4	0.22	0.31	0.0061
N*S	4	0.64	0.5	0.43
Contrasts				
Pea vs Flax at 0 N		0.46	0.26	0.83
Pea vs Flax at 30 N		0.0031	0.18	0.0146
Pea vs Flax at 90 N		0.0141	0.78	0.35
AN vs CRU		0.18	0.41	0.58
AN vs CRU - 30 N vs 90 N		0.69	0.31	0.8
0 N vs 30 N		0.77	0.3	0.77
30N vs 90 N		0.11	0.0005	0.0005
Pea vs Flax - 0 N vs 30 N		0.14	0.86	0.11
Pea vs Flax - 30 N vs 90 N		0.59	0.18	0.25
Pea at 30 N vs Flax 90 N		0.0623	0.0068	0.29
C.V. (%)		14.5	41.6	12.6

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.12. Estimated quantity of NO_3-N in the 30-50 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		----------kg NO_3-N ha^{-1}----------		
Flax	0	3.6	4.3	7.2
Flax	30 AN*	3.4	3.7	8.3
Flax	30 CRU**	3.8	3.7	7.5
Flax	90 AN	3.4	8.7	9.2
Flax	90 CRU	3.6	7.6	4.6
Pea	0	3.5	2.8	7.6
Pea	30 AN	4.6	3.6	8.2
Pea	30 CRU	5.2	3.9	7.5
Pea	90 AN	12.1	7.3	8.3
Pea	90 CRU	7.9	5.2	8.5
LSD (P=0.05)		4.1	4.4	3.3
Stubble				
Flax		3.6	5.6	7.4
Pea		6.4	4.5	8.0
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	3.5	3.5	7.4
	30 AN	4.0	3.6	8.2
	30 CRU	4.5	3.8	7.5
	90 AN	7.2	8.0	8.8
	90 CRU	5.8	6.4	6.6
	LSD (P=0.05)	2.7	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0761	0.58	0.45
N Applied ($kg\ ha^{-1}$)	4	0.0049	0.0688	0.11
N*S	4	0.0027	0.54	0.0841
Contrasts				
Pea vs Flax at 0 N		0.8	0.15	0.88
Pea vs Flax at 30 N		0.0433	0.98	0.77
Pea vs Flax at 90 N		<0.0001	0.62	0.0588
AN vs CRU		0.52	0.43	0.0192
AN vs CRU - 30 N vs 90 N		0.12	0.32	0.21
0 N vs 30 N		0.11	0.44	0.57
30N vs 90 N		0.0033	0.0003	0.54
Pea vs Flax - 0 N vs 30 N		0.21	0.19	0.96
Pea vs Flax - 30 N vs 90 N		0.002	0.68	0.18
Pea at 30 N vs Flax 90 N		0.0336	0.0073	0.14
C.V. (%)		18.0	49.6	11.9

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.13. Estimated quantity of NO_3-N in the 50-70 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---------- $kg\ NO_3\text{-}N\ ha^{-1}$	----------	----------
Flax	0	3.6	14.5	5.0
Flax	30 AN*	3.0	4.2	5.8
Flax	30 CRU**	3.1	5.9	5.6
Flax	90 AN	3.3	16.0	7.6
Flax	90 CRU	3.5	16.6	3.6
Pea	0	5.3	4.2	4.6
Pea	30 AN	5.1	6.3	4.5
Pea	30 CRU	5.8	6.2	3.8
Pea	90 AN	12.8	15.3	5.5
Pea	90 CRU	14.5	8.1	5.9
LSD (P=0.05)		7.0	ns	2.9
Stubble				
Flax		3.3	11.5	5.5
Pea		8.5	8.0	4.9
LSD (P=0.05)		1.6	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	4.4	9.4	4.8
	30 AN	4.1	5.3	5.2
	30 CRU	4.5	6.1	4.7
	90 AN	7.3	15.7	6.6
	90 CRU	9.0	12.4	4.8
	LSD (P=0.05)	2.9	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0255	0.97	0.42
N Applied ($kg\ ha^{-1}$)	4	0.0002	0.32	0.35
N*S	4	0.0016	0.37	0.25
Contrasts				
Pea vs Flax at 0 N		0.0816	0.14	0.85
Pea vs Flax at 30 N		0.0008	0.47	0.12
Pea vs Flax at 90 N		<0.0001	0.63	0.46
AN vs CRU		0.36	0.68	0.1
AN vs CRU - 30 N vs 90 N		0.99	0.51	0.36
0 N vs 30 N		0.85	0.86	0.79
30N vs 90 N		<0.0001	0.0063	0.48
Pea vs Flax - 0 N vs 30 N		0.36	0.0483	0.47
Pea vs Flax - 30 N vs 90 N		0.0005	0.83	0.12
Pea at 30 N vs Flax 90 N		0.0056	0.29	0.35
C.V. (%)		16.8	53.8	23.2

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.14. Estimated quantity of NO_3-N in the 70-90 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg NO_3-N ha^{-1}---		
Flax	0	3.2	21.7	3.9
Flax	30 AN*	2.3	8.3	4.2
Flax	30 CRU**	3.0	14.8	2.7
Flax	90 AN	3.3	25.9	4.7
Flax	90 CRU	3.0	25.5	3.0
Pea	0	7.8	8.4	3.6
Pea	30 AN	5.5	12.4	3.5
Pea	30 CRU	7.6	12.3	3.0
Pea	90 AN	10.3	22.9	6.3
Pea	90 CRU	13.2	11.0	5.2
LSD (P=0.05)		4.3	ns	2.5
Stubble				
Flax		3.0	19.2	3.7
Pea		8.8	13.4	4.3
LSD (P=0.05)		1.8	ns	ns
	N Applied (kg ha^{-1})			
	0	5.5	15.0	3.8
	30 AN	3.9	10.4	3.8
	30 CRU	5.3	13.5	2.9
	90 AN	6.3	24.4	5.5
	90 CRU	8.1	18.3	4.1
	LSD (P=0.05)	2.8	ns	1.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0105	0.95	0.7
N Applied (kg ha^{-1})	4	0.0252	0.81	0.033
N*S	4	0.45	0.7	0.4
Contrasts				
Pea vs Flax at 0 N		0.0031	0.36	0.94
Pea vs Flax at 30 N		<0.0001	0.57	1
Pea vs Flax at 90 N		<0.0001	0.78	0.0239
AN vs CRU		0.25	0.97	0.056
AN vs CRU - 30 N vs 90 N		0.59	0.76	0.97
0 N vs 30 N		0.27	0.73	0.38
30N vs 90 N		0.0025	0.36	0.0079
Pea vs Flax - 0 N vs 30 N		0.93	0.23	0.95
Pea vs Flax - 30 N vs 90 N		0.18	0.82	0.11
Pea at 30 N vs Flax 90 N		0.0021	0.88	0.37
C.V. (%)		23.6	33.0	25.8

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.15. Estimated quantity of NO_3-N in the 90-110 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----kg NO_3-N ha^{-1}-----		
Flax	0	2.1	25.2	3.4
Flax	30 AN*	2.3	17.7	3.3
Flax	30 CRU**	2.9	12.5	3.5
Flax	90 AN	2.8	21.1	3.2
Flax	90 CRU	2.6	24.4	4.0
Pea	0	8.5	12.4	4.8
Pea	30 AN	7.2	17.4	3.6
Pea	30 CRU	8.3	16.7	4.2
Pea	90 AN	7.7	18.7	5.0
Pea	90 CRU	7.7	13.3	4.3
LSD (P=0.05)		4.4	ns	ns
Stubble				
Flax		2.5	20.2	3.5
Pea		7.9	15.7	4.4
LSD (P=0.05)		2.1	ns	ns
	N Applied (kg ha^{-1})			
	0	5.3	18.8	4.1
	30 AN	4.7	17.6	3.4
	30 CRU	5.6	14.6	3.9
	90 AN	4.9	19.9	4.1
	90 CRU	5.2	18.9	4.2
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0031	0.94	0.29
N Applied (kg ha^{-1})	4	0.81	0.2	0.68
N*S	4	0.9	0.16	0.72
Contrasts				
Pea vs Flax at 0 N		0.0007	0.31	0.15
Pea vs Flax at 30 N		0.0002	0.57	0.55
Pea vs Flax at 90 N		0.0007	0.9	0.18
AN vs CRU		0.43	0.77	0.51
AN vs CRU - 30 N vs 90 N		0.41	0.58	0.84
0 N vs 30 N		0.97	0.83	0.34
30N vs 90 N		0.74	0.91	0.22
Pea vs Flax - 0 N vs 30 N		0.57	0.15	0.37
Pea vs Flax - 30 N vs 90 N		0.74	0.53	0.57
Pea at 30 N vs Flax 90 N		0.0006	0.78	0.86
C.V. (%)		36.2	49.1	24.3

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.16. Estimated quantity of NO_3-N in the 0-110 cm depth at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NO_3-N ha^{-1}----------		
Flax	0	26	72	35
Flax	30 AN*	24	40	33
Flax	30 CRU**	26	44	31
Flax	90 AN	28	81	47
Flax	90 CRU	30	83	35
Pea	0	41	33	36
Pea	30 AN	39	45	36
Pea	30 CRU	48	45	35
Pea	90 AN	67	73	45
Pea	90 CRU	70	46	50
LSD (P=0.05)		12	ns	12
Stubble				
Flax		27	64	36
Pea		52	48	40
LSD (P=0.05)		4	ns	ns
	N Applied (kg ha^{-1})			
	0	33	52	36
	30 AN	32	43	34
	30 CRU	37	44	46
	90 AN	45	77	33
	90 CRU	50	64	42
	LSD (P=0.05)	8	ns	9
ANOVA	df		Pr>F	
Stubble (S)	1	0.0199	0.88	0.0403
N Applied (kg ha^{-1})	4	<0.0001	0.35	0.0188
N*S	4	0.0115	0.45	0.52
Contrasts				
Pea vs Flax at 0 N		0.0019	0.17	0.74
Pea vs Flax at 30 N		<0.0001	0.66	0.24
Pea vs Flax at 90 N		<0.0001	0.96	0.1
AN vs CRU		0.0833	0.64	0.42
AN vs CRU - 30 N vs 90 N		0.35	0.81	0.62
0 N vs 30 N		0.75	0.81	0.52
30N vs 90 N		<0.0001	0.085	0.0015
Pea vs Flax - 0 N vs 30 N		0.42	0.1	0.69
Pea vs Flax - 30 N vs 90 N		0.0043	0.74	0.74
Pea at 30 N vs Flax 90 N		0.0003	0.43	0.25
C.V. (%)		3.6	11.8	5.8

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.17. Estimated quantity of NO_3-N at anthesis at the Swift Current-01 site.[a]

Treatment		Sampling Depth						
Stubble	N Applied (kg ha^{-1})	0-10 cm	10-30 cm	30-50 cm	50-70 cm	70-90 cm	90-110 cm	0-110 cm
		kg NO_3-N ha^{-1}						
Durum	34	5.5	3.7	1.3	1.8	2.2	4.5	19.1
Durum	50	8.2	2.9	1.7	2.1	3.4	3.4	21.6
Durum	78	7.8	3.9	1.8	1.4	2.1	2.4	19.4
Pea	34	18.0	7.5	2.7	2.8	2.8	3.7	37.6
Pea	50	25.7	13.5	3.7	3.6	3.1	5.3	55.0
Pea	78	13.9	7.6	3.0	2.0	3.3	3.9	33.7
LSD (P=0.05)		18.4	6.3	1.7	2.1	ns	ns	22.7
Stubble								
Durum		7.2	3.5	1.6	1.8	2.5	3.4	20.1
Pea		19.2	9.5	3.1	2.8	3.1	4.3	42.1
LSD (P=0.05)		10.6	3.7	1.0	ns	ns	ns	13.1
	N Applied (kg ha^{-1})							
	34	11.8	5.6	2.0	2.3	2.5	4.1	28.3
	50	17.0	8.2	2.7	2.9	3.2	4.3	38.3
	78	10.9	5.7	2.4	1.7	2.7	3.1	26.6
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns
ANOVA	df				Pr>F			
Stubble (S)	1	0.0343	0.003	0.0064	0.0786	0.27	0.34	0.0039
N Applied (kg ha^{-1})	2	0.5	0.68	0.36	0.34	0.82	0.68	0.33
N*S	2	0.96	0.46	0.9	0.88	0.69	0.51	0.82
Contrasts								
34 N vs 50 N		0.44	0.58	0.18	0.3	0.54	0.51	0.31
50 N vs 78 N		0.26	0.4	0.73	0.16	0.81	0.87	0.15
Pea vs Flax - 34 N vs 50 N		0.99	0.25	0.97	0.69	0.51	0.33	0.61
Pea vs Flax - 50 N vs 78 N		0.8	0.34	0.71	0.96	0.43	0.99	0.57
Durum at 50 N vs Pea at 34 N		0.37	0.0782	0.3	0.65	1	0.44	0.17
Durum at 78 N vs Pea at 50 N		0.0517	0.0092	0.0631	0.0733	0.49	0.26	0.0069
C.V. (%)		35.2	35.9	67.8	97.0	57.6	50.6	13.5

*Days after anthesis

a Statistics are based on log transformed data due to the high variability of the NO3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.18. Estimated quantity of NH4-N in the 0-10 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		------kg NH4-N ha^{-1}------		
Flax	0	5.4	11.8	3.8
Flax	30 AN*	7.0	15.0	3.8
Flax	30 CRU**	5.1	12.2	3.8
Flax	90 AN	5.6	11.7	4.6
Flax	90 CRU	6.4	13.6	4.6
Pea	0	6.4	15.7	4.3
Pea	30 AN	5.5	14.1	4.0
Pea	30 CRU	7.7	13.3	4.3
Pea	90 AN	5.5	13.3	3.8
Pea	90 CRU	6.9	12.9	4.8
LSD (P=0.05)		ns	ns	
Stubble				
Flax		5.9	12.9	4.1
Pea		6.4	13.9	4.2
LSD (P=0.05)		ns	ns	ns
N Applied ($kg\ ha^{-1}$)				
	0	5.9	13.7	4.1
	30 AN	6.2	14.5	3.9
	30 CRU	6.4	12.8	4.1
	90 AN	5.5	12.5	4.2
	90 CRU	6.6	13.3	4.7
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.046	0.098	0.086
N Applied ($kg\ ha^{-1}$)	4	0.9	0.75	0.3
N*S	4	0.23	0.62	0.81
Contrasts				
Pea vs Flax at 0 N		0.42	0.0963	0.77
Pea vs Flax at 30 N		0.38	0.95	0.41
Pea vs Flax at 90 N		0.16	0.76	0.59
AN vs CRU		0.0964	0.67	0.38
AN vs CRU - 30 N vs 90 N		0.69	0.29	0.1
0 N vs 30 N		0.61	0.95	0.24
30N vs 90 N		0.92	0.53	0.53
Pea vs Flax - 0 N vs 30 N		0.27	0.2	0.82
Pea vs Flax - 30 N vs 90 N		0.12	0.87	0.36
Pea at 30 N vs Flax 90 N		0.81	0.52	0.74
C.V. (%)		28.3	25.0	18.6

* Ammonium nitrate

** Controlled-release urea

Table E.19. Estimated quantity of NH4-N in the 10-30 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg NH4-N ha^{-1}---		
Flax	0	7.6	25.1	6.3
Flax	30 AN*	8.9	24.4	6.2
Flax	30 CRU**	9.2	24.0	6.1
Flax	90 AN	9.4	19.6	7.3
Flax	90 CRU	7.1	22.1	7.3
Pea	0	9.8	22.0	7.2
Pea	30 AN	10.7	24.4	6.4
Pea	30 CRU	9.4	17.8	6.4
Pea	90 AN	7.5	18.6	6.4
Pea	90 CRU	7.3	23.5	7.8
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		8.5	23.0	6.7
Pea		9.0	21.3	6.9
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	8.7	23.6	6.8
	30 AN	9.8	24.4	6.3
	30 CRU	9.3	20.9	6.3
	90 AN	8.6	19.1	6.9
	90 CRU	7.2	22.8	7.6
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.29	0.17	0.19
N Applied (kg ha^{-1})	4	0.56	0.49	0.68
N*S	4	0.79	0.78	0.55
Contrasts				
Pea vs Flax at 0 N		0.23	0.48	0.18
Pea vs Flax at 30 N		0.43	0.32	0.16
Pea vs Flax at 90 N		0.69	0.94	0.8
AN vs CRU		0.0337	0.97	0.89
AN vs CRU - 30 N vs 90 N		0.17	0.13	0.44
0 N vs 30 N		0.43	0.75	0.37
30N vs 90 N		0.3	0.47	0.65
Pea vs Flax - 0 N vs 30 N		0.1	1	0.78
Pea vs Flax - 30 N vs 90 N		0.64	0.47	0.25
Pea at 30 N vs Flax 90 N		0.88	0.94	0.79
C.V. (%)		36.4	28.9	16.1

* Ammonium nitrate

** Controlled-release urea

Table E.20. Estimated quantity of NH4-N in the 30-50 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NH4-N ha^{-1}----------		
Flax	0	9.0	21.0	8.9
Flax	30 AN*	11.3	21.4	7.0
Flax	30 CRU**	6.7	18.4	10.7
Flax	90 AN	6.7	22.7	8.8
Flax	90 CRU	7.8	21.3	8.5
Pea	0	10.0	13.4	8.7
Pea	30 AN	7.2	17.4	8.4
Pea	30 CRU	6.8	20.6	8.1
Pea	90 AN	5.8	18.3	8.0
Pea	90 CRU	8.2	17.3	8.0
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		8.3	20.9	8.8
Pea		7.7	17.4	8.3
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	9.5	17.2	8.8
	30 AN	9.2	19.4	7.7
	30 CRU	6.8	19.5	9.4
	90 AN	6.3	20.5	8.4
	90 CRU	8.0	19.3	8.3
	LSD (P=0.05)	2.4	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.57	0.4	0.7
N Applied (kg ha^{-1})	4	0.027	0.63	0.92
N*S	4	0.18	0.26	0.85
Contrasts				
Pea vs Flax at 0 N		0.0411	0.0633	0.58
Pea vs Flax at 30 N		0.97	0.75	0.58
Pea vs Flax at 90 N		0.76	0.14	0.71
AN vs CRU		0.78	0.72	0.8
AN vs CRU - 30 N vs 90 N		0.65	0.66	0.97
0 N vs 30 N		0.1	0.23	0.56
30N vs 90 N		0.59	0.75	0.71
Pea vs Flax - 0 N vs 30 N		0.1	0.0807	0.45
Pea vs Flax - 30 N vs 90 N		0.83	0.28	0.9
Pea at 30 N vs Flax 90 N		0.59	0.28	0.84
C.V. (%)		27.3	22.2	21.7

* Ammonium nitrate

** Controlled-release urea

Table E.21. Estimated quantity of NH4-N in the 50-70 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg NH4-N ha^{-1}---		
Flax	0	7.8	13.0	9.6
Flax	30 AN*	8.3	17.8	8.5
Flax	30 CRU**	8.2	20.3	12.0
Flax	90 AN	8.3	19.7	11.0
Flax	90 CRU	8.5	18.5	9.0
Pea	0	8.8	20.7	9.4
Pea	30 AN	7.1	15.2	9.7
Pea	30 CRU	6.5	16.3	8.7
Pea	90 AN	6.1	16.2	7.9
Pea	90 CRU	7.2	20.6	8.8
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		8.2	17.9	10.0
Pea		7.2	17.8	8.9
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	8.3	16.9	9.5
	30 AN	7.7	16.5	9.1
	30 CRU	7.4	18.3	10.4
	90 AN	7.4	18.0	9.4
	90 CRU	7.9	19.6	8.9
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.46	0.98	0.0664
N Applied (kg ha^{-1})	4	0.93	0.73	0.6
N*S	4	0.79	0.11	0.97
Contrasts				
Pea vs Flax at 0 N		0.0958	0.0341	0.0915
Pea vs Flax at 30 N		0.89	0.19	0.18
Pea vs Flax at 90 N		0.3	0.78	0.15
AN vs CRU		0.56	0.33	0.18
AN vs CRU - 30 N vs 90 N		0.31	0.95	0.9
0 N vs 30 N		0.27	0.81	0.84
30N vs 90 N		0.92	0.43	0.38
Pea vs Flax - 0 N vs 30 N		0.18	0.0145	0.53
Pea vs Flax - 30 N vs 90 N		0.36	0.45	0.94
Pea at 30 N vs Flax 90 N		0.57	0.18	0.45
C.V. (%)		35.9	27.0	22.3

* Ammonium nitrate

** Controlled-release urea

Table E.22. Estimated quantity of NH4-N in the 70-90 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NH4-N ha^{-1}----------		
Flax	0	7.3	14.6	11.0
Flax	30 AN*	6.7	16.8	9.1
Flax	30 CRU**	7.4	21.1	11.4
Flax	90 AN	7.7	17.7	10.5
Flax	90 CRU	7.0	19.8	10.0
Pea	0	8.7	18.1	10.7
Pea	30 AN	7.4	19.1	10.4
Pea	30 CRU	6.9	17.9	8.9
Pea	90 AN	7.0	20.7	9.5
Pea	90 CRU	6.3	21.1	10.2
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		7.2	18.0	10.4
Pea		7.3	19.4	9.9
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	8.0	16.4	10.9
	30 AN	7.0	17.9	9.8
	30 CRU	7.1	19.5	10.1
	90 AN	7.4	19.2	10.0
	90 CRU	6.6	20.4	10.1
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.95	0.66	0.74
N Applied (kg ha^{-1})	4	0.62	0.62	0.58
N*S	4	0.66	0.74	0.65
Contrasts				
Pea vs Flax at 0 N		0.83	0.42	0.29
Pea vs Flax at 30 N		0.29	0.87	0.76
Pea vs Flax at 90 N		0.11	0.47	0.54
AN vs CRU		0.62	0.48	0.85
AN vs CRU - 30 N vs 90 N		0.0306	0.93	0.41
0 N vs 30 N		0.45	0.33	0.17
30N vs 90 N		0.35	0.57	0.36
Pea vs Flax - 0 N vs 30 N		0.67	0.41	0.22
Pea vs Flax - 30 N vs 90 N		0.73	0.5	0.45
Pea at 30 N vs Flax 90 N		0.54	0.93	0.49
C.V. (%)		24.4	29.1	19.5

* Ammonium nitrate

** Controlled-release urea

Table E.23. Estimated quantity of NH4-N in the 90-110 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NH4-N ha^{-1}----------		
Flax	0	7.0	17.6	10.5
Flax	30 AN*	6.6	18.7	10.7
Flax	30 CRU**	4.1	15.9	11.5
Flax	90 AN	8.2	17.3	9.8
Flax	90 CRU	8.6	20.7	10.1
Pea	0	8.2	18.4	9.9
Pea	30 AN	8.8	15.3	11.3
Pea	30 CRU	8.4	17.2	8.6
Pea	90 AN	7.4	14.9	10.9
Pea	90 CRU	9.4	15.4	11.8
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		6.9	18.0	10.5
Pea		8.5	16.2	10.5
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	7.6	18.0	10.2
	30 AN	7.7	17.0	11.0
	30 CRU	6.3	16.5	10.0
	90 AN	7.9	16.1	10.4
	90 CRU	9.0	18.0	10.9
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.32	0.45	0.96
N Applied (kg ha^{-1})	4	0.31	0.91	0.38
N*S	4	0.29	0.64	0.75
Contrasts				
Pea vs Flax at 0 N		0.0666	0.83	0.55
Pea vs Flax at 30 N		0.18	0.69	0.68
Pea vs Flax at 90 N		0.65	0.15	0.93
AN vs CRU		0.47	0.68	0.14
AN vs CRU - 30 N vs 90 N		0.75	0.5	0.44
0 N vs 30 N		0.89	0.57	0.25
30N vs 90 N		0.25	0.87	0.74
Pea vs Flax - 0 N vs 30 N		0.0279	0.67	0.46
Pea vs Flax - 30 N vs 90 N		0.2	0.43	0.72
Pea at 30 N vs Flax 90 N		0.22	0.3	0.7
C.V. (%)		31.5	28.9	32.5

* Ammonium nitrate

** Controlled-release urea

Table E.24. Estimated quantity of NH4-N in the 0-110 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------kg NH4-N ha^{-1}---------		
Flax	0	44	103	50
Flax	30 AN*	49	114	45
Flax	30 CRU**	41	112	56
Flax	90 AN	46	109	52
Flax	90 CRU	45	116	50
Pea	0	52	108	50
Pea	30 AN	47	105	50
Pea	30 CRU	46	103	45
Pea	90 AN	39	102	47
Pea	90 CRU	45	111	51
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		45	111	51
Pea		46	106	49
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	48	106	50
	30 AN	48	110	47
	30 CRU	43	107	50
	90 AN	43	105	49
	90 CRU	45	113	50
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.87	0.6	0.45
N Applied (kg ha^{-1})	4	0.63	0.76	0.84
N*S	4	0.45	0.84	0.0659
Contrasts				
Pea vs Flax at 0 N		0.22	0.65	0.97
Pea vs Flax at 30 N		0.75	0.28	0.31
Pea vs Flax at 90 N		0.63	0.46	0.53
AN vs CRU		0.75	0.56	0.34
AN vs CRU - 30 N vs 90 N		0.23	0.3	0.73
0 N vs 30 N		0.47	0.63	0.61
30N vs 90 N		0.61	0.87	0.65
Pea vs Flax - 0 N vs 30 N		0.36	0.26	0.52
Pea vs Flax - 30 N vs 90 N		0.42	0.77	0.78
Pea at 30 N vs Flax 90 N		0.9	0.31	0.26
C.V. (%)		17.3	12.6	11.0

* Ammonium nitrate

** Controlled-release urea

Table E.25. Estimated quantity of NH4-N at harvest at various soil depths at the Swift Current-01 site.

Treatment		Sampling Depth						
Stubble	N Applied (kg ha^{-1})	0-10 cm	10-30 cm	30-50 cm	50-70 cm	70-90 cm	90-110 cm	0-110 cm
		kg NH4-N ha^{-1}						
Durum	34	3.2	7.0	7.0	5.2	5.6	7.5	35.6
Durum	50	3.9	10.1	10.1	8.6	8.0	8.1	48.9
Durum	78	4.1	7.9	9.1	12.5	12.4	11.3	57.4
Pea	34	4.3	8.6	11.1	11.8	10.5	10.6	56.9
Pea	50	3.7	9.0	10.1	8.2	7.7	8.4	47.1
Pea	78	3.7	8.5	11.0	10.0	8.7	9.4	51.3
LSD (P=0.05)		ns	ns	ns	ns	3.7	ns	ns
Stubble								
Durum		3.8	8.4	8.7	8.8	8.7	8.9	47.3
Pea		3.9	8.7	10.7	10.0	9.0	9.4	51.8
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns
	N Applied (kg ha^{-1})							
	34	3.8	7.8	9.0	8.5	8.1	9.0	46.2
	50	3.8	9.6	10.1	8.4	7.8	8.2	48.0
	78	3.9	8.2	10.1	11.3	10.6	10.3	54.4
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns
ANOVA	df				Pr>F			
Stubble (S)	1	0.87	0.86	0.33	0.37	0.78	0.61	0.53
N Applied (kg ha^{-1})	2	0.98	0.75	0.88	0.17	0.0793	0.25	0.61
N*S	2	0.67	0.85	0.7	0.0352	0.0126	0.15	0.26
Contrasts								
34 N vs 50 N		0.95	0.48	0.67	0.93	0.86	0.51	0.84
50 N vs 78 N		0.89	0.58	1	0.0982	0.0432	0.11	0.46
Pea vs Durum - 34 N vs 50 N		0.48	0.59	0.41	0.0479	0.052	0.27	0.2
Pea vs Durum - 50 N vs 78 N		0.92	0.73	0.7	0.52	0.19	0.36	0.81
Durum at 50 N vs Pea at 34 N		0.8	0.66	0.78	0.18	0.17	0.16	0.52
Durum at 78 N vs Pea at 50 N		0.72	0.75	0.79	0.0791	0.0165	0.11	0.41
C.V. (%)		38.7	48.7	43.1	29.7	23.6	22.1	29.6

*Days after anthesis

Table E.26. Estimated quantity of NO_3-N in the 0-10 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg NO_3-N ha^{-1}----------		
Flax	0	10.6	10.3	5.0
Flax	30 AN*	11.2	12.0	4.9
Flax	30 CRU**	9.4	11.5	4.3
Flax	90 AN	10.9	12.7	5.1
Flax	90 CRU	10.0	16.2	6.2
Pea	0	10.2	8.8	4.8
Pea	30 AN	12.8	13.6	4.2
Pea	30 CRU	11.0	13.8	3.8
Pea	90 AN	11.9	14.4	4.8
Pea	90 CRU	13.4	18.1	4.6
LSD (P=0.05)		ns	ns	3.9
Stubble				
Flax		10.4	12.5	5.1
Pea		11.8	13.7	4.4
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	10.4	9.6	4.9
	30 AN	12.0	12.8	4.5
	30 CRU	10.2	12.6	4.1
	90 AN	11.4	13.5	5.0
	90 CRU	11.7	17.1	5.4
	LSD (P=0.05)	ns	3.7	2.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.28	0.49	0.13
N Applied (kg ha^{-1})	4	0.84	0.0092	0.81
N*S	4	0.76	0.71	0.88
Contrasts				
Pea vs Flax at 0 N		0.91	0.48	0.77
Pea vs Flax at 30 N		0.3	0.25	0.39
Pea vs Flax at 90 N		0.1	0.36	0.13
AN vs CRU		0.62	0.24	0.7
AN vs CRU - 30 N vs 90 N		0.38	0.26	0.57
0 N vs 30 N		0.65	0.028	0.54
30N vs 90 N		0.96	0.0875	0.31
Pea vs Flax - 0 N vs 30 N		0.48	0.2	0.8
Pea vs Flax - 30 N vs 90 N		0.69	0.85	0.64
Pea at 30 N vs Flax 90 N		0.2	0.88	0.0603
C.V. (%)		11.5	10.5	27.2

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.27. Estimated quantity of NO_3-N in the 10-30 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		----------kg NO_3-N ha^{-1}----------		
Flax	0	7.2	8.7	3.7
Flax	30 AN*	7.7	10.3	3.1
Flax	30 CRU**	7.2	10.0	3.5
Flax	90 AN	9.9	11.5	3.4
Flax	90 CRU	8.9	14.1	3.1
Pea	0	6.9	7.8	3.9
Pea	30 AN	10.7	12.4	2.4
Pea	30 CRU	8.6	12.3	2.7
Pea	90 AN	10.5	11.3	3.9
Pea	90 CRU	8.2	15.3	4.5
LSD (P=0.05)		ns	1.6	3.1
Stubble				
Flax		8.2	10.9	3.4
Pea		8.9	11.8	3.5
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	7.1	8.3	3.8
	30 AN	9.2	11.4	2.8
	30 CRU	7.9	11.1	3.1
	90 AN	10.2	11.4	3.7
	90 CRU	8.6	14.7	3.8
	LSD (P=0.05)	ns	2.7	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.77	0.59	0.46
N Applied ($kg\ ha^{-1}$)	4	0.51	0.0013	0.31
N*S	4	0.75	0.58	0.5
Contrasts				
Pea vs Flax at 0 N		0.79	0.56	0.92
Pea vs Flax at 30 N		0.26	0.12	0.0647
Pea vs Flax at 90 N		0.82	0.8	0.62
AN vs CRU		0.39	0.15	0.66
AN vs CRU - 30 N vs 90 N		0.84	0.13	0.35
0 N vs 30 N		0.26	0.0071	0.0881
30N vs 90 N		0.55	0.0641	0.13
Pea vs Flax - 0 N vs 30 N		0.31	0.14	0.24
Pea vs Flax - 30 N vs 90 N		0.34	0.31	0.1
Pea at 30 N vs Flax 90 N		0.85	0.74	0.0824
C.V. (%)		15.0	9.3	41.6

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.28. Estimated quantity of NO_3-N in the 30-50 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg NO_3-N ha^{-1}---		
Flax	0	5.9	6.6	2.7
Flax	30 AN*	6.3	5.0	2.9
Flax	30 CRU**	8.3	8.0	2.2
Flax	90 AN	7.8	9.4	2.4
Flax	90 CRU	6.3	7.6	2.7
Pea	0	7.5	5.2	2.9
Pea	30 AN	7.5	7.4	2.3
Pea	30 CRU	8.2	7.6	1.5
Pea	90 AN	6.8	10.3	1.8
Pea	90 CRU	7.9	8.0	2.2
LSD (P=0.05)		ns	4.4	ns
Stubble				
Flax		6.9	7.3	2.6
Pea		7.6	7.7	2.2
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	6.7	5.9	2.8
	30 AN	6.9	6.2	2.6
	30 CRU	8.2	7.8	1.9
	90 AN	7.4	9.9	2.1
	90 CRU	7.1	7.8	2.4
	LSD (P=0.05)	ns	1.6	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.62	0.72	0.17
N Applied (kg ha^{-1})	4	0.94	<0.0001	0.0688
N*S	4	0.62	0.0539	0.54
Contrasts				
Pea vs Flax at 0 N		0.31	0.15	0.84
Pea vs Flax at 30 N		0.71	0.12	0.0513
Pea vs Flax at 90 N		0.34	0.53	0.0656
AN vs CRU		0.74	0.94	0.59
AN vs CRU - 30 N vs 90 N		0.79	0.0014	0.024
0 N vs 30 N		0.46	0.12	0.0785
30N vs 90 N		0.68	0.0013	0.94
Pea vs Flax - 0 N vs 30 N		0.39	0.016	0.17
Pea vs Flax - 30 N vs 90 N		0.7	0.41	0.93
Pea at 30 N vs Flax 90 N		0.43	0.32	0.052
C.V. (%)		14.9	9.7	49.6

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.29. Estimated quantity of NO_3-N in the 50-70 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		kg NO_3-N ha^{-1}		
Flax	0	3.9	3.6	2.5
Flax	30 AN*	5.1	3.5	2.5
Flax	30 CRU**	3.9	4.2	2.5
Flax	90 AN	4.9	8.5	2.6
Flax	90 CRU	4.1	5.7	2.5
Pea	0	5.1	2.7	2.6
Pea	30 AN	5.3	3.1	3.0
Pea	30 CRU	4.9	3.5	1.6
Pea	90 AN	4.8	5.0	3.3
Pea	90 CRU	7.1	4.7	2.7
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		4.4	5.1	2.5
Pea		5.5	3.8	2.6
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	4.5	3.2	2.6
	30 AN	5.2	3.3	2.8
	30 CRU	4.4	3.8	2.0
	90 AN	4.9	6.7	2.9
	90 CRU	5.6	5.2	2.6
	LSD (P=0.05)	ns	3.1	ns
ANOVA	df	Pr>F		
Stubble (S)	1	0.42	0.62	0.6
N Applied (kg ha^{-1})	4	0.49	0.0363	0.32
N*S	4	0.44	0.97	0.37
Contrasts				
Pea vs Flax at 0 N		0.4	0.38	0.97
Pea vs Flax at 30 N		0.48	0.66	0.0929
Pea vs Flax at 90 N		0.086	0.73	0.51
AN vs CRU		0.83	0.58	0.19
AN vs CRU - 30 N vs 90 N		0.1	0.56	0.82
0 N vs 30 N		0.73	0.45	0.3
30N vs 90 N		0.71	0.0123	0.1
Pea vs Flax - 0 N vs 30 N		0.71	0.6	0.3
Pea vs Flax - 30 N vs 90 N		0.42	0.93	0.1
Pea at 30 N vs Flax 90 N		0.35	0.0461	0.0939
C.V. (%)		19.1	28.1	53.8

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.30. Estimated quantity of NO_3-N in the 70-90 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-kg NO_3-N ha^{-1}-		
Flax	0	3.3	4.9	2.2
Flax	30 AN*	3.2	5.6	2.0
Flax	30 CRU**	3.6	4.4	2.1
Flax	90 AN	3.2	9.1	2.0
Flax	90 CRU	4.1	12.3	2.2
Pea	0	4.5	2.2	2.2
Pea	30 AN	4.2	3.5	1.3
Pea	30 CRU	5.3	5.8	1.4
Pea	90 AN	5.3	7.0	4.3
Pea	90 CRU	6.4	7.3	2.2
LSD (P=0.05)		ns	4.6	ns
Stubble				
Flax		3.4	7.3	2.1
Pea		5.1	5.2	2.3
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	3.9	3.6	2.2
	30 AN	3.7	4.5	1.6
	30 CRU	4.4	5.1	1.8
	90 AN	4.1	8.1	3.2
	90 CRU	5.2	9.8	2.2
	LSD (P=0.05)	ns	3.1	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.13	0.35	0.7
N Applied (kg ha^{-1})	4	0.47	0.0007	0.1
N*S	4	0.94	0.2	0.21
Contrasts				
Pea vs Flax at 0 N		0.33	0.0358	0.85
Pea vs Flax at 30 N		0.11	0.66	0.39
Pea vs Flax at 90 N		0.0176	0.36	0.11
AN vs CRU		0.23	0.33	0.44
AN vs CRU - 30 N vs 90 N		0.89	0.5	0.39
0 N vs 30 N		0.91	0.0844	0.41
30N vs 90 N		0.23	0.0011	0.0367
Pea vs Flax - 0 N vs 30 N		0.87	0.0909	0.48
Pea vs Flax - 30 N vs 90 N		0.52	0.7	0.0654
Pea at 30 N vs Flax 90 N		0.22	0.006	0.3
C.V. (%)		27.1	26.1	57.1

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.31. Estimated quantity of NO_3-N in the 90-110 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		----------kg NO_3-N ha^{-1}----------		
Flax	0	2.4	10.0	2.6
Flax	30 AN*	2.7	14.5	3.1
Flax	30 CRU**	2.0	9.6	2.9
Flax	90 AN	3.8	17.5	3.0
Flax	90 CRU	3.5	27.0	3.6
Pea	0	4.2	3.3	3.7
Pea	30 AN	3.7	8.5	2.5
Pea	30 CRU	4.7	9.9	1.7
Pea	90 AN	4.8	11.6	3.8
Pea	90 CRU	5.8	12.4	2.8
LSD (P=0.05)		2.2	ns	ns
Stubble				
Flax		2.9	15.7	3.0
Pea		4.6	9.1	2.9
LSD (P=0.05)		ns	ns	ns
N Applied ($kg\ ha^{-1}$)				
	0	3.3	6.6	3.1
	30 AN	3.2	11.5	2.8
	30 CRU	3.3	9.8	2.3
	90 AN	4.2	14.5	3.4
	90 CRU	4.7	19.7	3.2
	LSD (P=0.05)	ns	8.2	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0856	0.42	0.61
N Applied ($kg\ ha^{-1}$)	4	0.13	0.0091	0.2
N*S	4	0.5	0.51	0.16
Contrasts				
Pea vs Flax at 0 N		0.1	0.0502	0.36
Pea vs Flax at 30 N		0.0093	0.49	0.0679
Pea vs Flax at 90 N		0.0749	0.42	0.98
AN vs CRU		0.9	0.64	0.21
AN vs CRU - 30 N vs 90 N		0.67	0.19	0.45
0 N vs 30 N		0.73	0.0923	0.26
30N vs 90 N		0.0139	0.0214	0.0535
Pea vs Flax - 0 N vs 30 N		0.83	0.12	0.0593
Pea vs Flax - 30 N vs 90 N		0.48	0.91	0.17
Pea at 30 N vs Flax 90 N		0.6	0.0438	0.0289
C.V. (%)		31.0	29.1	49.1

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table E.32. Estimated quantity of NO_3-N in the 0-110 cm depth at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment: Stubble	N Applied ($kg\ ha^{-1}$)	Site: Carman-00	Carman-01	Brandon-01
		--------------------kg NO_3-N ha^{-1}	--------------------	
Flax	0	33	44	19
Flax	30 AN*	36	51	19
Flax	30 CRU**	34	48	17
Flax	90 AN	41	69	18
Flax	90 CRU	37	83	20
Pea	0	38	30	20
Pea	30 AN	44	49	16
Pea	30 CRU	43	53	13
Pea	90 AN	44	60	22
Pea	90 CRU	49	66	19
LSD (P=0.05)		ns	17	ns
Stubble				
Flax		36	59	19
Pea		44	51	18
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	36	37	19
	30 AN	40	50	17
	30 CRU	39	50	15
	90 AN	42	64	20
	90 CRU	43	74	19
	LSD (P=0.05)	ns	11	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.37	0.44	0.17
N Applied ($kg\ ha^{-1}$)	4	0.7	<0.0001	0.24
N*S	4	0.86	0.0708	0.42
Contrasts				
Pea vs Flax at 0 N		0.53	0.0168	0.78
Pea vs Flax at 30 N		0.17	0.61	0.06
Pea vs Flax at 90 N		0.1	0.22	0.96
AN vs CRU		0.93	0.17	0.3
AN vs CRU - 30 N vs 90 N		0.58	0.13	0.72
0 N vs 30 N		0.44	0.0008	0.13
30N vs 90 N		0.51	<0.0001	0.0545
Pea vs Flax - 0 N vs 30 N		0.71	0.0096	0.2
Pea vs Flax - 30 N vs 90 N		0.9	0.15	0.2
Pea at 30 N vs Flax 90 N		0.28	0.0015	0.0193
C.V. (%)		6.2	4.4	10.6

* Ammonium nitrate

** Controlled-release urea

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

Table A.106. Estimated quantity of NO_3-N at harvest at the Swift Current-01 site.[a]

Treatment		Sampling Depth						
Stubble	N Applied (kg ha^{-1})	0-10 cm	10-30 cm	30-50 cm	50-70 cm	70-90 cm	90-110 cm	0-110 cm
		kg NO_3-N ha^{-1}						
Durum	34	1.5	2.4	1.9	2.6	3.1	6.1	17.6
Durum	50	2.0	1.4	1.4	2.6	6.7	7.4	22.0
Durum	78	12.4	11.8	2.9	4.3	6.4	7.5	45.3
Pea	34	11.0	5.4	2.9	3.6	4.0	4.8	31.8
Pea	50	7.0	2.7	1.4	1.9	2.3	2.4	17.6
Pea	78	14.4	6.2	1.9	1.6	2.5	3.4	30.4
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns
Stubble								
Durum		5.3	5.2	2.1	3.3	5.4	7.0	28.3
Pea		10.8	4.8	2.1	2.4	3.0	3.5	26.5
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns
N Applied (kg ha^{-1})								
	34	6.2	3.9	2.4	3.1	3.6	5.4	24.7
	50	4.5	2.1	1.4	2.5	4.5	4.9	19.8
	78	13.4	9.0	2.4	3.0	4.5	5.4	37.7
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F						
Stubble (S)	1	0.0685	0.58	0.82	0.79	0.73	0.43	0.7
N Applied (kg ha^{-1})	2	0.2	0.0566	0.32	0.84	0.9	0.69	0.34
N*S	2	0.3	0.19	0.45	0.75	0.54	0.79	0.55
Contrasts								
34 N vs 50 N		0.8	0.14	0.2	0.57	0.81	0.51	0.4
50 N vs 78 N		0.1	0.0192	0.19	0.84	0.82	0.42	0.15
Pea vs Flax - 34 N vs 50 N		0.57	0.77	0.59	0.94	0.36	0.55	0.59
Pea vs Flax - 50 N vs 78 N		0.33	0.16	0.48	0.55	0.93	1	0.58
Durum at 50 N vs Pea at 34 N		0.0736	0.0468	0.22	0.58	0.92	0.89	0.23
Durum at 78 N vs Pea at 50 N		0.55	0.0594	0.15	0.64	0.42	0.2	0.24
C.V. (%)		71.5	64.1	107.3	123.7	85.7	64.4	24.3

*Days after anthesis

[a] Statistics are based on log transformed data due to the high variability of the NO_3-N data. Treatment and group means as well as LSD values are not transformed.

8.6. APPENDIX F – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SOIL WATER CONTENT AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table F.1. Volumetric water content of the 0-10 cm soil depth at the Carman-00 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied ($kg\ ha^{-1}$)	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		VWC (%)									
Flax	0	26.5	36.0	34.4	23.8	22.2	18.2	31.2	28.8	0.24	*
Flax	30	26.3	36.1	34.8	25.4	22.2	17.3	29.7	28.9	0.27	*
Flax	90	25.9	35.6	33.6	23.2	21.5	16.7	28.8	27.9	0.07	*
Pea	0	26.3	37.7	33.8	24.5	23.3	19.4	30.3	29.0	*	*
Pea	30	26.7	36.1	34.5	24.5	22.6	16.4	28.6	28.0	0.19	*
Pea	90	26.4	37.2	32.9	24.1	22.9	18.1	28.9	26.6	0.06	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		26.2	35.9	34.3	24.1	21.9	17.4	29.9	28.5	*	*
Pea		26.5	37.0	33.7	24.4	22.9	18.0	29.2	27.8	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied ($kg\ ha^{-1}$)											
	0	26.4	36.8	34.1	24.1	22.7	18.8	30.8	28.9	*	*
	30	26.5	36.1	34.7	24.9	22.4	16.8	29.2	28.5	0.05	*
	90	26.1	36.4	33.3	23.7	22.2	17.4	28.8	27.2	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.9	0.33	0.43	0.72	0.12	0.62	0.63	0.36		
N Applied ($kg\ ha^{-1}$)	2	0.7	0.55	0.3	0.11	0.46	0.0083	0.0792	0.17		
N*S	2	0.46	0.4	0.98	0.23	0.57	0.09	0.74	0.65		
C.V. (%)		3.3	3.7	5.1	4.4	4.0	6.0	5.6	6.0		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.2. Volumetric water content of the 10-30 cm soil depth at the Carman-00 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		VWC (%)									
Flax	0	27.5	31.0	24.9	22.6	19.5	17.0	20.0	27.9	*	*
Flax	30	27.8	30.1	26.3	22.3	19.0	17.0	19.5	28.7	*	*
Flax	90	25.3	28.1	22.3	18.8	16.1	14.7	16.1	25.4	*	*
Pea	0	25.5	28.3	23.1	19.8	16.8	14.9	16.7	24.6	*	*
Pea	30	25.8	28.2	23.7	20.0	16.8	15.1	17.3	25.6	*	*
Pea	90	25.8	30.6	23.6	19.9	16.4	15.1	17.5	24.6	*	*
LSD (P=0.05)		ns	ns	ns	2.5	1.8	1.8	1.9	2.2		
Stubble											
Flax		26.9	29.7	24.5	21.2	18.2	16.2	18.5	27.3	*	*
Pea		25.7	29.0	23.5	19.9	16.7	15.0	17.2	24.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})											
	0	26.5	29.6	24.0	21.2	18.2	15.9	18.3	26.2	*	*
	30	26.8	29.2	25.0	21.1	17.9	16.0	18.4	27.1	*	*
	90	25.5	29.3	23.0	19.3	16.2	14.9	16.8	25.0	*	*
	LSD (P=0.05)	ns	ns	ns	ns	1.1	ns	1.2	1.1		
ANOVA	df	Pr>F									
Stubble (S)	1	0.53	0.79	0.38	0.0304	0.13	0.2	0.16	0.11		
N Applied (kg ha^{-1})	2	0.13	0.94	0.11	0.11	0.0034	0.0937	0.0235	0.003		
N*S	2	0.0894	0.13	0.1	0.1	0.0218	0.0672	0.0032	0.046		
C.V. (%)		4.6	8.7	7.3	8.8	5.6	6.6	6.3	3.8		

† Days after planting.
‡ Days after anthesis.
[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.3. Volumetric water content of the 30-50 cm soil depth at the Carman-00 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		---VWC (%)---									
Flax	0	27.2	29.8	23.8	23.8	21.8	19.8	19.9	24.5	*	*
Flax	30	27.6	29.5	25.7	23.9	21.6	20.0	20.1	25.3	*	*
Flax	90	26.4	29.2	23.7	22.5	19.8	18.4	18.2	22.5	*	*
Pea	0	24.9	27.1	21.4	19.9	17.6	16.0	16.2	20.6	*	*
Pea	30	26.6	28.9	23.7	22.0	19.2	17.6	17.5	22.5	*	*
Pea	90	26.1	28.2	23.7	22.9	19.5	17.3	17.4	21.1	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		27.1	29.5	24.4	23.4	21.0	19.4	19.4	24.1	*	*
Pea		25.8	28.0	23.0	21.6	18.8	17.0	17.0	21.4	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})										
	0	26.0	28.4	22.6	21.8	19.7	17.9	18.1	22.6	*	*
	30	27.1	29.2	24.7	22.9	20.4	18.8	18.8	23.9	*	*
	90	26.3	28.7	23.7	22.7	19.6	17.8	17.8	21.8	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.62	0.53	0.37	0.28	0.18	0.13	0.15	0.14		
N Applied (kg ha^{-1})	2	0.53	0.68	0.33	0.57	0.65	0.39	0.53	0.18		
N*S	2	0.55	0.46	0.66	0.17	0.12	0.25	0.31	0.51		
C.V. (%)		7.0	6.1	11.4	9.2	8.6	8.4	9.9	9.3		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.4. Volumetric water content of the 50-70 cm soil depth at the Carman-00 site.[a]

Treatment: Stubble	Treatment: N Applied ($kg\ ha^{-1}$)	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)									
Flax	0	28.5	32.2	28.1	26.7	24.6	23.1	23.3	24.4	*	*
Flax	30	28.5	31.6	27.9	26.8	24.5	22.3	22.5	24.2	*	*
Flax	90	26.2	31.0	27.2	26.0	23.9	22.5	22.3	23.3	*	*
Pea	0	25.1	28.6	23.3	21.6	18.5	16.5	16.1	17.8	*	*
Pea	30	28.4	31.9	27.1	25.3	22.9	20.2	19.8	21.8	*	*
Pea	90	25.5	28.3	24.5	23.2	20.4	17.5	17.2	17.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		27.7	31.6	27.7	26.5	24.4	22.7	22.7	24.0	*	*
Pea		26.3	29.6	25.0	23.3	20.6	18.0	17.7	18.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	4.4	4.1		
N Applied ($kg\ ha^{-1}$)											
	0	26.8	30.4	25.7	24.1	21.6	19.8	19.7	21.1	*	*
	30	28.5	31.8	27.5	26.1	23.7	21.3	21.1	23.0	*	*
	90	25.9	29.7	25.8	24.6	22.1	20.0	19.7	20.2	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.35	0.39	0.1	0.0946	0.0619	0.0519	0.0393	0.0186		
N Applied ($kg\ ha^{-1}$)	2	0.58	0.66	0.76	0.75	0.68	0.81	0.81	0.48		
N*S	2	0.79	0.69	0.77	0.79	0.68	0.64	0.68	0.61		
C.V. (%)		18.3	15.1	20.9	21.1	22.4	23.6	24.7	21.7		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.5. Volumetric water content of the 70-90 cm soil depth at the Carman-00 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		VWC (%)									
Flax	0	31.8	36.0	33.5	32.0	29.9	28.6	28.2	28.6	*	*
Flax	30	28.5	35.7	31.0	29.5	26.6	24.9	24.5	25.9	*	*
Flax	90	29.5	33.3	30.9	30.1	28.4	27.1	25.9	26.6	0.07	*
Pea	0	32.1	33.5	31.8	30.6	27.6	24.6	24.2	25.2	0.48	*
Pea	30	33.3	37.6	34.4	33.3	31.0	28.7	28.5	28.2	*	*
Pea	90	27.1	31.2	26.9	25.3	21.4	18.9	18.5	18.8	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		29.9	35.0	31.8	30.5	28.3	26.9	26.2	27.0	*	*
Pea		30.8	34.1	31.0	29.7	26.7	24.1	23.7	24.1	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})											
	0	31.9	34.7	32.6	31.3	28.8	26.6	26.2	26.9	0.07	*
	30	30.9	36.6	32.7	31.4	28.8	26.8	26.5	27.0	*	*
	90	28.3	32.2	28.9	27.7	24.9	23.0	22.2	22.7	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.63	0.48	0.74	0.74	0.48	0.28	0.39	0.26		
N Applied (kg ha^{-1})	2	0.4	0.12	0.32	0.35	0.35	0.36	0.33	0.25		
N*S	2	0.42	0.48	0.4	0.33	0.19	0.15	0.19	0.23		
C.V. (%)		17.5	11.3	17.4	18.6	21.3	22.7	24.3	22.0		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.6. Volumetric water content of the 90-110 cm soil depth at the Carman-00 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		--VWC (%)--									
Flax	0	38.9	41.3	40.0	39.3	38.5	37.2	37.1	37.4	0.24	*
Flax	30	35.6	39.8	37.2	36.5	33.8	31.4	30.8	31.1	*	*
Flax	90	33.4	36.3	35.5	35.0	32.8	31.2	30.5	30.4	0.44	*
Pea	0	36.1	39.6	37.5	36.8	34.3	32.8	31.2	28.8	0.18	*
Pea	30	35.1	39.2	37.0	35.8	34.0	31.1	30.4	30.6	0.27	*
Pea	90	38.5	40.2	39.3	38.7	36.0	33.7	33.3	33.7	0.15	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		35.9	39.1	37.6	36.9	35.0	33.3	32.8	33.0	*	*
Pea		36.6	39.6	37.9	37.1	34.8	32.6	31.6	31.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})											
	0	37.5	40.4	38.7	38.1	36.4	35.0	34.1	33.1	0.05	*
	30	35.3	39.5	37.1	36.1	33.9	31.3	30.6	30.9	*	*
	90	35.9	38.2	37.4	36.8	34.4	32.5	31.9	32.1	0.11	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.74	0.76	0.86	0.95	0.91	0.71	0.63	0.37		
N Applied (kg ha^{-1})	2	0.79	0.45	0.79	0.81	0.75	0.55	0.67	0.85		
N*S	2	0.45	0.25	0.48	0.59	0.57	0.61	0.54	0.33		
C.V. (%)		17.2	8.6	13.5	16.3	19.7	20.7	24.3	24.2		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.7. Total soil water content in the 0-110 cm depth at the Carman-00 site.

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	16DAP†	38DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA
		Soil Water (cm)							
Flax	0	33.4	37.6	33.5	31.3	29.1	27.0	28.8	31.5
Flax	30	32.2	37.0	33.1	30.3	27.3	24.9	26.5	29.9
Flax	90	30.7	35.1	31.3	28.8	26.3	24.5	25.5	28.4
Pea	0	30.7	35.2	30.8	28.2	25.3	22.9	23.9	26.3
Pea	30	32.5	36.8	32.6	29.7	27.0	24.2	25.6	28.6
Pea	90	31.2	35.4	30.9	28.4	25.0	22.3	23.7	25.7
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns
Stubble									
Flax		32.1	36.6	32.6	30.1	27.6	25.4	26.9	29.9
Pea		31.5	35.8	31.4	28.8	25.8	23.1	24.4	26.8
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	2.8
	N Applied (kg ha^{-1})								
	0	32.1	36.4	32.1	29.7	27.2	24.9	26.4	28.9
	30	32.4	36.9	32.9	30.0	27.2	24.5	26.0	29.2
	90	31.0	35.3	31.1	28.6	25.7	23.4	24.6	27.1
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F							
Stubble (S)	1	0.61	0.41	0.34	0.25	0.17	0.0873	0.1	0.0332
N Applied (kg ha^{-1})	2	0.65	0.38	0.49	0.57	0.53	0.58	0.56	0.36
N*S	2	0.52	0.46	0.67	0.58	0.5	0.55	0.5	0.49
C.V. (%)		9.6	6.3	9.0	9.3	11.2	12.4	13.5	11.1

† Days after planting.
‡ Days after anthesis.

Table F.8. Volumetric water content of the 0-10 cm depth at the Carman-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		---VWC (%)---									
Flax	0	30.9	23.6	23.2	28.7	24.9	32.8	29.8	29.4	*	*
Flax	30	30.1	23.7	22.6	28.2	24.3	30.8	30.0	29.8	*	*
Flax	90	31.1	22.4	21.0	27.2	22.6	31.5	27.8	27.9	*	*
Pea	0	31.5	24.3	21.4	28.7	24.3	32.0	29.9	30.0	*	*
Pea	30	31.5	23.6	21.6	28.2	23.5	31.0	28.7	29.1	*	*
Pea	90	30.2	23.5	22.4	28.3	22.4	31.1	27.5	28.4	*	*
LSD (P=0.05)		ns	ns	ns	ns	2.1	1.8	2.3	2.2		
Stubble											
Flax		30.7	23.2	22.3	28.0	23.9	31.7	29.2	29.0	*	*
Pea		31.1	23.8	21.8	28.4	23.4	31.3	28.7	29.2	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})											
	0	31.2	23.9	22.3	28.7	24.6	32.4	29.9	29.7	*	*
	30	30.8	23.6	22.1	28.2	23.9	30.9	29.4	29.4	*	*
	90	30.6	22.9	21.7	27.8	22.5	31.3	27.7	28.1	*	*
	LSD (P=0.05)	ns	ns	ns	ns	1.6	ns	1.6	ns		
ANOVA	**df**	Pr>F									
Stubble (S)	1	0.69	0.52	0.5	0.22	0.2	0.7	0.54	0.83		
N Applied (kg ha^{-1})	2	0.85	0.49	0.61	0.3	0.0468	0.28	0.034	0.16		
N*S	2	0.55	0.76	0.0643	0.5	0.93	0.84	0.59	0.69		
C.V. (%)		5.9	6.5	7.9	4.2	8.5	8.4	6.8	7.5		

† Days after planting.
‡ Days after anthesis.
[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.9. Volumetric water content of the 10-30 cm depth at the Carman-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)									
Flax	0	29.8	24.7	19.8	20.7	20.6	32.3	29.4	29.8	*	*
Flax	30	30.4	24.8	19.8	20.2	20.4	33.5	30.5	29.8	*	*
Flax	90	30.2	24.5	20.2	20.2	20.7	32.5	30.6	30.2	*	*
Pea	0	30.8	24.9	20.1	20.8	20.9	33.3	29.6	29.4	*	*
Pea	30	29.8	24.2	19.8	19.9	19.8	33.5	30.6	30.6	*	*
Pea	90	29.6	22.8	18.6	19.7	19.2	33.1	30.2	30.1	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		30.1	24.7	19.9	20.4	20.6	32.8	30.2	29.9	*	*
Pea		30.1	24.0	19.5	20.1	20.0	33.3	30.1	30.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})										
	0	30.3	24.8	19.9	20.8	20.7	32.8	29.5	29.6	*	*
	30	30.1	24.5	19.8	20.0	20.1	33.5	30.6	30.2	*	*
	90	29.9	23.7	19.4	19.9	20.0	32.8	30.4	30.1	*	*
	LSD (P=0.05)	ns	ns	ns	0.6	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.98	0.73	0.64	0.66	0.28	0.73	0.99	0.96		
N Applied (kg ha^{-1})	2	0.73	0.1	0.48	0.0213	0.15	0.34	0.14	0.49		
N*S	2	0.21	0.24	0.11	0.52	0.0854	0.67	0.82	0.49		
C.V. (%)		5.1	9.1	6.7	5.5	5.9	6.5	7.1	7		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.10. Volumetric water content of the 30-50 cm depth at the Carman-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)									
Flax	0	28.0	25.3	21.9	21.1	20.3	30.2	29.0	28.2	*	*
Flax	30	28.0	24.4	20.5	19.3	18.8	32.2	30.4	29.6	*	*
Flax	90	29.4	26.1	22.3	21.8	20.7	32.2	30.7	30.1	*	*
Pea	0	28.0	25.0	22.1	21.0	20.3	30.6	29.5	29.1	*	*
Pea	30	27.6	23.6	20.3	19.3	18.8	31.1	29.5	28.8	*	*
Pea	90	29.0	24.4	19.5	18.7	17.6	32.0	29.9	29.5	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		28.5	25.3	21.6	20.7	19.9	31.6	30.0	29.3	*	*
Pea		28.2	24.3	20.6	19.6	18.9	31.2	29.6	29.1	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})											
	0	28.0	25.2	22.0	21.1	20.3	30.4	29.2	28.7	*	*
	30	27.8	24.0	20.4	19.3	18.8	31.7	29.9	29.2	*	*
	90	29.2	25.3	20.9	20.3	19.2	32.1	30.3	29.8	*	*
	LSD (P=0.05)	1.1	ns	ns	ns	ns	1.2	ns	ns		
ANOVA	**df**	Pr>F									
Stubble (S)	1	0.78	0.55	0.54	0.39	0.35	0.89	0.86	0.93		
N Applied (kg ha^{-1})	2	0.0345	0.24	0.14	0.0712	0.0763	0.028	0.17	0.21		
N*S	2	0.87	0.69	0.13	0.0792	0.0403	0.39	0.37	0.33		
C.V. (%)		5.6	8.5	9.7	9.7	9.4	7.7	7.5	7.3		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.11. Volumetric water content of the 50-70 cm depth at the Carman-01 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied ($kg\ ha^{-1}$)	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		-----VWC (%)-----									
Flax	0	28.7	25.9	22.3	21.2	20.2	31.9	31.2	30.8	*	*
Flax	30	27.7	23.7	19.6	18.6	17.8	33.4	31.6	31.0	*	*
Flax	90	29.0	26.9	24.0	23.6	22.9	33.1	32.2	31.7	*	*
Pea	0	28.5	26.6	22.9	22.5	21.3	32.5	31.2	30.3	*	*
Pea	30	28.1	26.0	21.3	20.2	19.4	31.4	29.7	28.9	*	*
Pea	90	28.6	25.8	20.6	19.4	18.8	30.8	29.9	29.4	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		28.4	25.5	22.0	21.1	20.3	32.8	31.7	31.2	*	*
Pea		28.4	26.1	21.6	20.7	19.8	31.5	30.3	29.5	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied ($kg\ ha^{-1}$)											
	0	28.6	26.2	22.6	21.8	20.8	32.2	31.2	30.5	*	*
	30	27.9	24.9	20.5	19.4	18.6	32.4	30.7	30.0	*	*
	90	28.8	26.3	22.3	21.5	20.9	32.0	31.0	30.6	*	*
	LSD (P=0.05)	ns	1.3	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.97	0.5	0.81	0.8	0.77	0.7	0.67	0.58		
N Applied ($kg\ ha^{-1}$)	2	0.21	0.0661	0.21	0.2	0.12	0.77	0.59	0.59		
N*S	2	0.76	0.0541	0.14	0.1	0.0506	0.0562	0.1	0.3		
C.V. (%)		6.5	7.8	14.1	16.5	16.7	9.7	9.9	9.3		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.12. Volumetric water content of the 70-90 cm depth at the Carman-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)									
Flax	0	31.3	29.5	25.7	25.2	23.5	33.6	32.6	33.7	*	*
Flax	30	31.9	31.5	26.7	25.8	22.2	36.4	36.6	36.3	*	*
Flax	90	31.2	29.5	26.9	26.2	24.8	35.5	34.3	35.0	*	*
Pea	0	29.9	27.3	24.0	23.6	22.0	33.2	32.4	32.1	*	*
Pea	30	30.6	31.8	24.0	23.1	21.6	32.1	31.3	30.8	0.06	*
Pea	90	29.3	26.8	23.3	22.0	20.9	33.2	29.6	29.7	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		31.5	30.1	26.5	25.7	23.5	35.1	34.5	35.0	*	*
Pea		30.0	28.6	23.8	22.9	21.5	32.9	31.1	30.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})											
	0	30.6	28.4	24.9	24.4	22.8	33.4	32.5	32.9	*	*
	30	31.3	31.6	25.3	24.4	21.9	34.3	33.9	33.6	*	*
	90	30.3	28.1	25.1	24.1	22.8	34.3	32.0	32.4	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.35	0.54	0.41	0.42	0.56	0.48	0.36	0.22		
N Applied (kg ha^{-1})	2	0.54	0.2	0.93	0.98	0.68	0.72	0.13	0.64		
N*S	2	0.94	0.74	0.73	0.7	0.36	0.33	0.0337	0.26		
C.V. (%)		7.4	14.7	15.6	18	18	11	13	12		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.13. Volumetric water content of the 90-110 cm depth at the Carman-01 site.[a]

Treatment										Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		---VWC (%)---									
Flax	0	34.1	32.1	29.3	27.9	26.0	34.8	35.5	35.2	*	*
Flax	30	39.1	39.6	36.8	36.4	34.1	41.0	41.2	40.6	*	*
Flax	90	33.8	31.6	26.9	25.4	23.7	36.0	35.8	36.0	*	*
Pea	0	31.4	28.7	24.8	23.4	22.1	35.9	35.0	34.7	*	0.08
Pea	30	33.7	32.7	30.2	27.9	28.0	36.7	36.3	35.9	0.11	*
Pea	90	33.9	32.5	29.9	29.1	27.7	35.5	35.1	34.5	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
Stubble											
Flax		35.6	34.4	31.0	29.9	27.9	37.3	37.5	37.3	*	*
Pea		33.0	31.3	28.3	26.8	25.9	36.0	35.5	35.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})										
	0	32.7	30.4	27.0	25.7	24.0	35.3	35.2	35.0	*	*
	30	36.4	36.1	33.5	32.2	31.0	38.9	38.8	38.3	*	*
	90	33.8	32.0	28.4	27.3	25.7	35.8	35.5	35.3	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F									
Stubble (S)	1	0.12	0.045	0.0847	0.12	0.38	0.67	0.43	0.41		
N Applied (kg ha^{-1})	2	0.15	0.0829	0.0906	0.16	0.14	0.072	0.0528	0.14		
N*S	2	0.34	0.29	0.24	0.21	0.33	0.22	0.25	0.45		
C.V. (%)		11.5	15.8	20.1	23.5	25.3	10.8	10.4	11.2		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.14. Total soil water content in the 0-110 cm depth at the Carman-01 site.

Treatment: Stubble	N Applied ($kg\ ha^{-1}$)	35DAP†	49DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA
		Soil Water (cm)							
Flax	0	33.4	29.9	26.1	26.1	24.6	35.8	34.5	34.5
Flax	30	34.4	31.2	26.9	26.9	25.1	38.4	37.1	36.4
Flax	90	33.8	29.9	26.2	26.2	24.9	37.0	35.5	35.4
Pea	0	32.9	28.9	24.9	25.1	23.7	36.3	34.5	34.1
Pea	30	33.1	30.0	25.3	24.9	23.9	36.1	34.4	33.9
Pea	90	33.1	28.8	24.6	24.6	23.1	36.0	33.7	33.5
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns
Stubble									
Flax		33.9	30.3	26.4	26.4	24.8	37.1	35.7	35.4
Pea		33.0	29.3	24.9	24.9	23.6	36.1	34.2	33.8
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns
	N Applied ($kg\ ha^{-1}$)								
	0	33.2	29.4	25.5	25.6	24.2	36.1	34.5	34.3
	30	33.8	30.6	26.1	25.9	24.5	37.2	35.7	35.2
	90	33.5	29.4	25.4	25.4	24.0	36.5	34.6	34.4
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	1.0	ns
ANOVA	df	Pr>F							
Stubble (S)	1	0.39	0.47	0.32	0.31	0.44	0.72	0.58	0.53
N Applied ($kg\ ha^{-1}$)	2	0.54	0.24	0.64	0.84	0.84	0.26	0.0381	0.31
N*S	2	0.74	0.99	0.96	0.83	0.87	0.15	0.0327	0.21
C.V. (%)		3.2	5.2	6.2	6.4	7.1	3.6	2.6	3.4

*Days after seeding.

**Days after anthesis.

Table F.15. Volumetric Water Content of the 0-10 cm soil depth at the Brandon-01 site.[a,b]

Treatment: Stubble	Treatment: N Applied ($kg\ ha^{-1}$)	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA	Implied extraction[b] Pre-anthesis	Implied extraction[b] Post-anthesis
		GWC (%)										
Flax	0	24.0	25.6	20.9	13.1	19.5	21.0	24.3	23.0	21.4	*	*
Flax	30	23.4	27.0	18.4	12.9	16.6	19.1	23.4	21.4	20.4	*	*
Flax	90	24.6	23.1	19.0	12.9	17.6	18.8	24.1	21.3	20.0	*	*
Pea	0	24.7	24.0	18.7	12.4	17.5	18.6	24.5	22.8	21.8	*	*
Pea	30	23.9	24.1	19.7	11.3	17.9	19.6	23.9	21.6	21.1	*	*
Pea	90	24.2	23.7	20.0	11.6	17.5	19.9	25.1	22.2	19.7	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble												
Flax		24.0	25.2	19.5	13.0	17.9	19.6	23.9	21.9	20.6	*	*
Pea		24.3	23.9	19.4	11.8	17.6	19.3	24.5	22.2	20.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied ($kg\ ha^{-1}$)											
	0	24.3	24.8	19.8	12.8	18.5	19.8	24.4	22.9	21.6	*	*
	30	23.6	25.5	19.1	12.1	17.2	19.3	23.7	21.5	20.7	*	*
	90	24.4	23.4	19.5	12.2	17.6	19.3	24.6	21.8	19.9	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	0.8	0.9		
ANOVA	df	Pr>F										
Stubble (S)	1	0.9	0.71	0.99	0.33	0.91	0.91	0.62	0.83	0.85		
N Applied ($kg\ ha^{-1}$	2	0.39	0.34	0.71	0.8	0.3	0.77	0.16	0.0307	0.0118		
N*S	2	0.68	0.49	0.13	0.89	0.18	0.065	0.68	0.49	0.61		
C.V. (%)		5.0	11.4	9.0	16.6	9.4	7.4	3.9	4.3	5.1		

† Days after planting.

‡ Days after anthesis.

[a] VWC was calculated by multiplying gravimetric water content by bulk density (which is assumed to be 1.33 $g\ cm^3$)

[b] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.16. Volumetric Water Content of the 10-30 cm soil depth at the Brandon-01 site.[a]

Treatment											Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA	Pre-anthesis	Post-anthesis
		VWC (%)										
Flax	0	26.3	25.2	24.1	24.1	21.9	21.6	24.5	24.1	23.2	*	*
Flax	30	26.0	25.8	23.0	23.4	20.8	20.1	26.1	25.0	23.9	*	*
Flax	90	28.2	25.5	22.3	22.3	19.3	18.3	24.9	22.7	22.6	0.07	*
Pea	0	26.9	25.0	22.0	22.1	17.9	17.5	24.7	22.7	21.7	*	*
Pea	30	27.1	25.1	22.4	22.1	19.2	18.2	25.1	22.6	21.7	*	*
Pea	90	26.4	23.5	21.5	20.6	17.0	15.8	24.2	20.9	19.2	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	5.6	ns	3.3	3.8		
Stubble												
Flax		26.8	25.5	23.1	23.3	20.7	20.0	25.2	23.9	23.2	*	*
Pea		26.8	24.5	21.9	21.6	18.1	17.2	24.7	22.1	20.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})											
	0	26.6	25.1	23.1	23.1	19.9	19.6	24.6	23.4	22.5	*	*
	30	26.6	25.5	22.7	22.8	20.0	19.1	25.6	23.8	22.8	*	*
	90	27.3	24.5	21.9	21.4	18.2	17.1	24.6	21.8	20.9	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F										
Stubble (S)	1	0.95	0.62	0.65	0.55	0.33	0.32	0.6	0.15	0.13		
N Applied (kg ha^{-1})	2	0.7	0.67	0.74	0.44	0.43	0.25	0.55	0.2	0.28		
N*S	2	0.29	0.71	0.87	0.96	0.74	0.75	0.86	0.89	0.74		
C.V. (%)		7.1	9.0	13.9	12.0	15.6	16.3	8.2	9.3	11.0		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.17. Volumetric Water Content of the 30-50 cm soil depth at the Brandon-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA	Implied extraction[a] Pre-anthesis	Implied extraction[a] Post-anthesis
		VWC (%)										
Flax	0	26.0	27.1	26.2	25.7	25.4	24.9	26.0	25.3	24.9	*	*
Flax	30	28.6	28.8	28.2	27.8	27.3	27.2	28.6	28.3	27.5	0.25	*
Flax	90	28.0	26.7	25.6	24.8	23.8	22.0	26.1	25.5	25.2	*	*
Pea	0	29.1	28.6	27.6	27.6	26.1	24.9	27.4	26.7	26.3	*	*
Pea	30	30.6	29.7	29.2	28.7	27.2	25.9	27.9	27.6	27.6	*	*
Pea	90	28.1	27.2	26.0	25.8	23.9	22.0	26.0	24.8	24.4	*	*
LSD (P=0.05)		2.6	ns	3.2	3.1	ns	4.2	ns	3.4	2.9		
Stubble												
Flax		27.5	27.5	26.7	26.1	25.5	24.7	26.9	26.4	25.8	*	*
Pea		29.3	28.5	27.6	27.4	25.7	24.3	27.1	26.3	26.1	*	*
LSD (P=0.05)		1.6	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})											
	0	27.6	27.9	26.9	26.7	25.7	24.9	26.7	26.0	25.6	*	*
	30	29.6	29.2	28.7	28.2	27.2	26.6	28.2	27.9	27.5	*	*
	90	28.1	26.9	25.8	25.3	23.9	22.0	26.0	25.1	24.8	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	3.1	ns	ns	ns		
ANOVA	df	Pr>F										
Stubble (S)	1	0.0139	0.11	0.0663	0.11	0.78	0.71	0.8	0.96	0.6		
N Applied (kg ha^{-1})	2	0.11	0.21	0.0838	0.0598	0.0517	0.0227	0.14	0.094	0.0541		
N*S	2	0.31	0.92	0.89	0.88	0.94	0.86	0.59	0.63	0.56		
C.V. (%)		6.5	8.8	8.7	8.3	9.5	11.6	7.8	9.1	7.9		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.18. Volumetric Water Content of the 50-70 cm soil depth at the Brandon-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)										
Flax	0	30.5	30.2	30.0	29.7	29.1	29.1	29.1	28.9	28.8	0.37	*
Flax	30	29.7	31.0	30.8	30.6	29.9	29.6	30.3	30.0	30.0	0.58	*
Flax	90	30.3	30.1	28.9	28.7	28.0	27.7	29.5	28.5	28.5	*	*
Pea	0	30.2	29.9	29.5	29.2	28.7	28.0	29.2	28.1	28.3	0.06	*
Pea	30	30.0	30.1	29.8	29.7	29.0	27.9	28.8	28.9	28.5	0.36	*
Pea	90	29.6	29.6	28.9	28.7	27.9	26.7	27.9	27.6	27.3	0.28	*
LSD (P=0.05)		ns	ns	ns	ns	ns	2.6	ns	2.4	2.6		
Stubble												
Flax		30.2	30.4	29.9	29.7	29.0	28.8	29.6	29.1	29.1	*	*
Pea		29.9	29.9	29.4	29.2	28.5	27.5	28.6	28.2	28.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})											
	0	30.4	30.1	29.7	29.5	28.9	28.5	29.1	28.5	28.5	*	*
	30	29.9	30.5	30.3	30.1	29.5	28.8	29.5	29.4	29.3	0.05	*
	90	29.9	29.8	28.9	28.7	27.9	27.2	28.7	28.0	27.9	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	**df**	Pr>F										
Stubble (S)	1	0.87	0.65	0.66	0.57	0.66	0.24	0.4	0.39	0.35		
N Applied (kg ha^{-1})	2	0.82	0.67	0.16	0.18	0.14	0.15	0.64	0.16	0.21		
N*S	2	0.85	0.93	0.82	0.83	0.82	0.91	0.57	0.98	0.77		
C.V. (%)		5.5	5.2	4.6	5.1	4.9	5.7	5.9	4.7	5.1		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.19. Volumetric Water Content of the 70-90 cm soil depth at the Brandon-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)										
Flax	0	33.1	31.4	29.9	29.6	29.8	29.4	29.4	29.2	29.2	0.23	*
Flax	30	29.9	31.1	30.8	29.9	30.3	29.9	30.4	30.3	29.8	0.16	0.06
Flax	90	31.4	30.7	31.1	30.0	29.5	29.5	30.5	30.1	29.9	*	*
Pea	0	29.1	29.6	29.3	29.4	28.7	28.7	28.9	28.4	28.6	0.48	*
Pea	30	29.9	30.5	29.9	29.8	29.1	28.9	29.8	29.0	28.9	*	*
Pea	90	33.3	30.8	29.9	29.5	29.0	29.2	29.4	29.0	29.3	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble												
Flax		31.5	31.1	30.6	29.9	29.9	29.6	30.1	29.9	29.6	0.13	*
Pea		30.8	30.3	29.7	29.6	28.9	28.9	29.4	28.8	28.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})											
	0	31.1	30.5	29.6	29.5	29.3	29.1	29.1	28.8	28.9	0.28	*
	30	29.9	30.8	30.3	29.8	29.7	29.4	30.1	29.6	29.3	*	*
	90	32.5	30.8	30.5	29.8	29.3	29.3	29.9	29.6	29.6	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F										
Stubble (S)	1	0.48	0.43	0.52	0.62	0.35	0.54	0.5	0.36	0.43		
N Applied (kg ha^{-1})	2	0.42	0.55	0.49	0.75	0.52	0.72	0.61	0.43	0.44		
N*S	2	0.17	0.46	0.71	0.93	0.68	0.65	0.55	0.43	0.69		
C.V. (%)		8.4	6.0	5.3	5.9	5.5	6.1	18.6	-	5.1		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.20. Volumetric Water Content of the 90-110 cm soil depth at the Brandon-01 site.[a]

Treatment											Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA	Pre-anthesis	Post-anthesis
		VWC (%)										
Flax	0	36.0	37.8	32.1	32.5	32.6	32.6	34.0	32.8	33.5	0.16	0.19
Flax	30	34.0	33.5	34.7	33.6	32.4	32.6	33.0	33.7	32.7	-	0.23
Flax	90	34.4	33.9	35.1	32.8	33.2	33.9	35.0	35.3	33.0	0.10	-
Pea	0	33.0	32.4	33.2	32.3	33.5	33.1	32.4	32.5	33.3	0.09	0.12
Pea	30	32.5	33.0	33.0	32.1	32.4	32.4	32.9	33.0	32.2	0.76	0.28
Pea	90	36.7	33.0	33.5	32.9	32.2	33.4	32.1	33.2	32.0	0.16	0.13
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble												
Flax		34.9	35.5	33.5	32.9	32.7	33.0	33.8	33.8	33.1	0.39	0.09
Pea		34.2	32.7	33.2	32.4	32.7	33.0	32.4	32.9	32.5	0.09	0.06
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})											
	0	34.5	35.5	32.7	32.4	33.0	32.8	33.2	32.6	33.4	0.21	0.32
	30	33.2	33.4	33.6	32.8	32.4	32.5	32.9	33.3	32.5	0.95	0.21
	90	35.7	33.4	34.0	32.8	32.7	33.6	33.1	34.1	32.5	*	0.06
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F										
Stubble (S)	1	0.96	0.0763	0.54	0.68	0.0464	0.0772	0.82	0.62	0.07		
N Applied (kg ha^{-1})	2	0.84	0.24	0.2	0.73	0.15	0.16	0.57	0.48	0.72		
N*S	2	0.15	0.14	0.16	0.32	0.17	0.16	0.56	0.48	0.66		
C.V. (%)		8.0	7.8	4.6	7.2	27.0	214.5	346.7	26.3	59.3		

† Days after planting.

‡ Days after anthesis.

[a] Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.21. Total soil water content in the 0-110 cm depth at the Brandon-01 site.

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	35DAP†	50DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	42DAA
		Soil Water (cm)								
Flax	0	32.8	32.9	30.5	29.6	29.7	29.6	31.0	30.4	30.1
Flax	30	32.2	32.5	32.3	30.8	29.8	29.8	32.0	31.7	30.8
Flax	90	32.4	30.9	29.5	29.0	29.1	28.7	30.8	29.9	29.8
Pea	0	32.1	31.9	30.2	29.4	28.7	28.3	31.0	30.0	29.8
Pea	30	32.0	30.6	30.8	29.6	29.2	28.6	31.0	30.2	29.9
Pea	90	33.3	31.1	29.9	28.6	27.8	27.4	30.4	29.3	28.4
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns
Stubble										
Flax		32.5	32.3	30.7	29.7	29.6	29.4	31.4	30.6	30.2
Pea		32.5	31.4	30.3	29.2	28.6	28.1	30.8	29.8	29.4
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns
N Applied (kg ha^{-1})										
	0	32.5	32.5	30.4	29.5	29.2	29.0	31.0	30.2	29.9
	30	32.1	32.0	31.3	30.1	29.5	29.2	31.6	31.0	30.4
	90	32.9	31.0	29.8	28.8	28.3	28.0	30.6	29.6	29.1
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns
ANOVA	df	Pr>F								
Stubble (S)	1	0.98	0.41	0.61	0.52	0.26	0.17	0.40	0.26	0.16
N Applied (kg ha^{-1})	2	0.84	0.57	0.33	0.42	0.58	0.60	0.60	0.39	0.26
N*S	2	0.82	0.78	0.68	0.87	0.95	1.00	0.84	0.81	0.73
C.V. (%)		7.2	6.3	5.7	6.5	7.1	7.7	5.0	5.5	5.0

† Days after planting.
‡ Days after anthesis.

Table F.22. Volumetric water content of the 0-10 cm soil depth at the Swift Current-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)											
Durum	34	23.6	29.7	26.1	19.9	23.9	21.2	18.6	12.7	13.0	8.4	*	*
Durum	50	29.6	29.5	25.3	17.2	28.7	23.2	21.8	18.4	15.1	12.2	*	*
Durum	78	27.4	34.0	27.3	19.1	30.2	22.0	21.2	15.9	16.7	13.0	*	*
Pea	34	26.5	26.3	25.0	16.6	24.3	19.5	18.1	12.0	11.3	9.1	*	*
Pea	50	23.4	27.7	26.3	18.2	25.5	22.1	18.7	13.4	12.3	9.6	*	*
Pea	78	26.4	29.4	25.9	22.4	26.1	22.0	19.3	14.1	11.8	9.2	0.06	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble													
Durum		26.9	31.1	26.2	18.8	27.6	22.1	20.5	15.7	14.9	11.2	*	*
Pea		25.4	27.8	25.8	19.1	25.3	21.2	18.7	13.2	11.8	9.3	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})													
	34	25.1	28.0	25.6	18.3	24.1	20.4	18.4	12.3	12.2	8.8	*	*
	50	26.5	28.6	25.8	17.7	27.1	22.6	20.2	15.9	13.7	10.9	*	*
	78	26.9	31.7	26.6	20.7	28.2	22.0	20.3	15.0	14.3	11.1	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	**df**	Pr>F											
Stubble (S)	1	0.47	0.0827	0.82	0.87	0.23	0.37	0.12	0.0849	0.0582	0.1		
N Applied (kg ha^{-1})	2	0.72	0.22	0.91	0.41	0.21	0.21	0.31	0.12	0.51	0.17		
N*S	2	0.2	0.81	0.88	0.38	0.57	0.78	0.64	0.42	0.69	0.24		
C.V. (%)		15.8	12.5	16.9	21.3	14.6	9.8	12.0	19.7	23.7	21.7		

† Days after planting.

‡ Days after anthesis.

a Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.23. Volumetric water content of the 10-30 cm soil depth at the Swift Current-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)											
Durum	34	28.9	29.1	28.1	24.4	19.0	17.4	16.7	14.7	13.8	13.5	*	*
Durum	50	28.2	29.0	28.2	26.7	23.8	22.2	22.0	19.6	18.4	17.6	*	*
Durum	78	31.4	31.0	28.0	23.8	18.4	17.0	16.6	14.9	13.6	13.8	*	*
Pea	34	26.2	26.5	25.8	23.2	18.8	17.4	16.3	14.2	12.9	12.3	*	*
Pea	50	24.8	25.2	24.9	22.4	17.9	16.3	15.0	13.3	11.3	10.6	*	*
Pea	78	25.4	25.7	25.3	23.2	18.4	17.5	16.4	13.8	12.2	11.9	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	3.8	3.9	3.7	3.8		
Stubble													
Durum		29.5	29.7	28.1	25.0	20.4	18.8	18.4	16.4	15.2	15.0	*	*
Pea		25.5	25.8	25.3	23.0	18.4	17.0	15.9	13.8	12.1	11.6	*	*
LSD (P=0.05)		4.0	ns	ns	ns	ns	ns	2.2	2.3	2.1	2.2		
N Applied (kg ha^{-1})													
	34	27.5	27.8	26.9	23.8	18.9	17.4	16.5	14.5	13.3	12.9	*	*
	50	26.5	27.1	26.5	24.6	20.8	19.2	18.5	16.4	14.8	14.1	*	*
	78	28.4	28.3	26.7	23.5	18.4	17.2	16.5	14.4	12.9	12.8	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	**df**	Pr>F											
Stubble (S)	1	0.0493	0.057	0.19	0.35	0.12	0.12	0.0279	0.026	0.0087	0.0061		
N Applied (kg ha^{-1})	2	0.72	0.86	0.99	0.92	0.27	0.29	0.22	0.23	0.27	0.52		
N*S	2	0.76	0.83	0.98	0.75	0.12	0.0577	0.0307	0.0793	0.0453	0.073		
C.V. (%)		14.3	14.0	15.8	18.5	13.3	12.7	12.5	14.6	15.3	16.2		

† Days after planting.

‡ Days after anthesis.

a Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.24. Volumetric water content of the 30-50 cm soil depth at the Swift Current-01 site.[a]

Treatment												Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		VWC (%)											
Durum	34	28.8	28.9	28.1	27.0	18.8	18.3	17.3	16.1	15.2	16.0	*	*
Durum	50	31.7	31.6	31.4	30.3	25.7	25.1	23.6	22.5	21.5	21.5	*	*
Durum	78	28.4	28.9	27.8	26.6	19.8	19.2	17.9	17.2	16.6	16.3	*	0.10
Pea	34	23.9	24.7	24.7	23.8	18.8	18.1	17.4	16.3	14.8	14.9	*	*
Pea	50	22.8	23.3	23.6	23.5	17.9	17.5	16.4	14.7	13.2	13.2	*	*
Pea	78	24.5	24.7	24.3	24.2	19.3	18.7	18.0	16.6	15.4	15.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	4.4	4.6		
Stubble													
Durum		29.7	29.8	29.1	27.9	21.5	20.9	19.6	18.6	17.8	17.9	*	*
Pea		23.7	24.2	24.2	23.9	18.7	18.1	17.3	15.9	14.5	14.3	*	*
LSD (P=0.05)		5.6	5.1	4.8	ns	ns	ns	ns	ns	2.5	2.7		
N Applied (kg ha^{-1})													
	34	26.4	26.8	26.4	25.4	18.8	18.2	17.4	16.2	15.0	15.4	*	*
	50	27.3	27.5	27.5	26.9	21.8	21.3	20.0	18.6	17.4	17.3	*	*
	78	26.5	26.8	26.0	25.4	19.5	19.0	17.9	16.9	16.0	15.6	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F											
Stubble (S)	1	0.0411	0.0347	0.0439	0.0958	0.11	0.0734	0.11	0.0598	0.0147	0.0123		
N Applied (kg ha^{-1})	2	0.95	0.97	0.86	0.83	0.32	0.2	0.29	0.34	0.28	0.4		
N*S	2	0.72	0.73	0.66	0.71	0.13	0.0858	0.0744	0.0554	0.0313	0.053		
C.V. (%)		20.6	18.5	17.4	18.5	17.2	15.2	15.5	16.3	15.3	16.0		

† Days after planting.

‡ Days after anthesis.

a Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.25. Volumetric water content of the 50-70 cm soil depth at the Swift Current-01 site.[a]

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Implied extraction[a]: Post-anthesis
		VWC (%)											
Durum	34	23.8	23.7	23.7	23.2	19.9	19.0	18.3	16.8	16.7	16.9	*	*
Durum	50	28.5	28.6	28.1	27.8	24.4	23.9	23.0	21.9	21.3	21.6	0.07	0.06
Durum	78	29.0	29.5	29.5	29.0	26.5	25.8	25.2	24.0	24.1	23.9	0.12	*
Pea	34	24.5	24.7	24.8	24.6	22.2	22.2	20.7	19.5	18.2	18.2	*	*
Pea	50	24.7	24.9	25.0	25.2	22.7	22.3	21.3	20.1	19.1	18.8	0.05	*
Pea	78	27.3	27.2	26.0	27.0	24.2	23.8	22.7	21.8	20.4	20.1	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble													
Durum		27.1	27.3	27.1	26.7	23.6	22.9	22.1	20.9	20.7	20.8	*	*
Pea		25.5	25.6	25.3	25.6	23.0	22.8	21.6	20.4	19.2	19.0	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})												
	34	24.2	24.2	24.2	23.9	21.0	20.6	19.5	18.1	17.4	17.5	*	*
	50	26.6	26.7	26.5	26.5	23.5	23.1	22.1	21.0	20.2	20.2	*	*
	78	28.1	28.3	27.8	28.0	25.3	24.8	23.9	22.9	22.3	22.0	*	*
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F											
Stubble (S)	1	0.46	0.38	0.37	0.61	0.83	0.95	0.8	0.84	0.53	0.48		
N Applied (kg ha^{-1})	2	0.33	0.24	0.36	0.28	0.37	0.36	0.3	0.27	0.25	0.37		
N*S	2	0.68	0.59	0.59	0.69	0.7	0.61	0.64	0.64	0.62	0.69		
C.V. (%)		17.0	15.1	15.9	16.5	21.7	21.5	21.7	23.5	23.8	26.4		

† Days after planting.

‡ Days after anthesis.

a Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.26. Volumetric water content of the 70-90 cm soil depth at the Swift Current-01 site.[a]

Treatment												Implied extraction[a]	
Stubble	N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Pre-anthesis	Post-anthesis
		------VWC (%)------											
Durum	34	20.8	20.9	20.5	20.1	19.3	19.0	18.9	18.6	18.3	18.6	*	*
Durum	50	27.2	25.0	24.9	24.0	23.2	22.6	22.1	21.8	21.9	21.9	*	*
Durum	78	30.2	30.4	30.2	30.3	28.7	28.6	28.2	27.2	27.1	27.2	0.21	*
Pea	34	26.6	26.1	26.2	26.5	25.6	25.1	24.6	24.2	23.5	23.7	0.18	0.11
Pea	50	23.6	23.6	23.2	23.0	22.7	22.3	21.9	21.5	21.6	21.6	0.06	*
Pea	78	28.7	28.4	27.0	28.4	27.2	26.8	26.0	25.8	25.2	25.3	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble													
Durum		26.1	25.4	25.2	24.8	23.8	23.4	23.1	22.5	22.4	22.6	*	*
Pea		26.3	26.0	25.5	25.9	25.2	24.8	24.2	23.8	23.4	23.5	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
	N Applied (kg ha^{-1})												
	34	23.7	23.5	23.4	23.3	22.5	22.1	21.8	21.4	20.9	21.2	*	*
	50	25.4	24.3	24.0	23.5	23.0	22.4	22.0	21.6	21.7	21.7	*	*
	78	29.4	29.4	28.6	29.3	28.0	27.7	27.1	26.5	26.1	26.3	*	*
	LSD (P=0.05)	ns	4.7	ns	5.0	ns	ns	ns	ns	ns	ns		
ANOVA	df	Pr>F											
Stubble (S)	1	0.91	0.7	0.89	0.56	0.51	0.52	0.62	0.55	0.65	0.68		
N Applied (kg ha^{-1})	2	0.0693	0.035	0.0823	0.0371	0.1	0.0764	0.11	0.14	0.15	0.16		
N*S	2	0.14	0.22	0.15	0.19	0.29	0.28	0.33	0.39	0.41	0.42		
C.V. (%)		15.0	14.4	15.6	15.8	18.1	18.0	19.3	19.9	20.1	20.4		

† Days after planting.

‡ Days after anthesis.

a Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.27. Volumetric water content of the 90-110 cm soil depth at the Swift Current-01 site.[a]

Treatment: Stubble	N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA	Implied extraction[a]: Pre-anthesis	Post-anthesis
		VWC (%)											
Durum	34	23.8	23.9	23.6	23.5	23.6	23.1	22.6	22.9	22.7	22.5	0.15	*
Durum	50	22.3	21.1	21.1	21.0	22.4	20.8	20.4	20.2	19.8	20.1	0.42	*
Durum	78	29.9	30.2	30.0	29.9	29.1	29.5	28.5	27.7	28.0	27.9	0.14	*
Pea	34	28.7	28.7	28.3	28.5	27.8	28.0	28.2	27.4	27.2	27.6	*	*
Pea	50	24.1	23.7	23.8	23.9	23.7	23.9	23.5	23.4	23.5	23.5	0.26	0.17
Pea	78	29.9	30.3	29.9	30.2	29.5	29.0	28.7	28.4	28.5	28.7	0.10	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
Stubble													
Durum		25.3	25.0	24.9	24.8	25.0	24.4	23.8	23.6	23.5	23.5	0.25	*
Pea		27.6	27.6	27.3	27.5	27.0	26.9	26.8	26.4	26.4	26.6	*	*
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
N Applied (kg ha^{-1})													
	34	26.3	26.3	25.9	26.0	25.7	25.5	25.4	25.2	25.0	25.0	*	*
	50	23.2	22.4	22.4	22.4	23.0	22.3	21.9	21.8	21.6	21.8	0.23	*
	78	29.9	30.2	29.9	30.0	29.3	29.2	28.6	28.0	28.2	28.3	0.08	*
	LSD (P=0.05)	ns	5.4	5.3	5.3	ns	ns	ns	ns	ns	ns		
ANOVA	**df**	Pr>F											
Stubble (S)	1	0.27	0.23	0.23	0.2	0.34	0.27	0.19	0.21	0.19	0.15		
N Applied (kg ha^{-1})	2	0.0513	0.0257	0.0312	0.0272	0.0727	0.0654	0.0705	0.1	0.0713	0.0727		
N*S	2	0.61	0.64	0.62	0.64	0.72	0.59	0.61	0.76	0.72	0.7		
C.V. (%)		15.9	16.3	16.3	16.1	16.4	17.7	17.8	18.3	17.8	17.5		

† Days after planting.

‡ Days after anthesis.

a Water extraction at a given depth is assumed to have occurred when there is a significant difference at the 0.05 level, as indicated by an asterisk (based on a paired t-test) between at least one pair of sampling dates within a given phase of development, namely prior to or after anthesis. Where no paired t-test yields a significant result, the p-value is presented.

Table F.28. Total soil water content in the 0-110 cm depth at the Swift Current-01 site.

Treatment: Stubble	Treatment: N Applied (kg ha^{-1})	Planting	21DAP†	36DAP	46DAP	Anthesis	7DAA‡	14DAA	21DAA	28DAA	35DAA
		Soil Water (cm)									
Durum	34	23.4	23.9	24.3	23.0	19.5	19.0	18.7	14.4	15.0	14.7
Durum	50	26.0	25.4	25.7	24.5	23.7	22.7	22.6	18.8	18.6	18.3
Durum	78	25.6	26.3	25.6	23.8	22.2	20.6	20.7	16.7	17.5	17.1
Pea	34	22.6	22.0	23.2	21.8	20.0	19.2	19.0	14.7	14.7	14.6
Pea	50	21.5	21.8	23.0	22.0	20.0	19.4	18.8	14.6	14.5	14.2
Pea	78	23.1	23.0	23.4	23.5	20.8	20.2	19.8	15.6	15.3	14.9
LSD (P=0.05)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Stubble											
Durum		25.0	25.2	25.2	23.8	21.8	20.8	20.6	16.6	17.0	16.7
Pea		22.4	22.3	23.2	22.4	20.3	19.6	19.2	14.9	14.8	14.6
LSD (P=0.05)		3.2	ns	2.8	ns	ns	ns	ns	ns	ns	1.9
N Applied (kg ha^{-1})											
	34	23.0	23.0	23.7	22.4	19.8	19.1	18.8	14.5	14.9	14.6
	50	23.8	23.6	24.4	23.2	21.9	21.1	20.7	16.7	16.5	16.2
	78	24.4	24.6	24.5	23.6	21.5	20.4	20.2	16.1	16.4	16.0
	LSD (P=0.05)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ANOVA	**df**	Pr>F									
Stubble (S)	1	<0.0001	0.0721	0.0461	0.18	0.29	0.15	0.18	0.1	0.079	0.0246
N Applied (kg ha^{-1})	2	1	0.71	0.58	0.89	0.71	0.23	0.17	0.21	0.16	0.26
N*S	2	0.94	0.54	0.85	0.9	0.77	0.26	0.2	0.15	0.14	0.24
C.V. (%)		33.1	11.8	11.6	12.3	11.4	10.1	8.3	8.7	11.7	11.4

† Days after planting.

‡ Days after anthesis.

8.7. APPENDIX G – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SELECTED HARVEST MEASUREMENTS AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table G.1. Grain yield (14% moisture basis) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
		---kg ha^{-1}---		
Flax	0	3039	3739	1443
Flax	30 AN*	3535	3764	1824
Flax	30 CRU**	3434	3722	2090
Flax	90 AN	3218	3734	2564
Flax	90 CRU	3679	3661	2385
Pea	0	3919	3699	2147
Pea	30 AN	3592	3597	2513
Pea	30 CRU	3906	3607	2520
Pea	90 AN	3634	3737	2791
Pea	90 CRU	3680	3675	2951
LSD (P=0.05)		452	ns	390
Stubble				
Flax		3381	3724	2061
Pea		3746	3663	2584
LSD (P=0.05)		214	ns	151
	N Applied ($kg\ ha^{-1}$)			
	0	3479	3719	1795
	30 AN	3563	3680	2168
	30 CRU	3670	3664	2305
	90 AN	3426	3735	2678
	90 CRU	3679	3668	2668
	LSD (P=0.05)	ns	ns	239
ANOVA	df		Pr>F	
Stubble (S)	1	0.0026	0.5	0.039
N Applied ($kg\ ha^{-1}$)	4	0.46	0.91	<0.0001
N*S	4	0.0821	0.83	0.24
Contrasts				
Pea vs Flax at 0 N		0.0005	0.77	0.001
Pea vs Flax at 30 N		0.1	0.15	0.0003
Pea vs Flax at 90 N		0.19	0.93	0.0065
AN vs CRU		0.13	0.52	0.45
AN vs CRU - 30 N vs 90 N		0.53	0.69	0.38
0 N vs 30 N		0.34	0.56	0.0002
30N vs 90 N		0.59	0.65	<0.0001
Pea vs Flax - 0 N vs 30 N		0.0403	0.52	0.48
Pea vs Flax - 30 N vs 90 N		0.81	0.25	0.33
Pea at 30 N vs Flax 90 N		0.0647	0.32	0.76
C.V. (%)		9.2	4.9	10.0

* Ammonium nitrate

** Controlled-release urea

Table G.2. Grain protein content (14% moisture basis) at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	13.9	17.3	14.1
Flax	30 AN*	14.5	17.2	13.3
Flax	30 CRU**	14.5	17.3	13.7
Flax	90 AN	16.6	17.5	15.3
Flax	90 CRU	16.4	17.7	15.4
Pea	0	15.5	17.3	13.8
Pea	30 AN	16.9	17.8	14.7
Pea	30 CRU	16.4	17.8	14.6
Pea	90 AN	17.4	17.7	16.5
Pea	90 CRU	17.4	17.6	16.3
LSD (P=0.05)		1.1	ns	1.0
Stubble				
Flax		15.2	17.4	14.4
Pea		16.7	17.6	15.2
LSD (P=0.05)		0.4	ns	ns
	N Applied (kg ha^{-1})			
	0	14.7	17.3	13.9
	30 AN	15.7	17.5	14.0
	30 CRU	15.4	17.5	14.1
	90 AN	17.0	17.6	15.9
	90 CRU	16.9	17.7	15.8
	LSD (P=0.05)	0.7	ns	0.6
ANOVA	df		Pr>F	
Stubble (S)	1	0.0305	0.3	0.17
N Applied (kg ha^{-1})	4	<0.0001	0.51	<0.0001
N*S	4	0.16	0.49	0.0503
Contrasts				
Pea vs Flax at 0 N		0.0041	0.91	0.49
Pea vs Flax at 30 N		<0.0001	0.0327	0.0039
Pea vs Flax at 90 N		0.0198	0.88	0.0067
AN vs CRU		0.45	0.73	0.88
AN vs CRU - 30 N vs 90 N		0.76	0.95	0.63
0 N vs 30 N		0.0065	0.28	0.61
30N vs 90 N		<0.0001	0.4	<0.0001
Pea vs Flax - 0 N vs 30 N		0.43	0.17	0.0065
Pea vs Flax - 30 N vs 90 N		0.0166	0.14	0.85
Pea at 30 N vs Flax 90 N		0.65	0.55	0.0428
C.V. (%)		4.2	2.6	3.8

* Ammonium nitrate

** Controlled-release urea

[a] Protein content is expressed at per cent N multiplied by 5.7.

Table G.3. Grain N yield (14% moisture basis) at the Carman-00, Carman-01, and Brandon-01sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		----------kg N ha^{-1}----------		
Flax	0	74	114	36
Flax	30 AN*	90	113	43
Flax	30 CRU**	88	113	51
Flax	90 AN	93	115	69
Flax	90 CRU	105	114	65
Pea	0	107	112	52
Pea	30 AN	106	112	65
Pea	30 CRU	112	113	64
Pea	90 AN	111	116	81
Pea	90 CRU	112	114	84
LSD (P=0.05)		12	ns	11
Stubble				
Flax		90	114	52
Pea		110	113	69
LSD (P=0.05)		6	ns	4
	N Applied (kg ha^{-1})			
	0	91	113	44
	30 AN	98	113	54
	30 CRU	100	113	57
	90 AN	102	115	75
	90 CRU	109	114	74
	LSD (P=0.05)	9	ns	7
ANOVA	df		Pr>F	
Stubble (S)	1	0.0012	0.84	0.0382
N Applied (kg ha^{-1})	4	0.0057	0.93	<0.0001
N*S	4	0.0552	1	0.49
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.79	0.0061
Pea vs Flax at 30 N		<0.0001	0.79	<0.0001
Pea vs Flax at 90 N		0.0055	0.86	0.0004
AN vs CRU		0.14	0.7	0.44
AN vs CRU - 30 N vs 90 N		0.42	0.7	0.38
0 N vs 30 N		0.0308	0.95	0.0002
30N vs 90 N		0.0504	0.48	<0.0001
Pea vs Flax - 0 N vs 30 N		0.1	0.95	0.76
Pea vs Flax - 30 N vs 90 N		0.2	0.76	0.6
Pea at 30 N vs Flax 90 N		0.0204	0.58	0.59
C.V. (%)		8.5	5.9	10.4

* Ammonium nitrate

** Controlled-release urea

Table G.4. Total plant N uptake per unit grain protein content (dry matter basis) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	10.1	9.2	4.6
Flax	30 AN*	10.3	9.2	5.4
Flax	30 CRU**	10.0	10.2	6.2
Flax	90 AN	10.6	10.5	7.9
Flax	90 CRU	11.2	10.8	7.5
Pea	0	10.5	8.1	6.1
Pea	30 AN	11.2	8.7	7.2
Pea	30 CRU	10.2	10.1	7.8
Pea	90 AN	12.8	10.5	7.1
Pea	90 CRU	9.7	10.3	7.6
LSD (P=0.05)		ns	1.5	1.7
Stubble				
Flax		10.4	10.0	6.3
Pea		10.9	9.6	7.2
LSD (P=0.05)		ns	ns	0.8
N Applied (kg ha^{-1})				
	0	10.3	8.7	5.3
	30 AN	10.7	8.9	6.3
	30 CRU	10.1	10.2	7.0
	90 AN	11.7	10.5	7.5
	90 CRU	10.4	10.6	7.5
	LSD (P=0.05)	ns	1.0	1.3
ANOVA	df		Pr>F	
Stubble (S)	1	0.59	0.41	0.0446
N Applied (kg ha^{-1})	4	0.32	0.0005	0.0082
N*S	4	0.27	0.81	0.18
Contrasts				
Pea vs Flax at 0 N		0.75	0.16	0.0885
Pea vs Flax at 30 N		0.53	0.62	0.0077
Pea vs Flax at 90 N		0.71	0.62	0.57
AN vs CRU		0.11	0.0729	0.43
AN vs CRU - 30 N vs 90 N		0.58	0.0848	0.47
0 N vs 30 N		0.9	0.038	0.021
30N vs 90 N		0.24	0.0073	0.0657
Pea vs Flax - 0 N vs 30 N		0.91	0.36	0.83
Pea vs Flax - 30 N vs 90 N		0.85	1	0.0264
Pea at 30 N vs Flax 90 N		0.76	0.0199	0.8
C.V. (%)		15.4	9.7	18.4

* Ammonium nitrate

** Controlled-release urea

Table G.5. Total grain yield per unit total plant N uptake (dry matter basis) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment			Site	
Stubble	N Applied ($kg\ ha^{-1}$)	Carman-00	Carman-01	Brandon-01
Flax	0	19.1	18.0	16.8
Flax	30 AN*	21.5	18.1	19.0
Flax	30 CRU**	21.2	16.1	18.6
Flax	90 AN	16.1	15.6	16.5
Flax	90 CRU	18.2	14.4	15.8
Pea	0	21.0	20.0	19.3
Pea	30 AN	16.7	17.8	18.0
Pea	30 CRU	21.1	15.2	17.3
Pea	90 AN	14.4	15.2	18.3
Pea	90 CRU	19.6	15.5	18.1
LSD (P=0.05)		ns	2.8	ns
Stubble				
Flax		19.2	16.4	17.3
Pea		18.6	16.7	18.2
LSD (P=0.05)		ns	ns	ns
	N Applied ($kg\ ha^{-1}$)			
	0	20.1	19.0	18.1
	30 AN	19.1	18.0	18.5
	30 CRU	21.2	15.6	18.0
	90 AN	15.2	15.4	17.4
	90 CRU	18.9	14.9	17.0
	LSD (P=0.05)	ns	2.0	ns
ANOVA	df			
Stubble (S)	1	0.64	0.68	0.3
N Applied ($kg\ ha^{-1}$)	4	0.0628	0.0006	0.83
N*S	4	0.45	0.52	0.51
Contrasts				
Pea vs Flax at 0 N		0.51	0.14	0.2
Pea vs Flax at 30 N		0.23	0.52	0.43
Pea vs Flax at 90 N		0.95	0.75	0.14
AN vs CRU		0.0522	0.0482	0.64
AN vs CRU - 30 N vs 90 N		0.57	0.17	0.94
0 N vs 30 N		0.96	0.014	0.91
30N vs 90 N		0.0358	0.0215	0.3
Pea vs Flax - 0 N vs 30 N		0.22	0.12	0.15
Pea vs Flax - 30 N vs 90 N		0.41	0.49	0.12
Pea at 30 N vs Flax 90 N		0.37	0.13	0.27
C.V. (%)		20.9	11.4	15.7

* Ammonium nitrate

** Controlled-release urea

Table G.6. Grain yield, protein content, and N yield (14% moisture basis) at the Swift-Current-00 site.[a]

Treatment					
Stubble	N Applied (kg ha^{-1})		Grain Yield	Protein Content	Grain N Yield
			---kg ha^{-1}---	-----%-----	---kg N ha^{-1}---
Durum	34		1510	10.3	27.4
Durum	50		2075	11.7	42.2
Durum	78		2248	12.9	50.6
Pea	34		2645	12.8	59.9
Pea	50		2731	13.2	63.0
Pea	78		2359	13.8	56.2
LSD (P=0.05)			ns	1.5	23.0
Stubble					
Durum			1944	11.6	40.1
Pea			2578	13.2	59.7
LSD (P=0.05)			591	0.9	13.3
	N Applied (kg ha^{-1})				
	34		2077	11.5	43.7
	50		2403	12.5	52.6
	78		2304	13.3	53.4
	LSD (P=0.05)		ns	1.1	ns
ANOVA		df		Pr>F	
Stubble (S)		1	0.0376	0.0016	0.0074
N Applied (kg ha^{-1})		2	0.62	0.0125	0.38
N*S		2	0.34	0.33	0.24
Contrasts					
34 N vs 50 N			0.35	0.087	0.25
50 N vs 78 N			0.77	0.11	0.92
Pea vs Durum - 34 N vs 50 N			0.49	0.38	0.45
Pea vs Durum - 50 N vs 78 N			0.43	0.53	0.33
Durum at 50 N vs Pea at 34 N			0.25	0.15	0.12
Durum at 78 N vs Pea at 50 N			0.32	0.61	0.26
C.V. (%)			25.5	6.9	25.9

[a] Protein content is expressed at per cent N multiplied by 5.7.

Table G.7. Grain yield, grain protein content, grain N yield (14% moisture basis), plant N uptake per unit protein content, and grain yield per unit total plant N uptake (DM basis) at the Swift-Current-01 site.

Treatment						
Stubble	N Applied ($kg\ ha^{-1}$)	Grain Yield[a]	Protein Content[ab]	Grain N Yield[a]	N Uptake per unit PC[c]	Grain Yield per unit N Uptake[c]
		---$kg\ ha^{-1}$---	-----%-----	---$kg\ N\ ha^{-1}$---		
Durum	34	1321	14.6	34.1	4.4	17.6
Durum	50	1607	15.1	42.5	4.9	18.8
Durum	78	1405	16.7	41.1	5.0	15.5
Pea	34	1222	16.6	35.6	3.7	16.8
Pea	50	1399	17.0	41.7	3.2	23.3
Pea	78	1703	16.1	47.0	5.0	18.3
LSD (P=0.05)		ns	ns	ns	ns	ns
Stubble						
Durum		1444	15.5	39.3	4.8	17.3
Pea		1441	16.6	41.4	4.0	19.5
LSD (P=0.05)		ns	1.0	ns	ns	ns
	N Applied ($kg\ ha^{-1}$)					
	34	1271	15.6	34.9	4.1	17.2
	50	1503	16.1	42.1	4.1	21.1
	78	1554	16.4	44.0	5.0	16.9
	LSD (P=0.05)	ns	ns	ns	ns	ns
ANOVA	df			Pr>F		
Stubble (S)	1	0.99	0.0333	0.56	0.23	0.24
N Applied ($kg\ ha^{-1}$)	2	0.33	0.44	0.14	0.39	0.14
N*S	2	0.41	0.0788	0.76	0.52	0.48
Contrasts						
34 N vs 50 N		0.25	0.49	0.13	0.98	0.1
50 N vs 78 N		0.8	0.54	0.69	0.25	0.0782
Pea vs Durum - 34 N vs 50 N		0.78	0.96	0.8	0.5	0.42
Pea vs Durum - 50 N vs 78 N		0.21	0.0523	0.47	0.27	0.24
Durum at 50 N vs Pea at 34 N		0.18	0.0797	0.3	0.28	0.81
Durum at 78 N vs Pea at 50 N		0.98	0.68	0.92	0.13	0.52
C.V. (%)		23.1	6.2	19.4	29.9	20.4

*Days after anthesis

[a] Expressed on a 14 per cent moisture basis.

[b] Protein content is expressed at N multiplied by 5.7.

[c] Expressed on a dry matter basis.

8.8. APPENDIX H – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SELECT SOIL NITROGEN DATA AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table H.1. Change in NO_3-N status in the soil profile between anthesis and harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----kg NO_3-N ha^{-1}-----		
Flax	0	8	-28	-16
Flax	30 AN*	12	11	-14
Flax	30 CRU**	9	4	-13
Flax	90 AN	12	-13	-28
Flax	90 CRU	7	0	-14
Pea	0	-3	-3	-16
Pea	30 AN	5	4	-20
Pea	30 CRU	-5	8	-22
Pea	90 AN	-23	-13	-23
Pea	90 CRU	-21	20	-31
LSD (P=0.05)		17	ns	15
Stubble				
Flax		10	-5	-17
Pea		-9	3	-22
LSD (P=0.05)		8	ns	ns
N Applied (kg ha^{-1})				
	0	2	-15	-16
	30 AN	8	7	-17
	30 CRU	2	6	-18
	90 AN	-3	-13	-26
	90 CRU	-7	10	-23
	LSD (P=0.05)	ns	ns	ns
ANOVA	df			
Stubble (S)	1	0.0103	0.64	0.0028
N Applied (kg ha^{-1})	4	0.12	0.31	0.35
N*S	4	0.12	0.81	0.32
Contrasts				
Pea vs Flax at 0 N		0.23	0.3	0.97
Pea vs Flax at 30 N		0.0834	0.95	0.15
Pea vs Flax at 90 N		<0.0001	0.58	0.3
AN vs CRU		0.36	0.32	0.77
AN vs CRU - 30 N vs 90 N		0.55	0.27	0.64
0 N vs 30 N		0.59	0.11	0.8
30N vs 90 N		0.0129	0.46	0.0862
Pea vs Flax - 0 N vs 30 N		0.98	0.33	0.44
Pea vs Flax - 30 N vs 90 N		0.0188	0.63	0.77
Pea at 30 N vs Flax 90 N		0.11	0.47	0.94

* Ammonium nitrate

** Controlled-release urea

Table H.2. Change in NO_3-N status in the soil profile between planting and harvest at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---kg NO_3-N ha^{-1}---		
Flax	0	-108	-75	-44
Flax	30 AN*	-91	-51	-22
Flax	30 CRU**	-84	-69	-36
Flax	90 AN	-61	-39	-18
Flax	90 CRU	-66	-62	-12
Pea	0	-81	-56	-36
Pea	30 AN	-83	-61	-27
Pea	30 CRU	-64	-94	-33
Pea	90 AN	-62	-48	16
Pea	90 CRU	-7	-48	10
LSD (P=0.05)		39	30	12
Stubble				
Flax		-82	-59	-26
Pea		-59	-62	-14
LSD (P=0.05)		ns	ns	3
	N Applied (kg ha^{-1})			
	0	-95	-66	-40
	30 AN	-87	-56	-24
	30 CRU	-74	-82	-34
	90 AN	-62	-44	-1
	90 CRU	-37	-55	-1
	LSD (P=0.05)	16	11	5
ANOVA	df			
Stubble (S)	1	0.36	0.9	0.0726
N Applied (kg ha^{-1})	4	0.0087	0.0253	0.0007
N*S	4	0.36	0.27	0.31
Contrasts				
Pea vs Flax at 0 N		0.3	0.36	0.56
Pea vs Flax at 30 N		0.45	0.23	0.93
Pea vs Flax at 90 N		0.2	0.88	0.0064
AN vs CRU		0.0894	0.0248	0.5
AN vs CRU - 30 N vs 90 N		0.54	0.35	0.46
0 N vs 30 N		0.28	0.75	0.24
30N vs 90 N		0.0127	0.0196	0.0004
Pea vs Flax - 0 N vs 30 N		0.63	0.0687	0.61
Pea vs Flax - 30 N vs 90 N		0.55	0.21	0.0466
Pea at 30 N vs Flax 90 N		0.61	0.0677	0.13

* Ammonium nitrate

** Controlled-release urea

Table H.3. Apparent net mineralized nitrogen (NMN) between planting and anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		kg N ha^{-1}		
Flax	0	52	65	30
Flax	30 AN*	34	0	22
Flax	30 CRU**	34	16	19
Flax	90 AN	16	-8	28
Flax	90 CRU	0	7	-8
Pea	0	27	11	30
Pea	30 AN	34	15	30
Pea	30 CRU	49	27	7
Pea	90 AN	45	22	-3
Pea	90 CRU	13	-20	1
LSD (P=0.05)		27	54	26
Stubble				
Flax		27	16	18
Pea		33	11	13
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	39	38	30
	30 AN	34	7	26
	30 CRU	42	22	13
	90 AN	29	7	13
	90 CRU	6	-6	-3
	LSD (P=0.05)	23	ns	18
ANOVA	df			
Stubble (S)	1	0.63	0.23	0.45
N Applied (kg ha^{-1})	4	0.0002	0.24	0.007
N*S	4	0.0127	0.23	0.17
Contrasts				
Pea vs Flax at 0 N		0.0645	0.0497	0.98
Pea vs Flax at 30 N		0.4	0.51	0.8
Pea vs Flax at 90 N		0.0298	0.95	0.25
AN vs CRU		0.12	0.96	0.0275
AN vs CRU - 30 N vs 90 N		0.0039	0.34	0.84
0 N vs 30 N		0.78	0.18	0.17
30N vs 90 N		0.0006	0.32	0.0251
Pea vs Flax - 0 N vs 30 N		0.0118	0.0621	0.87
Pea vs Flax - 30 N vs 90 N		0.2	0.69	0.53
Pea at 30 N vs Flax 90 N		0.0009	0.27	0.34

* Ammonium nitrate

** Controlled-release urea

[a] NMN was calculated by subtracting the sum of NO_3-N to 110 cm at anthesis plus total aboveground plant N yield at anthesis from the sum of NO_3-N to 120 cm prior to planting plus fertilizer N rate.

Table H.4. Apparent net mineralized nitrogen (NMN) during the growing season at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--kg N ha^{-1}--		
Flax	0	108	75	44
Flax	30 AN*	91	51	22
Flax	30 CRU**	84	69	36
Flax	90 AN	61	75	18
Flax	90 CRU	66	62	12
Pea	0	81	56	36
Pea	30 AN	83	61	27
Pea	30 CRU	64	94	33
Pea	90 AN	62	48	-16
Pea	90 CRU	7	48	-10
LSD (P=0.05)		54	ns	28
Stubble				
Flax		82	66	26
Pea		59	62	14
LSD (P=0.05)		ns	ns	ns
N Applied (kg ha^{-1})				
	0	95	66	40
	30 AN	87	56	24
	30 CRU	74	82	34
	90 AN	62	61	1
	90 CRU	37	55	1
	LSD (P=0.05)	33	ns	20
ANOVA	df			
Stubble (S)	1	0.36	0.72	0.0726
N Applied (kg ha^{-1})	4	0.0094	0.63	0.0007
N*S	4	0.36	0.64	0.31
Contrasts				
Pea vs Flax at 0 N		0.3	0.49	0.56
Pea vs Flax at 30 N		0.45	0.36	0.93
Pea vs Flax at 90 N		0.2	0.3	0.0064
AN vs CRU		0.0894	0.48	0.5
AN vs CRU - 30 N vs 90 N		0.54	0.24	0.46
0 N vs 30 N		0.28	0.85	0.24
30N vs 90 N		0.0127	0.44	0.0004
Pea vs Flax - 0 N vs 30 N		0.63	0.28	0.61
Pea vs Flax - 30 N vs 90 N		0.55	0.17	0.0466
Pea at 30 N vs Flax 90 N		0.61	0.62	0.13

* Ammonium nitrate

** Controlled-release urea

[a] NMN was calculated by subtracting the sum of NO_3-N to 110 cm at maturity plus total aboveground plant N yield at maturity from the sum of NO_3-N to 120 cm prior to planting plus fertilizer N rate.

Table H.5. Apparent net mineralized nitrogen (NMN) between anthesis and harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--------kg N ha^{-1}--------		
Flax	0	57	10	13
Flax	30 AN*	57	51	0
Flax	30 CRU**	49	53	17
Flax	90 AN	45	83	-9
Flax	90 CRU	67	54	20
Pea	0	54	46	5
Pea	30 AN	48	46	-3
Pea	30 CRU	15	67	26
Pea	90 AN	17	27	-13
Pea	90 CRU	-6	68	-12
LSD (P=0.05)		50	64	ns
Stubble				
Flax		55	50	8
Pea		26	51	1
LSD (P=0.05)		19	ns	ns
N Applied (kg ha^{-1})				
	0	56	28	9
	30 AN	53	48	-2
	30 CRU	32	60	22
	90 AN	33	55	-11
	90 CRU	30	61	4
	LSD (P=0.05)	ns	ns	ns
ANOVA	df			
Stubble (S)	1	0.054	0.96	0.0355
N Applied (kg ha^{-1})	4	0.29	0.58	0.18
N*S	4	0.19	0.34	0.63
Contrasts				
Pea vs Flax at 0 N		0.9	0.26	0.65
Pea vs Flax at 30 N		0.16	0.82	0.81
Pea vs Flax at 90 N		0.0063	0.35	0.17
AN vs CRU		0.29	0.58	0.0497
AN vs CRU - 30 N vs 90 N		0.43	0.87	0.68
0 N vs 30 N		0.33	0.19	0.95
30N vs 90 N		0.34	0.82	0.16
Pea vs Flax - 0 N vs 30 N		0.48	0.44	0.63
Pea vs Flax - 30 N vs 90 N		0.24	0.42	0.28
Pea at 30 N vs Flax 90 N		0.12	0.6	0.63

* Ammonium nitrate

** Controlled-release urea

[a] Calculated by subtracting apparent NMN at anthesis from apparent NMN during the growing season.

Table H.6. Change in NO_3-N status in the soil profile during the growing season at the Swift Current-01 site.

Treatment		Soil NO_3-N balance	
Stubble	N Applied ($kg\ ha^{-1}$)	Anthesis to Harvest	Planting to Harvest
		---kg NO_3-N ha^{-1}---	
Durum	34	-1	-13
Durum	50	0	1
Durum	78	26	20
Pea	34	-6	-6
Pea	50	-37	-9
Pea	78	-4	5
LSD (P=0.05)		28	ns
Stubble			
Durum		8	3
Pea		-16	-3
LSD (P=0.05)		16	ns
N Applied ($kg\ ha^{-1}$)			
	34	-4	-9
	50	-19	-4
	78	11	13
	LSD (P=0.05)	19	ns
ANOVA	df		
Stubble (S)	1	0.0067	0.47
N Applied ($kg\ ha^{-1}$)	2	0.02	0.12
N*S	2	0.19	0.52
Contrasts			
34 N vs 50 N		0.12	0.62
50 N vs 78 N		0.006	0.12
Pea vs Durum - 34 N vs 50 N		0.0865	0.39
Pea vs Durum - 50 N vs 78 N		0.65	0.84
Durum at 50 N vs Pea at 34 N		0.63	0.64
Durum at 78 N vs Pea at 50 N		0.0003	0.0608

Table H.7. Apparent net mineralized nitrogen (NMN) during the growing season at the Swift Current-01 site.[a,b,c]

Treatment		Apparent Net Mineralized N		
Stubble	N Applied ($kg\ ha^{-1}$)	Planting to Anthesis[a]	Growing Season[b]	Anthesis to Harvest[c]
		------------------------- $kg\ N\ ha^{-1}$ -------------------------		
Durum	34	11	18	7
Durum	50	8	26	18
Durum	78	-15	25	40
Pea	34	9	22	13
Pea	50	28	-5	-32
Pea	78	3	6	3
LSD (P=0.05)		ns	ns	ns
Stubble				
Durum		1	23	22
Pea		13	8	-5
LSD (P=0.05)		ns	ns	23
	N Applied ($kg\ ha^{-1}$)			
	34	10	20	10
	50	18	11	-7
	78	-6	16	22
	LSD (P=0.05)	ns	ns	ns
ANOVA	df			
Stubble (S)	1	0.18	0.12	0.0222
N Applied ($kg\ ha^{-1}$)	2	0.11	0.71	0.11
N*S	2	0.54	0.3	0.10
Contrasts				
34 N vs 50 N		0.5	0.41	0.2
50 N vs 78 N		0.0411	0.66	0.0411
Pea vs Durum - 34 N vs 50 N		0.33	0.13	0.045
Pea vs Durum - 50 N vs 78 N		0.96	0.61	0.63
Durum at 50 N vs Pea at 34 N		0.94	0.82	0.8
Durum at 78 N vs Pea at 50 N		0.0132	0.0797	0.0016

[a] Calculated by subtracting the sum of NO_3-N to 110 cm at anthesis plus total aboveground plant N yield at anthesis from the sum of NO_3-N to 120 cm prior to planting plus fertilizer N rate.

[b] Calculated by subtracting the sum of NO_3-N to 110 cm at maturity plus total aboveground plant N yield at maturity from the sum of NO_3-N to 120 cm prior to planting plus fertilizer N rate.

[c] Calculated by subtracting apparent NMN at anthesis from apparent NMN during the growing season.

Table H.8. Recoverable N at anthesis at the Carman-00, Carman-01, and Brandon-01 sites.[a,b]

Treatment			Site	
Stubble	N Applied (kg ha⁻¹)	Carman-00[a]	Carman-01[a]	Brandon-01[b]
		-----------------------	kg N ha^{-1}	-----------------------
Flax	0	117	215	80
Flax	30 AN*	129	180	102
Flax	30 CRU**	130	196	98
Flax	90 AN	172	232	167
Flax	90 CRU	155	247	131
Pea	0	147	145	112
Pea	30 AN	184	179	141
Pea	30 CRU	199	191	118
Pea	90 AN	257	246	169
Pea	90 CRU	223	204	173
LSD (P=0.05)			65	25
Stubble				
Flax		141	214	116
Pea		199	193	143
LSD (P=0.05)		9	ns	11
	N Applied (kg ha^{-1})			
	0	132	180	96
	30 AN	157	179	122
	30 CRU	164	194	108
	90 AN	208	239	168
	90 CRU	189	226	152
	LSD (P=0.05)		41	18
ANOVA	df			
Stubble (S)	1	0.005	0.44	0.0122
N Applied (kg ha^{-1})	4	<0.0001	0.0156	<0.0001
N*S	4	0.0166	0.23	0.13
Contrasts				
Pea vs Flax at 0 N		0.0078	0.0364	0.0166
Pea vs Flax at 30 N		<0.0001	0.89	0.0021
Pea vs Flax at 90 N		<0.0001	0.52	0.0232
AN vs CRU		0.0628	0.96	0.0223
AN vs CRU - 30 N vs 90 N		0.004	0.34	0.86
0 N vs 30 N		0.0001	0.71	0.0148
30N vs 90 N		<0.0001	0.0032	<0.0001
Pea vs Flax - 0 N vs 30 N		0.0246	0.0621	0.91
Pea vs Flax - 30 N vs 90 N		0.12	0.69	0.49
Pea at 30 N vs Flax 90 N		0.0012	0.0223	0.0261
C.V. (%)		7.7	19.4	13.7

* Ammonium nitrate

** Controlled-release urea

[a] Calculated as the sum of soil NO_3-N to 110 cm plus aboveground plant N yield.

[b] Calculated as the sum of soil NO_3-N to 90 cm plus aboveground plant N yield.

Table H.9. Recoverable N at harvest at the Carman-00, Carman-01, and Brandon-01 sites.[a,b]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00[a]	Carman-01[a]	Brandon-01[b]
		kg N ha^{-1}		
Flax	0	174	225	93
Flax	30 AN*	186	231	102
Flax	30 CRU**	179	249	115
Flax	90 AN	217	315	158
Flax	90 CRU	222	302	152
Pea	0	202	191	117
Pea	30 AN	233	225	138
Pea	30 CRU	214	259	144
Pea	90 AN	274	273	156
Pea	90 CRU	217	272	161
LSD (P=0.05)			56	28
Stubble				
Flax		196	264	124
Pea		225	244	143
LSD (P=0.05)		21	ns	11
	N Applied (kg ha^{-1})			
	0	132	208	105
	30 AN	157	228	120
	30 CRU	164	254	130
	90 AN	208	294	157
	90 CRU	189	287	156
	LSD (P=0.05)		39	20
ANOVA	**df**			
Stubble (S)	1	0.14	0.26	0.0333
N Applied (kg ha^{-1})	4	0.0224	0.0004	<0.0001
N*S	4	0.38	0.64	0.29
Contrasts				
Pea vs Flax at 0 N		0.25	0.22	0.11
Pea vs Flax at 30 N		0.0242	0.92	0.0017
Pea vs Flax at 90 N		0.1	0.0783	0.71
AN vs CRU		0.1	0.48	0.47
AN vs CRU - 30 N vs 90 N		0.56	0.24	0.45
0 N vs 30 N		0.26	0.0556	0.0242
30N vs 90 N		0.0159	0.0011	0.0002
Pea vs Flax - 0 N vs 30 N		0.65	0.28	0.53
Pea vs Flax - 30 N vs 90 N		0.56	0.17	0.0411
Pea at 30 N vs Flax 90 N		0.78	0.0021	0.21
C.V. (%)		14.5	14.9	15.0

* Ammonium nitrate

** Controlled-release urea

[a] Calculated as the sum of soil NO_3-N to 110 cm plus aboveground plant N yield 35 days after anthesis.

[b] Calculated as the sum of soil NO_3-N to 90 cm plus aboveground plant N yield 35 days after anthesis.

Table H.10. Recoverable N at anthesis and harvest at the Swift Current-01 site.[a,b]

Treatment			
Stubble	N Applied (kg ha^{-1})	Anthesis[a]	Harvest[b]
		-----------------kg N ha^{-1}-----------------	
Durum	34	71	76
Durum	50	75	89
Durum	78	86	121
Pea	34	77	89
Pea	50	99	70
Pea	78	102	106
LSD (P=0.05)		ns	ns
Stubble			
Durum		77	95
Pea		93	88
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	74	82
	50	87	80
	78	94	113
	LSD (P=0.05)	ns	29
ANOVA	df		
Stubble (S)	1	0.1	0.44
N Applied (kg ha^{-1})	2	0.2	0.0178
N*S	2	0.72	0.32
Contrasts			
34 N vs 50 N		0.23	0.81
50 N vs 78 N		0.54	0.0101
Pea vs Durum - 34 N vs 50 N		0.43	0.17
Pea vs Durum - 50 N vs 78 N		0.74	0.87
Durum at 50 N vs Pea at 34 N		0.93	0.98
Durum at 78 N vs Pea at 50 N		0.39	0.0069
C.V. (%)		22.0	21.0

[a] Calculated as the sum of soil NO_3-N to 90 cm plus aboveground plant N yield.

[b] Calculated as the sum of soil NO_3-N to 90 cm plus aboveground plant N yield 35 days after anthesis.

8.9. APPENDIX I - MATERIALS AND METHODS FOR THE SWIFT CURRENT EXPERIMENTAL SITES

An experiment was initiated in 1999 at the Semiarid Prairie Agricultural Research Centre on a Haverhill loam as part of a larger study evaluating the value of annual grain legumes for low disturbance direct seeding. In the first phase of the study, seven main plots were established in 1999 (Swift-00) and 2000 (Swift-01) including field pea (*Pisum sativum* L. cv. Alfetta) and durum wheat (*Triticum durum* Desf. cv. Kyle). Legumes received phosphorous based on soil test recommendations, as well as sulphur at the rate of one unit of S per unit of P. Three replicates were arranged in a strip block design. Dimensions of the main plots were 4.6 m x 13.7 m.

In the re-crop phase of the study, spring wheat (*Triticum aestivum* L. cv. AC Barrie) was sown with a low-disturbance seeder at a rate of 90 kg ha^{-1}. Main plots were not tilled between harvest of the main crop and wheat sowing. Three N fertilizer treatments (34, 50, and 78 kg N ha^{-1} as commercial grade urea (46-0-0)) were randomly arranged as sub-plots to each block. N treatments were based on soil test recommendations for average, dry, and wet growing conditions, respectively. Sub-plot dimensions were 4.6 m x 4.6 m.

Detailed agronomic data were collected only at the Swift-01 site; harvest data were collected at the Swift-00 site. Methods concerning collection of agronomic data were identical to the methods used at the Brandon and Carman sites with minor changes. Prior to planting and fertilization of the wheat, soil in each plot (9 plots per stubble type) was sampled at depths of 0-15 cm, 15-60 cm, and 60-120 cm. Composites of three to five 50 mm diameter soil cores were prepared for each replicate and stored at 5°C until they could be air-dried. A summary of soil characteristics based on the average of the nine replicates of each main plot (previous crop) for each site is provided in Table I.3. Neutron access tubes were installed in all sub-plots immediately after planting. Anthesis tissue and soil sampling was initiated once at least 50 per cent of main stems were in the mid-anthesis stage. At the end of each sub-plot opposite to where neutron access tubes were installed, two adjacent rows 1-1.5 m long (depending on location and row spacing) were removed just above the soil surface. Every 7 d thereafter until 35 days after anthesis (DAA), a single row 1-1.5 m long was removed at a distance of at least 30 cm from the last row sampled.

Data were analyzed by analysis of variance (ANOVA) for a factorial experiment arranged in a completely randomized design using the Proc GLM procedure (SAS Institute Inc. 2001). Statistical analysis of all soil NO_3-N data was preceded by natural log transformation in order to ensure more homogeneous variances. The effect of previous crop on spring soil NO_3-N was analyzed by ANOVA using the Proc GLM procedure. Pre-determined, non-orthogonal single degree of freedom contrasts were used to evaluate stubble*N rate combinations.

8.10. APPENDIX J – MATERIALS AND METHODS FOR SELECTED GRAIN QUALITY ANALYSES

J. 1. Spectophotometric Protein Quality

This protein extraction procedure utilized in this study (Sapirstein and Johnson 2000) is based on the solubility of flour protein subjected to various concentrations of 50 per cent 1-propanol. Initially, 100 mg of flour is extracted with 1 mL 50 per cent (v/v) 1-propanol for 30 min at room temperature in a 1.5 mL microcentrifuge tube with intermittent vortexing every 10 min for 5 sec. After the initial extraction, the mixture is centrifuged for 3 min at 2200 g (Biofuge A, Heraeus-Christ) and the supernatant is used to quantify 50 per cent 1-propanol soluble protein. This fraction consitsts of albumin, globulin, gliadin, and low molecular weight glutenin. The method was modified to utilize a 50 mg flour sample because of the high flour protein contents of some of the samples.

Once the supernatant is removed from the microcentrifuge tube, the remaining pellet is reduced with 1 mL of 50 per cent 1-propanol containing 0.1 per cent dithiothreitol for 30 min at 55°C in a heating block. The samples are then vortexed for 2 min and at 14 min intervals thereafter. The mixture is then centrifuged for 3 min at 15000 g. The microcentrifuge tube is inverted to ensure a homogeneous supernatant and placed in a rack. An aliquot of the supernatant is collected, diluted 100-fold in a fresh tube with 50 per cent 1-propanol, and vortexed. The supernatant consists of high molecular weight glutenin.

Absorbance of samples is determined with a spectrophotometer that measures peptide bond absorbance. The blank sample used in the analysis is a 1 mL aliquot of 50 per cent 1-propanol. Absorbance is based on a 10 mm path length cuvette at 214 nm. A calibration curve is prepared and values are adjusted to a 14 per cent moisture basis.

Flour N content was determined by combustion with a LECO Model CNS Analyzer (LECO Corporation, St. Joseph, MI) and expressed on a 14 per cent moisture basis. Total flour protein content was expressed as N content multiplied by a factor of 5.7. Three protein fractions were differentiated based on this extraction procedure, namely soluble protein (SP, described previously), insoluble glutenin (IG, which is comprised of high molecular weight glutenin), and residue protein (RP, or unextractable protein), which contains unextractable high molecular weight glutenin as well as high molecular weight globulin. RP was calculated by subtracting the sum of SP and IG from total flour protein. Total insoluble protein (IP) was determined by difference as well (i.e. FP-SP). Each of the four protein fractions were also expressed as a percentage of total flour protein content. The ratio of SP to IG and the ratio of SP to IP were also calculated.

J. 2. Mixograph

A 10 g computerized torque-recording Mixograph was utilized in this experiment to evaluate dough-mixing properties (National Manufacturing, Lincoln, NE). Dough mixing was performed in duplicate using 10 g flour (+/- 0.01 g) and 62 per cent distilled water at 25°C for 8 min. Temperature is regulated using a water-jacketed mixing bowl. Computerized data acquisition was performed using Mixsmart software Version 3.8 (Walker and Walker 1995) with the following settings: Mixograph speed 88 rpm; spring setting 10; sampling at 10 points sec^{-1}; top, mid-, and bottom curve filter values and filter stages of 160 and 1, respectively; minimum and maximum torque standard readings of 63 and 900, respectively.

A computer-generated dough mixing curve, is generated based the power consumption of the Mixograph, which is a measure of torque (%) transferred to the mixing bowl. A typical mixogram is presented in Fig J.2.1. Dough mixing time to peak development (MDT) is the time (min) required to reach peak dough resistance (PDR), or Mixogram height (% torque). Work input to peak (WIP, expressed as % torque*min) is based on an integral of dough development time and % torque, while peak band width (PBW, expressed as % torque) is the range of % torque at MDT. Dough breakdown resistance (BR, expressed as %) is calculated as 100-(dough resistance 2 min after MDT/PDR)*100, while strength index (SI) is calculated at MDT*PBW.

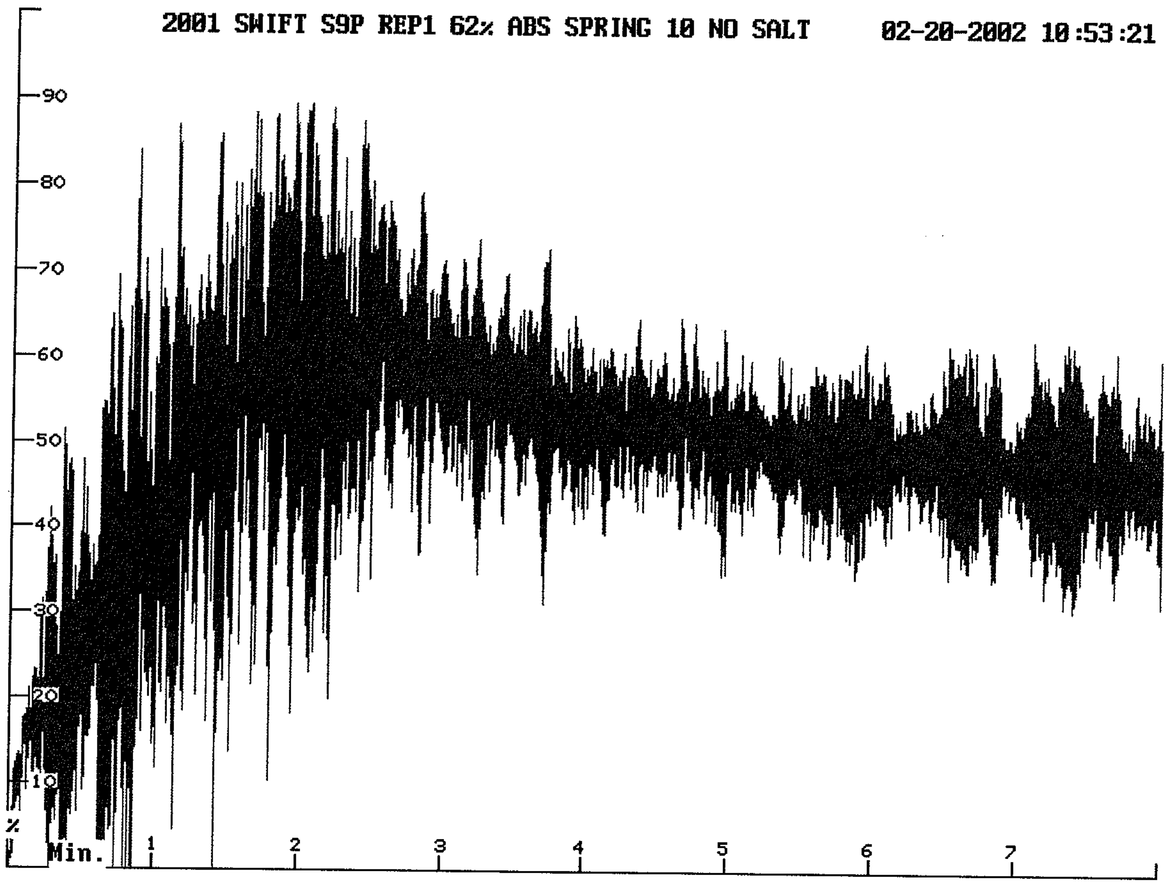


Figure J.2.1. Typical Mixogram generated with 10 g Mixograph.

J. 3. Mixro-extension test

Dough extensibility was evaluated using a TA.XT2*i* texture analyzer fitted with a Kieffer rig (Texture Technologies, Inc., Scarsdale, NY; Stable Microsystems, SMS, Surry, UK) as described by Smewing (1995) with small modifications. Dough was prepared with the Mixograph as described previously; 0.2 g salt was added to the flour prior to addition of distilled water. The first run of the Mixograph is carried out in order to determine peak dough resistance. The process is repeated and mixing is halted once PDR is reached. The dough is removed from the mixing bowl and formed into strips using a Teflon block apparatus lubricated with Crisco™ oil, and allowed to rest for approximately 40 min at room temperature.

The test was done in duplicate (and triplicate if necessary) using 4-6 dough strips per replicate. A dough strip is removed from the Teflon block, loaded into the Kieffer rig apparatus and is pulled by a hook located on the texture analyzer at a rate of 3 mm sec^{-1} until the dough piece tears. A computerized extensigram is generated during the procedure using Texture Expert for Windows Version 1.0 software (Stable Micro Systems Ltd. 1995) with the following settings; pre-test speed 2 mm sec^{-1}, trigger force 5 g; test speed 3 mm sec^{-1}, post-test speed 10 mm sec^{-1}, data acquisition rate 200 pps.

A typical extensigram is presented in Figure J.2.2. Maximum dough resistance (Rmax, expressed as g) is a measure of dough strength and resistance to extension, dough extensibility at Rmax and dough extensibility at dough rupture (E) are expressed in mm. Extensigram area (E Area) is calculated as an integral of resistance to extension over time. The dough visco-elastic ratio was calculated as Rmax/E.

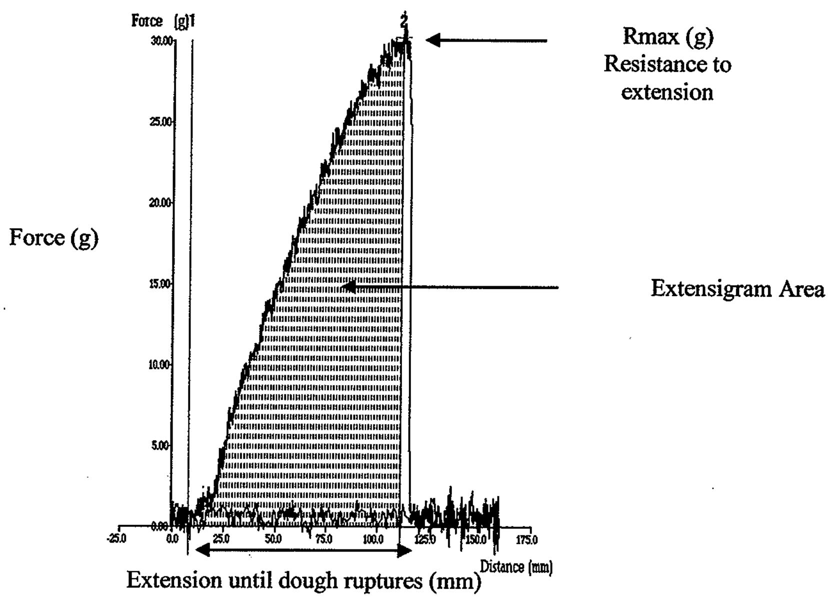


Figure J.3.1. A typical extensigram.

J. 4. Canadian Short Process (CSP) Bake Test

The CSP bake test was performed randomly in duplicate (and triplicate where necessary) as described by Preston et al. (1981), and is indicative of procedures used by Canadian commercial bakeries, namely optimized dough development and short fermentation time (CGC 1992). The formulation is as follows: 100 g flour (14 per cent moisture basis), 3.2 g compressed yeast, 2.4 g non-iodized salt, 4.0 g sugar, 4.0 g whey, 3.0 g shortening, 0.2 g malt syrup, 0.1 g ammonium phosphate, and 0.0075 g ascorbic acid. Water addition is roughly equivalent to Farinograph water absorption plus 4 per cent and is determined by the baker.

Dough is mixed with a GRL 200 mixer at 165 rpm at 30°C; floor time is 15 min at 30°C. Dough is then lightly punched 7 times and is then proofed for 15 min at 30°C. Dough is then sheeted by passing it 3 times through a National sheeter at 11/32", 3/16", and 1/8", respectively, and is then molded for 30 seconds using a GRL moulder. The dough is proofed for approximately 70 min +/- 5 min at 37.5°C and 83 per cent relative humidity, baked for 30 min at 204°C, and allowed to cool to ambient temperature. The loaf is weighed and volume is determined using a rapeseed displacement apparatus.

8.11. APPENDIX K – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON SELECTED GRAIN AND FLOUR NITROGEN AND SULPHUR ANALYSES AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table K.1. Per cent grain N at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	2.43	3.04	2.48
Flax	30 AN*	2.55	3.01	2.34
Flax	30 CRU**	2.54	3.03	2.41
Flax	90 AN	2.91	3.08	2.69
Flax	90 CRU	2.87	3.11	2.70
Pea	0	2.73	3.03	2.42
Pea	30 AN	2.96	3.11	2.57
Pea	30 CRU	2.88	3.12	2.56
Pea	90 AN	3.05	3.11	2.89
Pea	90 CRU	3.05	3.09	2.85
LSD (P=0.05)		0.19	ns	0.18
Stubble				
Flax		2.66	3.05	2.52
Pea		2.93	3.09	2.66
LSD (P=0.05)		0.08	ns	0.06
	N Applied (kg ha^{-1})			
	0	2.58	3.03	2.45
	30 AN	2.75	3.06	2.46
	30 CRU	2.71	3.08	2.48
	90 AN	2.98	3.09	2.79
	90 CRU	2.96	3.10	2.78
	LSD (P=0.05)	0.12	ns	0.10
ANOVA	df		Pr>F	
Stubble (S)	1	0.0307	0.3	0.17
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.51	<0.0001
N*S	4	0.16	0.5	0.0513
Contrasts				
Pea vs Flax at 0 N		0.0041	0.9	0.49
Pea vs Flax at 30 N		<0.0001	0.0335	0.0039
Pea vs Flax at 90 N		0.02	0.88	0.0067
AN vs CRU		0.45	0.74	0.87
AN vs CRU - 30 N vs 90 N		0.76	0.96	0.63
0 N vs 30 N		0.0066	0.28	0.61
30N vs 90 N		<0.0001	0.4	<0.0001
Pea vs Flax - 0 N vs 30 N		0.42	0.17	0.0067
Pea vs Flax - 30 N vs 90 N		0.0164	0.14	0.85
Pea at 30 N vs Flax 90 N		0.65	0.55	0.0433
Pea at 0 N vs Flax at 30 N		0.0303	0.93	0.56
Pea at 0 N vs Flax at 90 N		0.0595	0.22	0.0009
C.V. (%)		4.2	2.6	3.8

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 14 per cent moisture basis.

Table K.2. Per cent grain N at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	n.d.*	2.57
Durum	50	n.d.	2.65
Durum	78	n.d.	2.93
Pea	34	n.d.	2.92
Pea	50	n.d.	2.99
Pea	78	n.d.	2.83
LSD (P=0.05)			ns
Stubble			
Durum		n.d.	2.71
Pea		n.d.	2.91
LSD (P=0.05)			0.18
	N Applied (kg ha^{-1})		
	34	n.d.	2.74
	50	n.d.	2.82
	78	n.d.	2.88
	LSD (P=0.05)		ns
ANOVA	df	Pr > F	
Stubble (S)	1	n.d.	0.0353
N Applied (kg ha^{-1})	2	n.d.	0.44
N*S	2	n.d.	0.0769
Contrasts			
Pea vs Durum at 34N		n.d.	0.0267
Pea vs Durum at 50N		n.d.	0.0091
Pea vs Durum at 78N		n.d.	0.41
34 N vs 50 N		n.d.	0.49
50 N vs 78 N		n.d.	0.54
34 N vs 78 N		n.d.	0.21
Pea vs Durum - 34 N vs 50 N		n.d.	0.96
Pea vs Durum - 50 N vs 78 N		n.d.	0.0511
Durum at 50 N vs Pea at 34 N		n.d.	0.0813
Durum at 78 N vs Pea at 50 N		n.d.	0.7
Durum at 78 N vs Pea at 34 N		n.d.	0.95
C.V. (%)		n.d.	6.3

[a] Expressed on a 14 per cent moisture basis.

* Data were not collected.

Table K.3. Per cent grain S at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	0.152	0.172	0.139
Flax	30 AN*	0.157	0.172	0.137
Flax	30 CRU**	0.158	0.171	0.140
Flax	90 AN	0.177	0.175	0.157
Flax	90 CRU	0.175	0.179	0.156
Pea	0	0.168	0.172	0.140
Pea	30 AN	0.178	0.178	0.150
Pea	30 CRU	0.174	0.177	0.147
Pea	90 AN	0.184	0.178	0.163
Pea	90 CRU	0.184	0.177	0.161
LSD (P=0.05)		0.010	ns	0.008
Stubble				
Flax		0.164	0.174	0.146
Pea		0.178	0.176	0.152
LSD (P=0.05)		0.003	ns	0.003
	N Applied (kg ha^{-1})			
	0	0.160	0.172	0.139
	30 AN	0.168	0.175	0.143
	30 CRU	0.166	0.174	0.143
	90 AN	0.181	0.176	0.160
	90 CRU	0.179	0.178	0.159
	LSD (P=0.05)	0.006	ns	0.005
ANOVA	df		Pr>F	
Stubble (S)	1	0.0378	0.35	0.18
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.1	<0.0001
N*S	4	0.1	0.17	0.17
Contrasts				
Pea vs Flax at 0 N		0.002	1	0.91
Pea vs Flax at 30 N		<0.0001	0.0097	0.0023
Pea vs Flax at 90 N		0.016	0.96	0.0664
AN vs CRU		0.45	0.9	0.64
AN vs CRU - 30 N vs 90 N		0.87	0.54	0.8
0 N vs 30 N		0.0043	0.18	0.0576
30N vs 90 N		<0.0001	0.0845	<0.0001
Pea vs Flax - 0 N vs 30 N		0.49	0.0883	0.031
Pea vs Flax - 30 N vs 90 N		0.0093	0.0363	0.21
Pea at 30 N vs Flax 90 N		0.82	0.83	0.0157
Pea at 0 N vs Flax at 30 N		0.017	0.8	0.76
Pea at 0 N vs Flax at 90 N		0.0518	0.0775	0.0001
C.V. (%)		3.1	2.4	3.3

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 14 per cent moisture basis.

Table K.4. Per cent grain S at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	n.d.	0.172
Durum	50	n.d.	0.175
Durum	78	n.d.	0.189
Pea	34	n.d.	0.181
Pea	50	n.d.	0.186
Pea	78	n.d.	0.178
LSD (P=0.05)			ns
Stubble			
Durum		n.d.	0.179
Pea		n.d.	0.182
LSD (P=0.05)			ns
	N Applied (kg ha^{-1})		
	34	n.d.	0.177
	50	n.d.	0.181
	78	n.d.	0.183
	LSD (P=0.05)		ns
ANOVA	df	Pr > F	
Stubble (S)	1	n.d.	0.32
N Applied (kg ha^{-1})	2	n.d.	0.28
N*S	2	n.d.	0.096
Contrasts			
Pea vs Durum at 34N		n.d.	0.36
Pea vs Durum at 50N		n.d.	0.0787
Pea vs Durum at 78N		n.d.	0.0787
34 N vs 50 N		n.d.	0.14
50 N vs 78 N		n.d.	0.76
34 N vs 78 N		n.d.	0.23
Pea vs Durum - 34 N vs 50 N		n.d.	0.76
Pea vs Durum - 50 N vs 78 N		n.d.	0.047
Durum at 50 N vs Pea at 34 N		n.d.	0.66
Durum at 78 N vs Pea at 50 N		n.d.	0.66
Durum at 78 N vs Pea at 34 N		n.d.	0.39
C.V. (%)		n.d.	5.1

[a] Expressed on a 14 per cent moisture basis.

* Data were not collected.

Table K.5. Ratio of grain N to grain S at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	15.99	17.63	17.80
Flax	30 AN*	16.18	17.56	17.13
Flax	30 CRU**	16.09	17.75	17.19
Flax	90 AN	16.46	17.55	17.16
Flax	90 CRU	16.39	17.35	17.32
Pea	0	16.25	17.58	17.30
Pea	30 AN	16.60	17.48	17.15
Pea	30 CRU	16.49	17.61	17.41
Pea	90 AN	16.55	17.49	17.76
Pea	90 CRU	16.59	17.49	17.71
LSD (P=0.05)		ns	ns	0.41
Stubble				
Flax		16.22	17.57	17.32
Pea		16.50	17.53	17.46
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	16.12	17.61	17.55
	30 AN	16.39	17.52	17.14
	30 CRU	16.29	17.68	17.30
	90 AN	16.50	17.52	17.46
	90 CRU	16.49	17.42	17.51
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0768	0.84	0.19
N Applied (kg ha^{-1}) (N)	4	0.11	0.36	0.0448
N*S	4	0.82	0.84	0.0087
Contrasts				
Pea vs Flax at 0 N		0.25	0.84	0.0183
Pea vs Flax at 30 N		0.0149	0.46	0.41
Pea vs Flax at 90 N		0.36	0.78	0.0017
AN vs CRU		0.59	0.75	0.31
AN vs CRU - 30 N vs 90 N		0.67	0.17	0.61
0 N vs 30 N		0.12	0.93	0.0133
30N vs 90 N		0.15	0.18	0.0133
Pea vs Flax - 0 N vs 30 N		0.59	0.76	0.0187
Pea vs Flax - 30 N vs 90 N		0.25	0.41	0.0756
Pea at 30 N vs Flax 90 N		0.47	0.55	0.8
Pea at 0 N vs Flax at 30 N		0.54	0.71	0.44
Pea at 0 N vs Flax at 90 N		0.37	0.47	0.75
C.V. (%)		1.9	1.5	1.6

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 14 per cent moisture basis.

Table K.6. Ratio of grain N to grain S at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	n.d.	14.92
Durum	50	n.d.	15.14
Durum	78	n.d.	15.52
Pea	34	n.d.	16.14
Pea	50	n.d.	16.03
Pea	78	n.d.	15.92
LSD (P=0.05)			ns
Stubble			
Durum		n.d.	15.20
Pea		n.d.	16.03
LSD (P=0.05)			0.68
	N Applied (kg ha^{-1})		
	34	n.d.	15.53
	50	n.d.	15.59
	78	n.d.	15.72
	LSD (P=0.05)		ns
ANOVA	df	Pr > F	
Stubble (S)	1	n.d.	0.0201
N Applied (kg ha^{-1})	2	n.d.	0.88
N*S	2	n.d.	0.58
Contrasts			
Pea vs Durum at 34N		n.d.	0.0292
Pea vs Durum at 50N		n.d.	0.0759
Pea vs Durum at 78N		n.d.	0.39
34 N vs 50 N		n.d.	0.88
50 N vs 78 N		n.d.	0.74
34 N vs 78 N		n.d.	0.62
Pea vs Durum - 34 N vs 50 N		n.d.	0.68
Pea vs Durum - 50 N vs 78 N		n.d.	0.54
Durum at 50 N vs Pea at 34 N		n.d.	0.0916
Durum at 78 N vs Pea at 50 N		n.d.	0.36
Durum at 78 N vs Pea at 34 N		n.d.	0.28
C.V. (%)		n.d.	4.2

[a] Expressed on a 14 per cent moisture basis.

* Data were not collected.

Table K.7. Per cent flour N at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	2.22	2.85	2.36
Flax	30 AN*	2.38	2.84	2.29
Flax	30 CRU**	2.29	2.84	2.30
Flax	90 AN	2.63	2.91	2.56
Flax	90 CRU	2.60	2.91	2.69
Pea	0	2.56	2.82	2.38
Pea	30 AN	2.71	2.90	2.48
Pea	30 CRU	2.65	2.87	2.47
Pea	90 AN	2.79	2.89	2.83
Pea	90 CRU	2.83	2.94	2.80
LSD (P=0.05)		0.17	ns	0.16
Stubble				
Flax		2.42	2.87	2.44
Pea		2.71	2.89	2.59
LSD (P=0.05)		0.06	ns	0.06
	N Applied (kg ha^{-1})			
	0	2.39	2.84	2.37
	30 AN	2.54	2.87	2.38
	30 CRU	2.47	2.86	2.39
	90 AN	2.71	2.90	2.70
	90 CRU	2.72	2.93	2.75
	LSD (P=0.05)	0.09	ns	0.09
ANOVA	df		Pr>F	
Stubble (S)	1	0.0368	0.55	0.13
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.11	<0.0001
N*S	4	0.15	0.62	0.0902
Contrasts				
Pea vs Flax at 0 N		0.0004	0.58	0.85
Pea vs Flax at 30 N		<0.0001	0.17	0.0036
Pea vs Flax at 90 N		0.0032	0.95	0.0026
AN vs CRU		0.34	0.82	0.43
AN vs CRU - 30 N vs 90 N		0.22	0.38	0.43
0 N vs 30 N		0.0058	0.38	0.67
30N vs 90 N		<0.0001	0.0538	<0.0001
Pea vs Flax - 0 N vs 30 N		0.96	0.21	0.0421
Pea vs Flax - 30 N vs 90 N		0.0257	0.35	0.91
Pea at 30 N vs Flax 90 N		0.3	0.5	0.011
Pea at 0 N vs Flax at 30 N		0.0048	0.71	0.25
Pea at 0 N vs Flax at 90 N		0.44	0.0459	0.0011
C.V. (%)		3.6	2.4	3.5

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 14 per cent moisture basis.

Table K.8. Per cent flour N at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	1.68	2.40
Durum	50	1.89	2.44
Durum	78	2.12	2.78
Pea	34	1.97	2.73
Pea	50	2.16	2.84
Pea	78	2.43	2.66
LSD (P=0.05)		0.24	0.29
Stubble			
Durum		1.90	2.54
Pea		2.19	2.75
LSD (P=0.05)		0.14	0.17
	N Applied (kg ha^{-1})		
	34	1.82	2.57
	50	2.03	2.64
	78	2.27	2.72
	LSD (P=0.05)	0.14	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0006	0.0175
N Applied (kg ha^{-1})	2	0.0003	0.3
N*S	2	0.95	0.0333
Contrasts			
Pea vs Durum at 34N		0.0214	0.0267
Pea vs Durum at 50N		0.032	0.0091
Pea vs Durum at 78N		0.0138	0.41
34 N vs 50 N		0.0225	0.46
50 N vs 78 N		0.0074	0.4
34 N vs 78 N		<0.0001	0.13
Pea vs Durum - 34 N vs 50 N		0.88	0.69
Pea vs Durum - 50 N vs 78 N		0.75	0.016
Durum at 50 N vs Pea at 34 N		0.51	0.0423
Durum at 78 N vs Pea at 50 N		0.71	0.62
Durum at 78 N vs Pea at 34 N		0.20	0.75
C.V. (%)		6.6	6.1

[a] Expressed on a 14 per cent moisture basis.

Table K.9. Per cent flour S at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	0.129	0.145	0.136
Flax	30 AN*	0.138	0.146	0.134
Flax	30 CRU**	0.135	0.146	0.133
Flax	90 AN	0.148	0.149	0.148
Flax	90 CRU	0.148	0.150	0.151
Pea	0	0.146	0.147	0.135
Pea	30 AN	0.153	0.149	0.141
Pea	30 CRU	0.151	0.149	0.140
Pea	90 AN	0.156	0.151	0.157
Pea	90 CRU	0.158	0.151	0.153
LSD (P=0.05)		0.009	ns	0.010
Stubble				
Flax		0.140	0.147	0.140
Pea		0.153	0.150	0.145
LSD (P=0.05)		0.003	ns	0.004
	N Applied (kg ha^{-1})			
	0	0.138	0.146	0.135
	30 AN	0.145	0.148	0.137
	30 CRU	0.143	0.148	0.136
	90 AN	0.152	0.150	0.152
	90 CRU	0.153	0.151	0.152
	LSD (P=0.05)	0.005	0.003	0.006
ANOVA	df		Pr>F	
Stubble (S)	1	0.0452	0.25	0.27
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.0371	<0.0001
N*S	4	0.17	0.96	0.71
Contrasts				
Pea vs Flax at 0 N		0.0003	0.44	1
Pea vs Flax at 30 N		<0.0001	0.0675	0.0381
Pea vs Flax at 90 N		0.006	0.35	0.29
AN vs CRU		0.63	1	0.78
AN vs CRU - 30 N vs 90 N		0.27	0.63	0.78
0 N vs 30 N		0.0027	0.24	0.65
30N vs 90 N		<0.0001	0.0216	<0.0001
Pea vs Flax - 0 N vs 30 N		0.6	0.62	0.18
Pea vs Flax - 30 N vs 90 N		0.0476	0.47	0.41
Pea at 30 N vs Flax 90 N		0.3	0.88	0.0029
Pea at 0 N vs Flax at 30 N		0.0106	0.65	0.56
Pea at 0 N vs Flax at 90 N		0.54	0.23	0.0006
C.V. (%)		3.0	1.9	4.4

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 14 per cent moisture basis.

Table K.10. Per cent flour S at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment			Year	
Stubble	N Applied (kg ha^{-1})		2000	2001
Durum	34		0.104	0.149
Durum	50		0.115	0.146
Durum	78		0.125	0.165
Pea	34		0.120	0.156
Pea	50		0.123	0.160
Pea	78		0.141	0.153
LSD (P=0.05)			0.015	ns
Stubble				
Durum			0.115	0.153
Pea			0.128	0.156
LSD (P=0.05)			0.009	ns
	N Applied (kg ha^{-1})			
	34		0.112	0.152
	50		0.119	0.153
	78		0.133	0.159
	LSD (P=0.05)		0.009	ns
ANOVA		df	Pr > F	
Stubble (S)		1	0.0055	0.59
N Applied (kg ha^{-1})		2	0.0027	0.33
N*S		2	0.62	0.0467
Contrasts				
Pea vs Durum at 34N			0.0349	0.36
Pea vs Durum at 50N			0.28	0.0787
Pea vs Durum at 78N			0.0382	0.0787
34 N vs 50 N			0.13	1
50 N vs 78 N			0.016	0.2
34 N vs 78 N			0.0008	0.2
Pea vs Durum - 34 N vs 50 N			0.4	0.51
Pea vs Durum - 50 N vs 78 N			0.42	0.0187
Durum at 50 N vs Pea at 34 N			0.56	0.18
Durum at 78 N vs Pea at 50 N			0.81	0.36
Durum at 78 N vs Pea at 34 N			0.44	0.18
C.V. (%)			6.8	5.5

[a] Expressed on a 14 per cent moisture basis.

Table K.11. Ratio of flour N to flour S at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	17.21	19.62	17.38
Flax	30 AN*	17.22	19.39	17.13
Flax	30 CRU**	17.02	19.45	17.29
Flax	90 AN	17.73	19.52	17.33
Flax	90 CRU	17.55	19.43	17.75
Pea	0	17.48	19.18	17.62
Pea	30 AN	17.75	19.43	17.63
Pea	30 CRU	17.61	19.27	17.64
Pea	90 AN	17.86	19.15	18.04
Pea	90 CRU	17.92	19.44	18.28
LSD (P=0.05)		0.39	ns	0.38
Stubble				
Flax		17.34	19.48	17.38
Pea		17.72	19.29	17.84
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	17.34	19.40	17.50
	30 AN	17.48	19.41	17.38
	30 CRU	17.31	19.36	17.46
	90 AN	17.79	19.34	17.69
	90 CRU	17.74	19.44	18.02
	LSD (P=0.05)	0.24	ns	0.23
ANOVA	df		Pr>F	
Stubble (S)	1	0.081	0.18	0.0524
N Applied (kg ha^{-1}) (N)	4	0.0006	0.9	<0.0001
N*S	4	0.3	0.18	0.32
Contrasts				
Pea vs Flax at 0 N		0.17	0.0183	0.19
Pea vs Flax at 30 N		0.0003	0.57	0.0031
Pea vs Flax at 90 N		0.0785	0.15	<0.0001
AN vs CRU		0.17	0.79	0.0147
AN vs CRU - 30 N vs 90 N		0.5	0.35	0.13
0 N vs 30 N		0.6	0.89	0.43
30N vs 90 N		0.0002	0.99	<0.0001
Pea vs Flax - 0 N vs 30 N		0.16	0.0812	0.37
Pea vs Flax - 30 N vs 90 N		0.0689	0.51	0.24
Pea at 30 N vs Flax 90 N		0.78	0.32	0.5
Pea at 0 N vs Flax at 30 N		0.0373	0.12	0.0155
Pea at 0 N vs Flax at 90 N		0.33	0.0616	0.63
C.V. (%)		1.3	1.2	1.3

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 14 per cent moisture basis.

Table K.12. Ratio of grain N to grain S at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	16.21	16.14
Durum	50	16.42	16.68
Durum	78	16.95	16.88
Pea	34	16.44	17.51
Pea	50	17.62	17.77
Pea	78	17.28	17.38
LSD (P=0.05)		ns	ns
Stubble			
Durum		16.53	16.57
Pea		17.12	17.55
LSD (P=0.05)		ns	0.70
N Applied (kg ha^{-1})			
	34	16.33	16.82
	50	17.02	17.22
	78	17.12	17.13
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.18	0.0097
N Applied (kg ha^{-1})	2	0.28	0.59
N*S	2	0.6	0.54
Contrasts			
Pea vs Durum at 34N		0.75	0.0292
Pea vs Durum at 50N		0.12	0.0759
Pea vs Durum at 78N		0.65	0.39
34 N vs 50 N		0.2	0.33
50 N vs 78 N		0.86	0.81
34 N vs 78 N		0.15	0.46
Pea vs Durum - 34 N vs 50 N		0.37	0.71
Pea vs Durum - 50 N vs 78 N		0.41	0.47
Durum at 50 N vs Pea at 34 N		0.97	0.16
Durum at 78 N vs Pea at 50 N		0.37	0.14
Durum at 78 N vs Pea at 34 N		0.50	0.27
C.V. (%)		5.3	4.0

[a] Expressed on a 14 per cent moisture basis.

Table K.13. Flour protein content (14% moisture basis) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	12.6	16.3	13.5
Flax	30 AN*	13.6	16.2	13.1
Flax	30 CRU**	13.1	16.2	13.1
Flax	90 AN	15.0	16.6	14.6
Flax	90 CRU	14.8	16.6	15.3
Pea	0	14.6	16.1	13.5
Pea	30 AN	15.4	16.6	14.1
Pea	30 CRU	15.1	16.4	14.1
Pea	90 AN	15.9	16.5	16.1
Pea	90 CRU	16.2	16.8	16.0
LSD (P=0.05)		1.0	ns	0.9
Stubble				
Flax		13.8	16.4	13.9
Pea		15.4	16.5	14.8
LSD (P=0.05)		0.3	ns	0.3
	N Applied (kg ha^{-1})			
	0	13.6	16.2	13.5
	30 AN	14.5	16.4	13.6
	30 CRU	14.1	16.3	13.6
	90 AN	15.4	16.5	15.4
	90 CRU	15.5	16.7	15.6
	LSD (P=0.05)	0.5	ns	0.5
ANOVA	df		Pr>F	
Stubble (S)	1	0.0369	0.55	0.13
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.11	<0.0001
N*S	4	0.15	0.61	0.0895
Contrasts				
Pea vs Flax at 0 N		0.0004	0.58	0.85
Pea vs Flax at 30 N		<0.0001	0.17	0.0036
Pea vs Flax at 90 N		0.0032	0.94	0.0026
AN vs CRU		0.33	0.82	0.42
AN vs CRU - 30 N vs 90 N		0.22	0.38	0.43
0 N vs 30 N		0.0058	0.38	0.67
30N vs 90 N		<0.0001	0.0539	<0.0001
Pea vs Flax - 0 N vs 30 N		0.96	0.21	0.0421
Pea vs Flax - 30 N vs 90 N		0.0257	0.35	0.9
Pea at 30 N vs Flax 90 N		0.3	0.5	0.0107
Pea at 0 N vs Flax at 30 N		0.0048	0.71	0.25
Pea at 0 N vs Flax at 90 N		0.44	0.0464	0.0011
C.V. (%)		3.6	2.4	3.5

* Ammonium nitrate

** Controlled-release urea

Table K.14. Flour protein content (14% moisture basis) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	9.6	13.7
Durum	50	10.8	13.9
Durum	78	12.1	15.8
Pea	34	11.2	15.6
Pea	50	12.3	16.2
Pea	78	13.9	15.2
LSD (P=0.05)		1.4	1.6
Stubble			
Durum		10.8	14.5
Pea		12.5	15.6
LSD (P=0.05)		0.8	0.9
N Applied (kg ha^{-1})			
	34	10.4	14.6
	50	11.6	15.0
	78	13.0	15.5
	LSD (P=0.05)	0.8	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0006	0.0182
N Applied (kg ha^{-1})	2	0.0003	0.3
N*S	2	0.95	0.0328
Contrasts			
Pea vs Durum at 34N		0.0214	0.027
Pea vs Durum at 50N		0.032	0.0093
Pea vs Durum at 78N		0.0137	0.4
34 N vs 50 N		0.0222	0.44
50 N vs 78 N		0.0075	0.41
34 N vs 78 N		<0.0001	0.13
Pea vs Durum - 34 N vs 50 N		0.88	0.69
Pea vs Durum - 50 N vs 78 N		0.75	0.0159
Durum at 50 N vs Pea at 34 N		0.51	0.0441
Durum at 78 N vs Pea at 50 N		0.71	0.63
Durum at 78 N vs Pea at 34 N		0.20	0.74
C.V. (%)		6.6	6.1

8.12. APPENDIX L – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON GENERAL END-USE QUALITY ANALYSES AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table L.1. Grain test weight (kg hl^{-1}) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	75.5	75.9	79.8
Flax	30 AN*	74.4	75.1	79.7
Flax	30 CRU**	75.1	75.1	79.5
Flax	90 AN	74.0	74.4	79.4
Flax	90 CRU	75.6	73.8	79.0
Pea	0	74.5	76.4	79.8
Pea	30 AN	74.6	74.8	79.6
Pea	30 CRU	74.9	74.5	79.6
Pea	90 AN	75.0	74.7	78.9
Pea	90 CRU	74.9	73.9	78.9
LSD (P=0.05)		ns	1.5	ns
Stubble				
Flax		74.9	74.9	79.5
Pea		74.8	74.9	79.4
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	75.0	76.1	79.8
	30 AN	74.5	74.9	79.6
	30 CRU	75.0	74.8	79.6
	90 AN	74.5	74.6	79.2
	90 CRU	75.2	73.9	79.0
	LSD (P=0.05)	ns	0.9	0.5
ANOVA	df		Pr>F	
Stubble (S)	1	0.78	0.99	0.74
N Applied (kg ha^{-1}) (N)	4	0.72	0.0012	0.0065
N*S	4	0.55	0.77	0.71
Contrasts				
Pea vs Flax at 0 N		0.3	0.47	0.9
Pea vs Flax at 30 N		0.92	0.42	0.93
Pea vs Flax at 90 N		0.81	0.75	0.32
AN vs CRU		0.19	0.18	0.41
AN vs CRU - 30 N vs 90 N		0.78	0.38	0.6
0 N vs 30 N		0.68	0.0041	0.46
30N vs 90 N		0.76	0.0599	0.0021
Pea vs Flax - 0 N vs 30 N		0.41	0.25	0.85
Pea vs Flax - 30 N vs 90 N		0.81	0.38	0.45
Pea at 30 N vs Flax 90 N		0.89	0.32	0.14
Pea at 0 N vs Flax at 30 N		0.71	0.0441	0.63
Pea at 0 N vs Flax at 90 N		0.69	0.0013	0.0802
C.V. (%)		1.6	1.2	0.6

* Ammonium nitrate

** Controlled-release urea

Table L.2. Grain test weight (kg hl^{-1}) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	n.d.*	79.3
Durum	50	n.d.	79.5
Durum	78	n.d.	78.8
Pea	34	n.d.	79.5
Pea	50	n.d.	79.0
Pea	78	n.d.	79.6
LSD (P=0.05)			ns
Stubble			
Durum		n.d.	79.2
Pea		n.d.	79.4
LSD (P=0.05)			ns
N Applied (kg ha^{-1})			
	34	n.d.	79.4
	50	n.d.	79.2
	78	n.d.	79.2
	LSD (P=0.05)		ns
ANOVA	df	Pr > F	
Stubble (S)	1	n.d.	0.31
N Applied (kg ha^{-1})	2	n.d.	0.66
N*S	2	n.d.	0.0245
Contrasts			
Pea vs Durum at 34N		n.d.	0.6
Pea vs Durum at 50N		n.d.	0.13
Pea vs Durum at 78N		n.d.	0.013
34 N vs 50 N		n.d.	0.55
50 N vs 78 N		n.d.	0.77
34 N vs 78 N		n.d.	0.38
Pea vs Durum - 34 N vs 50 N		n.d.	0.15
Pea vs Durum - 50 N vs 78 N		n.d.	0.0076
Durum at 50 N vs Pea at 34 N		n.d.	0.92
Durum at 78 N vs Pea at 50 N		n.d.	0.41
Durum at 78 N vs Pea at 34 N		n.d.	0.0353
C.V. (%)		n.d.	0.5

* Data were not collected.

Table L.3. Thousand kernel weight (g) at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	31.5	31.7	33.1
Flax	30 AN*	31.4	30.3	33.3
Flax	30 CRU**	30.9	30.9	33.1
Flax	90 AN	30.1	29.6	34.6
Flax	90 CRU	30.8	30.4	35.6
Pea	0	30.6	32.4	34.2
Pea	30 AN	30.5	30.5	35.5
Pea	30 CRU	30.5	29.3	34.7
Pea	90 AN	30.8	31.1	36.5
Pea	90 CRU	30.5	30.0	37.2
LSD (P=0.05)		ns	1.6	1.5
Stubble				
Flax		31.0	30.6	33.9
Pea		30.6	30.7	35.6
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	31.1	32.1	33.6
	30 AN	31.0	30.4	34.4
	30 CRU	30.7	30.1	33.9
	90 AN	30.5	30.4	35.5
	90 CRU	30.7	30.2	36.4
	LSD (P=0.05)	ns	1.1	0.7
ANOVA	df		Pr>F	
Stubble (S)	1	0.43	0.9	0.11
N Applied (kg ha^{-1}) (N)	4	0.93	0.0049	<0.0001
N*S	4	0.84	0.0681	0.62
Contrasts				
Pea vs Flax at 0 N		0.39	0.35	0.13
Pea vs Flax at 30 N		0.39	0.22	0.0007
Pea vs Flax at 90 N		0.86	0.39	0.0019
AN vs CRU		0.95	0.61	0.4
AN vs CRU - 30 N vs 90 N		0.69	0.88	0.0138
0 N vs 30 N		0.69	0.0005	0.0861
30N vs 90 N		0.64	0.91	<0.0001
Pea vs Flax - 0 N vs 30 N		0.84	0.12	0.18
Pea vs Flax - 30 N vs 90 N		0.47	0.12	0.7
Pea at 30 N vs Flax 90 N		1	0.79	0.94
Pea at 0 N vs Flax at 30 N		0.57	0.0105	0.12
Pea at 0 N vs Flax at 90 N		0.89	0.0014	0.16
C.V. (%)		4.9	3.4	2.0

* Ammonium nitrate

** Controlled-release urea

[a] Expressed on a 13.5 per cent moisture basis.

Table L.4. Thousand kernel weight (g) at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	31.2	29.7
Durum	50	31.4	29.9
Durum	78	33.1	30.2
Pea	34	31.7	32.3
Pea	50	32.4	31.0
Pea	78	28.7	31.5
LSD (P=0.05)		ns	1.2
Stubble			
Durum		31.9	29.9
Pea		30.9	31.6
LSD (P=0.05)		ns	0.7
	N Applied (kg ha^{-1})		
	34	31.5	31.0
	50	31.9	30.4
	78	30.9	30.8
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.62	0.0003
N Applied (kg ha^{-1})	2	0.92	0.38
N*S	2	0.51	0.15
Contrasts			
Pea vs Durum at 34N		0.91	0.0005
Pea vs Durum at 50N		0.78	0.0868
Pea vs Durum at 78N		0.23	0.038
34 N vs 50 N		0.85	0.19
50 N vs 78 N		0.7	0.34
34 N vs 78 N		0.83	0.69
Pea vs Durum - 34 N vs 50 N		0.91	0.0713
Pea vs Durum - 50 N vs 78 N		0.29	0.75
Durum at 50 N vs Pea at 34 N		0.95	0.0011
Durum at 78 N vs Pea at 50 N		0.84	0.19
Durum at 78 N vs Pea at 34 N		0.68	0.0026
C.V. (%)		13.7	2.3

[a] Expressed on a 13.5 per cent moisture basis.

Table L.5. SDS sedimentation value (ml) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	63.3	69.1	62.9
Flax	30 AN*	65.3	68.4	61.4
Flax	30 CRU**	63.9	68.3	63.0
Flax	90 AN	69.5	69.2	66.4
Flax	90 CRU	69.0	69.1	66.4
Pea	0	69.4	68.5	62.7
Pea	30 AN	70.3	69.5	64.6
Pea	30 CRU	69.5	69.8	63.9
Pea	90 AN	73.8	69.0	65.4
Pea	90 CRU	72.4	69.3	66.3
LSD (P=0.05)		2.6	ns	2.3
Stubble				
Flax		66.2	68.8	64.0
Pea		71.1	69.2	64.6
LSD (P=0.05)		1.1	0.9	ns
	N Applied (kg ha^{-1})			
	0	66.3	68.8	62.8
	30 AN	67.8	68.9	63.0
	30 CRU	66.7	69.0	63.5
	90 AN	71.6	69.1	65.9
	90 CRU	70.7	69.2	66.3
	LSD (P=0.05)	1.7	ns	1.4
ANOVA	df		Pr>F	
Stubble (S)	1	0.0092	0.75	0.58
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.98	<0.0001
N*S	4	0.5	0.48	0.045
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.61	0.88
Pea vs Flax at 30 N		<0.0001	0.14	0.0153
Pea vs Flax at 90 N		0.0002	0.97	0.45
AN vs CRU		0.1	0.88	0.38
AN vs CRU - 30 N vs 90 N		0.92	0.98	0.99
0 N vs 30 N		0.22	0.79	0.43
30N vs 90 N		<0.0001	0.71	<0.0001
Pea vs Flax - 0 N vs 30 N		0.58	0.11	0.0729
Pea vs Flax - 30 N vs 90 N		0.22	0.17	0.0114
Pea at 30 N vs Flax 90 N		0.49	0.59	0.0109
Pea at 0 N vs Flax at 30 N		0.0002	0.86	0.64
Pea at 0 N vs Flax at 90 N		0.91	0.53	0.0006
C.V. (%)		2.4	1.9	2.1

* Ammonium nitrate

** Controlled-release urea

Table L.6. Per cent fusarium-damaged kernels at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	1.38	0.33	0.75
Flax	30 AN*	1.15	0.66	1.00
Flax	30 CRU**	1.23	0.45	0.80
Flax	90 AN	1.13	0.80	1.38
Flax	90 CRU	1.35	0.69	1.48
Pea	0	1.03	0.42	0.98
Pea	30 AN	1.38	0.50	1.18
Pea	30 CRU	1.28	0.71	1.58
Pea	90 AN	0.80	0.54	1.40
Pea	90 CRU	1.58	0.81	1.25
LSD (P=0.05)		ns	ns	0.51
Stubble				
Flax		1.25	0.59	1.08
Pea		1.21	0.60	1.28
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	1.20	0.38	0.86
	30 AN	1.26	0.58	1.09
	30 CRU	1.25	0.58	1.19
	90 AN	0.96	0.67	1.39
	90 CRU	1.46	0.75	1.36
	LSD (P=0.05)	ns	ns	0.36
ANOVA	df		Pr>F	
Stubble (S)	1	0.79	0.96	0.19
N Applied (kg ha^{-1}) (N)	4	0.17	0.0514	0.0364
N*S	4	0.37	0.27	0.1
Contrasts				
Pea vs Flax at 0 N		0.21	0.66	0.37
Pea vs Flax at 30 N		0.47	0.76	0.0117
Pea vs Flax at 90 N		0.8	0.61	0.57
AN vs CRU		0.0835	0.56	0.76
AN vs CRU - 30 N vs 90 N		0.0697	0.67	0.62
0 N vs 30 N		0.74	0.0723	0.0813
30N vs 90 N		0.75	0.12	0.0662
Pea vs Flax - 0 N vs 30 N		0.15	0.86	0.42
Pea vs Flax - 30 N vs 90 N		0.37	0.56	0.0286
Pea at 30 N vs Flax 90 N		0.65	0.22	0.78
Pea at 0 N vs Flax at 30 N		0.49	0.36	0.73
Pea at 0 N vs Flax at 90 N		0.37	0.0367	0.0459
C.V. (%)		31.1	39.8	29.6

* Ammonium nitrate

** Controlled-release urea

[a] Based on Canadian Grain Commission grading standards.

Table L.7. Grain deoxynivalenol content (parts per million) at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	1.20	0.78	1.78
Flax	30 AN*	1.04	0.70	1.95
Flax	30 CRU**	0.98	0.55	2.40
Flax	90 AN	0.93	0.71	2.30
Flax	90 CRU	1.10	0.85	2.83
Pea	0	0.78	0.63	1.95
Pea	30 AN	0.86	1.10	2.30
Pea	30 CRU	0.80	0.90	2.45
Pea	90 AN	0.90	0.94	2.45
Pea	90 CRU	0.93	1.08	2.06
LSD (P=0.05)		ns	0.36	ns
Stubble				
Flax		1.05	0.72	2.25
Pea		0.85	0.93	2.24
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	0.99	0.70	1.86
	30 AN	0.95	0.90	2.13
	30 CRU	0.89	0.73	2.43
	90 AN	0.91	0.83	2.38
	90 CRU	1.01	0.96	2.44
	LSD (P=0.05)	ns	ns	0.38
ANOVA	df		Pr>F	
Stubble (S)	1	0.0772	0.19	0.99
N Applied (kg ha^{-1}) (N)	4	0.77	0.11	0.0168
N*S	4	0.5	0.14	0.052
Contrasts				
Pea vs Flax at 0 N		0.0113	0.39	0.66
Pea vs Flax at 30 N		0.12	0.0049	0.48
Pea vs Flax at 90 N		0.37	0.0771	0.29
AN vs CRU		0.87	0.75	0.16
AN vs CRU - 30 N vs 90 N		0.27	0.0649	0.4
0 N vs 30 N		0.52	0.25	0.016
30N vs 90 N		0.63	0.27	0.3
Pea vs Flax - 0 N vs 30 N		0.2	0.0108	0.94
Pea vs Flax - 30 N vs 90 N		0.63	0.34	0.0662
Pea at 30 N vs Flax 90 N		0.12	0.094	0.5
Pea at 0 N vs Flax at 30 N		0.0906	1	0.51
Pea at 0 N vs Flax at 90 N		0.0906	0.29	0.0818
C.V. (%)		23.0	26.6	16.3

* Ammonium nitrate

** Controlled-release urea

[a] Based on the method of Sinha and Savard (1996).

Table L.8. Flour deoxynivalenol content (parts per million) at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	0.40	0.25	0.73
Flax	30 AN*	0.33	0.28	0.91
Flax	30 CRU**	0.38	0.35	0.85
Flax	90 AN	0.40	0.30	1.00
Flax	90 CRU	0.36	0.30	1.08
Pea	0	0.30	0.28	0.95
Pea	30 AN	0.39	0.33	1.05
Pea	30 CRU	0.35	0.38	1.05
Pea	90 AN	0.33	0.38	1.00
Pea	90 CRU	0.38	0.40	1.00
LSD (P=0.05)		ns	ns	0.16
Stubble				
Flax		0.37	0.30	0.91
Pea		0.35	0.35	1.01
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	0.35	0.26	0.84
	30 AN	0.36	0.30	0.98
	30 CRU	0.36	0.36	0.95
	90 AN	0.36	0.34	1.00
	90 CRU	0.37	0.35	1.04
	LSD (P=0.05)	ns	ns	0.10
ANOVA	df		Pr>F	
Stubble (S)	1	0.19	0.12	0.21
N Applied (kg ha^{-1}) (N)	4	0.92	0.15	0.006
N*S	4	0.0215	0.88	0.0258
Contrasts				
Pea vs Flax at 0 N		0.0102	0.68	0.0089
Pea vs Flax at 30 N		0.34	0.38	0.0077
Pea vs Flax at 90 N		0.15	0.0459	0.51
AN vs CRU		0.74	0.22	1
AN vs CRU - 30 N vs 90 N		0.74	0.41	0.3
0 N vs 30 N		0.58	0.0714	0.0057
30N vs 90 N		0.74	0.68	0.17
Pea vs Flax - 0 N vs 30 N		0.01	0.87	0.48
Pea vs Flax - 30 N vs 90 N		0.1	0.41	0.0092
Pea at 30 N vs Flax 90 N		0.63	0.24	0.83
Pea at 0 N vs Flax at 30 N		0.12	0.47	0.37
Pea at 0 N vs Flax at 90 N		0.0095	0.63	0.22
C.V. (%)		14.2	26.1	10.4

* Ammonium nitrate

** Controlled-release urea

[a] Based on the method of Sinha and Savard (1996).

Table L.9. Particle size index (%) at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	55.8	53.8	54.9
Flax	30 AN*	54.1	53.0	54.5
Flax	30 CRU**	54.5	53.9	55.0
Flax	90 AN	55.4	55.2	53.5
Flax	90 CRU	55.5	54.5	54.7
Pea	0	53.2	53.6	53.8
Pea	30 AN	54.6	53.3	55.2
Pea	30 CRU	54.2	53.5	54.9
Pea	90 AN	55.4	54.2	53.8
Pea	90 CRU	55.4	54.4	54.4
LSD (P=0.05)		1.5	ns	ns
Stubble				
Flax		55.0	54.1	54.5
Pea		54.6	53.8	54.4
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	54.5	53.7	54.4
	30 AN	54.4	53.2	54.9
	30 CRU	54.3	53.7	54.9
	90 AN	55.4	54.7	53.6
	90 CRU	55.5	54.5	54.5
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.31	0.24	0.94
N Applied (kg ha^{-1}) (N)	4	0.0522	0.51	0.21
N*S	4	0.043	0.97	0.61
Contrasts				
Pea vs Flax at 0 N		0.0015	0.86	0.28
Pea vs Flax at 30 N		0.86	0.98	0.64
Pea vs Flax at 90 N		0.98	0.53	0.91
AN vs CRU		1	0.84	0.24
AN vs CRU - 30 N vs 90 N		0.91	0.6	0.34
0 N vs 30 N		0.74	0.71	0.29
30N vs 90 N		0.0044	0.1	0.0629
Pea vs Flax - 0 N vs 30 N		0.0051	0.91	0.19
Pea vs Flax - 30 N vs 90 N		0.89	0.69	0.78
Pea at 30 N vs Flax 90 N		0.0473	0.12	0.15
Pea at 0 N vs Flax at 30 N		0.0937	0.87	0.27
Pea at 0 N vs Flax at 90 N		0.0013	0.27	0.78
C.V. (%)		1.8	3.6	2.1

* Ammonium nitrate

** Controlled-release urea

[a] Determined on ground grain.

Table L.10. Particle size index (%) at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	n.d.*	53.7
Durum	50	n.d.	54.5
Durum	78	n.d.	55.1
Pea	34	n.d.	55.2
Pea	50	n.d.	53.8
Pea	78	n.d.	54.4
LSD (P=0.05)			ns
Stubble			
Durum		n.d.	54.4
Pea		n.d.	54.5
LSD (P=0.05)			ns
	N Applied (kg ha^{-1})		
	34	n.d.	54.4
	50	n.d.	54.1
	78	n.d.	54.8
	LSD (P=0.05)		ns
ANOVA	df	Pr > F	
Stubble (S)	1	n.d.	0.91
N Applied (kg ha^{-1})	2	n.d.	0.69
N*S	2	n.d.	0.26
Contrasts			
Pea vs Durum at 34N		n.d.	0.17
Pea vs Durum at 50N		n.d.	0.53
Pea vs Durum at 78N		n.d.	0.53
34 N vs 50 N		n.d.	0.69
50 N vs 78 N		n.d.	0.41
34 N vs 78 N		n.d.	0.66
Pea vs Durum - 34 N vs 50 N		n.d.	0.16
Pea vs Durum - 50 N vs 78 N		n.d.	1
Durum at 50 N vs Pea at 34 N		n.d.	0.49
Durum at 78 N vs Pea at 50 N		n.d.	0.23
Durum at 78 N vs Pea at 34 N		n.d.	0.92
C.V. (%)		n.d.	2.3

* Data were not collected.

[a] Determined on ground grain.

Table L.11. Flour yield (%) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	75.1	73.0	74.3
Flax	30 AN*	74.7	72.8	74.2
Flax	30 CRU**	74.9	73.3	74.2
Flax	90 AN	74.1	73.4	74.3
Flax	90 CRU	74.2	72.7	74.4
Pea	0	74.8	73.1	74.4
Pea	30 AN	74.1	72.8	74.5
Pea	30 CRU	74.1	72.5	74.4
Pea	90 AN	73.5	72.9	74.3
Pea	90 CRU	74.2	72.8	74.5
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		74.6	73.0	74.3
Pea		74.1	72.8	74.4
LSD (P=0.05)		0.4	ns	ns
	N Applied (kg ha^{-1})			
	0	74.9	73.1	74.3
	30 AN	74.4	72.8	74.3
	30 CRU	74.5	72.9	74.3
	90 AN	73.8	73.1	74.3
	90 CRU	74.2	72.7	74.4
	LSD (P=0.05)	0.7	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0218	0.49	0.31
N Applied (kg ha^{-1}) (N)	4	0.0341	0.8	0.85
N*S	4	0.85	0.58	0.92
Contrasts				
Pea vs Flax at 0 N		0.54	0.81	0.91
Pea vs Flax at 30 N		0.0476	0.27	0.22
Pea vs Flax at 90 N		0.33	0.63	0.76
AN vs CRU		0.33	0.54	0.52
AN vs CRU - 30 N vs 90 N		0.58	0.39	0.39
0 N vs 30 N		0.0907	0.48	0.79
30N vs 90 N		0.0749	0.75	0.75
Pea vs Flax - 0 N vs 30 N		0.51	0.39	0.54
Pea vs Flax - 30 N vs 90 N		0.47	0.64	0.52
Pea at 30 N vs Flax 90 N		0.87	0.31	0.59
Pea at 0 N vs Flax at 30 N		0.92	0.87	0.45
Pea at 0 N vs Flax at 90 N		0.11	0.8	0.85
C.V. (%)		0.9	1.0	0.4

* Ammonium nitrate

** Controlled-release urea

Table L.12. Flour yield (%) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	75.9	74.8
Durum	50	76.1	75.0
Durum	78	76.7	74.8
Pea	34	77.3	75.3
Pea	50	77.1	75.0
Pea	78	76.8	74.9
LSD (P=0.05)		0.8	ns
Stubble			
Durum		76.3	74.9
Pea		77.0	75.1
LSD (P=0.05)		0.5	ns
	N Applied (kg ha^{-1})		
	34	76.6	75.1
	50	76.6	75.0
	78	76.8	74.9
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0041	0.49
N Applied (kg ha^{-1})	2	0.76	0.74
N*S	2	0.1	0.64
Contrasts			
Pea vs Durum at 34N		0.0048	0.81
Pea vs Durum at 50N		0.0278	0.27
Pea vs Durum at 78N		0.87	0.87
34 N vs 50 N		0.95	0.82
50 N vs 78 N		0.51	0.61
34 N vs 78 N		0.55	0.46
Pea vs Durum - 34 N vs 50 N		0.51	0.37
Pea vs Durum - 50 N vs 78 N		0.13	0.77
Durum at 50 N vs Pea at 34 N		0.0107	0.52
Durum at 78 N vs Pea at 50 N		0.41	0.69
Durum at 78 N vs Pea at 34 N		0.19	0.24
C.V. (%)		0.6	0.7

8.13. APPENDIX M – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON MIXOGRAPH ANALYSES AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table M.1. Mixograph dough development time (min) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	3.99	3.67	3.71
Flax	30 AN*	3.81	3.64	3.65
Flax	30 CRU**	3.89	3.42	3.65
Flax	90 AN	3.46	3.42	2.80
Flax	90 CRU	3.36	3.56	3.03
Pea	0	3.21	3.42	3.46
Pea	30 AN	3.11	3.52	3.12
Pea	30 CRU	3.09	3.36	2.96
Pea	90 AN	3.10	3.32	2.90
Pea	90 CRU	3.06	3.41	2.86
LSD (P=0.05)		0.35	ns	0.30
Stubble				
Flax		3.70	3.54	3.37
Pea		3.12	3.41	3.06
LSD (P=0.05)		0.13	ns	0.13
	N Applied (kg ha^{-1})			
	0	3.60	3.55	3.59
	30 AN	3.46	3.58	3.38
	30 CRU	3.49	3.39	3.31
	90 AN	3.28	3.37	2.85
	90 CRU	3.21	3.48	2.94
	LSD (P=0.05)	0.20	ns	0.20
ANOVA	df		Pr>F	
Stubble (S)	1	0.0285	0.21	0.0298
N Applied (kg ha^{-1}) (N)	4	0.0038	0.25	<0.0001
N*S	4	0.0428	0.94	0.005
Contrasts				
Pea vs Flax at 0 N		0.0001	0.15	0.0921
Pea vs Flax at 30 N		<0.0001	0.45	<0.0001
Pea vs Flax at 90 N		0.0113	0.29	0.72
AN vs CRU		0.77	0.62	0.9
AN vs CRU - 30 N vs 90 N		0.5	0.0626	0.24
0 N vs 30 N		0.16	0.53	0.0092
30N vs 90 N		0.0032	0.45	<0.0001
Pea vs Flax - 0 N vs 30 N		0.86	0.43	0.0463
Pea vs Flax - 30 N vs 90 N		0.0063	0.82	0.0004
Pea at 30 N vs Flax 90 N		0.0166	0.7	0.23
Pea at 0 N vs Flax at 30 N		0.0002	0.47	0.14
Pea at 0 N vs Flax at 90 N		0.19	0.67	0.0002
C.V. (%)		5.8	6.5	6.2

* Ammonium nitrate

** Controlled-release urea

Table M.2. Mixograph dough development time (min) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	5.50	3.11
Durum	50	4.39	3.03
Durum	78	3.68	2.57
Pea	34	3.55	2.57
Pea	50	3.53	2.57
Pea	78	3.37	2.72
LSD (P=0.05)		0.59	ns
Stubble			
Durum		4.52	2.90
Pea		3.49	2.62
LSD (P=0.05)		0.34	0.26
	N Applied (kg ha^{-1})		
	34	4.53	2.84
	50	3.96	2.80
	78	3.52	2.64
	LSD (P=0.05)	0.42	ns
ANOVA	df	Pr > F	
Stubble (S)	1	<0.0001	0.0362
N Applied (kg ha^{-1})	2	0.0009	0.4
N*S	2	0.0037	0.075
Contrasts			
Pea vs Durum at 34N		<0.0001	0.0235
Pea vs Durum at 50N		0.0082	0.0487
Pea vs Durum at 78N		0.28	0.49
34 N vs 50 N		0.0129	0.82
50 N vs 78 N		0.0431	0.3
34 N vs 78 N		0.0002	0.21
Pea vs Durum - 34 N vs 50 N		0.0161	0.78
Pea vs Durum - 50 N vs 78 N		0.18	0.063
Durum at 50 N vs Pea at 34 N		0.0096	0.046
Durum at 78 N vs Pea at 50 N		0.59	0.99
Durum at 78 N vs Pea at 34 N		0.65	0.99
C.V. (%)		8.4	9.2

Table M.3. Mixograph peak dough resistance (% torque) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	48.6	57.1	50.0
Flax	30 AN*	52.5	57.3	48.7
Flax	30 CRU**	49.5	57.9	48.4
Flax	90 AN	55.7	59.1	55.1
Flax	90 CRU	54.5	58.4	55.1
Pea	0	56.0	58.8	49.3
Pea	30 AN	57.7	60.2	52.3
Pea	30 CRU	58.1	59.3	52.3
Pea	90 AN	58.6	58.4	57.5
Pea	90 CRU	60.6	59.9	57.4
LSD (P=0.05)		3.7	ns	2.9
Stubble				
Flax		52.1	58.0	51.4
Pea		58.2	59.3	53.8
LSD (P=0.05)		1.2	ns	ns
	N Applied (kg ha^{-1})			
	0	52.3	57.9	49.7
	30 AN	55.1	58.7	50.5
	30 CRU	53.8	58.6	50.4
	90 AN	57.1	58.7	56.3
	90 CRU	57.5	59.2	56.2
	LSD (P=0.05)	1.9	ns	1.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0447	0.0888	0.12
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.67	<0.0001
N*S	4	0.0499	0.31	0.1
Contrasts				
Pea vs Flax at 0 N		0.0004	0.15	0.66
Pea vs Flax at 30 N		<0.0001	0.0149	0.0008
Pea vs Flax at 90 N		0.0017	0.65	0.025
AN vs CRU		0.48	0.8	0.83
AN vs CRU - 30 N vs 90 N		0.2	0.61	0.93
0 N vs 30 N		0.0119	0.34	0.31
30N vs 90 N		0.0002	0.59	<0.0001
Pea vs Flax - 0 N vs 30 N		0.76	0.77	0.0069
Pea vs Flax - 30 N vs 90 N		0.073	0.14	0.26
Pea at 30 N vs Flax 90 N		0.039	0.26	0.0113
Pea at 0 N vs Flax at 30 N		0.0038	0.23	0.52
Pea at 0 N vs Flax at 90 N		0.58	0.97	<0.0001
C.V. (%)		3.3	2.8	3.3

* Ammonium nitrate

** Controlled-release urea

Table M.4. Mixograph peak dough resistance (% torque) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	35.2	50.8
Durum	50	41.8	52.1
Durum	78	48.3	55.8
Pea	34	45.8	54.8
Pea	50	49.1	55.4
Pea	78	53.6	52.6
LSD (P=0.05)		5.2	3.5
Stubble			
Durum		41.8	52.9
Pea		49.5	54.3
LSD (P=0.05)		3.0	ns
	N Applied (kg ha^{-1})		
	34	40.5	52.8
	50	45.5	53.7
	78	50.9	54.2
	LSD (P=0.05)	3.7	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0001	0.17
N Applied (kg ha^{-1})	2	0.0002	0.47
N*S	2	0.3	0.0146
Contrasts			
Pea vs Durum at 34N		0.33	0.0286
Pea vs Durum at 50N		0.57	0.064
Pea vs Durum at 78N		0.12	0.0676
34 N vs 50 N		0.0121	0.44
50 N vs 78 N		0.0067	0.66
34 N vs 78 N		<0.0001	0.23
Pea vs Durum - 34 N vs 50 N		0.33	0.76
Pea vs Durum - 50 N vs 78 N		0.57	0.0143
Durum at 50 N vs Pea at 34 N		0.12	0.12
Durum at 78 N vs Pea at 50 N		0.76	0.77
Durum at 78 N vs Pea at 34 N		0.32	0.53
C.V. (%)		6.4	3.7

Table M.5. Mixograph work input to peak (% torque*min) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	142.4	150.8	140.0
Flax	30 AN*	146.2	154.5	134.6
Flax	30 CRU**	143.8	145.1	134.9
Flax	90 AN	140.4	149.3	115.5
Flax	90 CRU	134.0	152.0	123.4
Pea	0	131.1	145.3	129.5
Pea	30 AN	131.6	153.8	120.2
Pea	30 CRU	131.0	144.2	117.0
Pea	90 AN	132.9	142.0	121.9
Pea	90 CRU	135.2	148.9	118.0
LSD (P=0.05)		ns	ns	9.2
Stubble				
Flax		141.4	150.3	129.7
Pea		132.4	146.8	121.3
LSD (P=0.05)		ns	ns	4.3
	N Applied (kg ha^{-1})			
	0	136.8	148.0	134.8
	30 AN	138.9	154.1	127.4
	30 CRU	137.4	144.6	126.0
	90 AN	136.7	145.6	118.7
	90 CRU	134.6	150.5	120.7
	LSD (P=0.05)	ns	ns	6.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.0843	0.11	0.0016
N Applied (kg ha^{-1}) (N)	4	0.87	0.21	0.0005
N*S	4	0.3	0.92	0.0102
Contrasts				
Pea vs Flax at 0 N		0.0649	0.35	0.0273
Pea vs Flax at 30 N		0.0027	0.84	<0.0001
Pea vs Flax at 90 N		0.46	0.22	0.87
AN vs CRU		0.53	0.44	0.89
AN vs CRU - 30 N vs 90 N		0.93	0.0271	0.46
0 N vs 30 N		0.69	0.72	0.0086
30N vs 90 N		0.37	0.67	0.006
Pea vs Flax - 0 N vs 30 N		0.72	0.53	0.33
Pea vs Flax - 30 N vs 90 N		0.0683	0.48	0.0014
Pea at 30 N vs Flax 90 N		0.17	0.68	0.79
Pea at 0 N vs Flax at 30 N		0.0108	0.38	0.19
Pea at 0 N vs Flax at 90 N		0.24	0.3	0.0155
C.V. (%)		5.7	5.8	5.2

* Ammonium nitrate

** Controlled-release urea

Table M.6. Mixograph work inut to peak (% torque*min) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	154.9	118.7
Durum	50	145.4	116.4
Durum	78	133.6	108.2
Pea	34	124.7	104.1
Pea	50	127.1	104.8
Pea	78	133.4	106.6
LSD (P=0.05)		13.2	ns
Stubble			
Durum		144.7	114.4
Pea		128.4	105.2
LSD (P=0.05)		7.6	ns
	N Applied (kg ha^{-1})		
	34	139.8	111.4
	50	136.3	110.6
	78	133.5	107.4
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0005	0.0676
N Applied (kg ha^{-1})	2	0.37	0.76
N*S	2	0.0136	0.5
Contrasts			
Pea vs Durum at 34N		0.0003	0.0919
Pea vs Durum at 50N		0.0103	0.17
Pea vs Durum at 78N		0.94	0.85
34 N vs 50 N		0.43	0.89
50 N vs 78 N		0.53	0.58
34 N vs 78 N		0.17	0.49
Pea vs Durum - 34 N vs 50 N		0.19	0.8
Pea vs Durum - 50 N vs 78 N		0.0549	0.39
Durum at 50 N vs Pea at 34 N		0.0048	0.15
Durum at 78 N vs Pea at 50 N		0.3	0.68
Durum at 78 N vs Pea at 34 N		0.16	0.62
C.V. (%)		5.4	8.9

Table M.7. Mixograph peak band width (% torque) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	32.6	36.8	33.8
Flax	30 AN*	33.1	37.2	34.0
Flax	30 CRU**	32.2	35.2	32.7
Flax	90 AN	34.8	35.4	34.2
Flax	90 CRU	35.1	35.3	32.0
Pea	0	34.1	34.3	33.0
Pea	30 AN	34.4	35.9	33.5
Pea	30 CRU	35.3	36.9	34.2
Pea	90 AN	35.1	36.1	31.2
Pea	90 CRU	33.0	36.6	31.5
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		33.6	36.0	33.4
Pea		34.4	36.0	32.7
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	33.4	35.5	33.4
	30 AN	33.8	36.5	33.8
	30 CRU	33.7	36.1	33.4
	90 AN	35.0	35.8	32.7
	90 CRU	34.0	36.0	31.7
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.0756	1	0.33
N Applied (kg ha^{-1}) (N)	4	0.53	0.61	0.29
N*S	4	0.12	0.0108	0.29
Contrasts				
Pea vs Flax at 0 N		0.26	0.0205	0.56
Pea vs Flax at 30 N		0.0237	0.75	0.58
Pea vs Flax at 90 N		0.33	0.17	0.0805
AN vs CRU		0.47	0.77	0.35
AN vs CRU - 30 N vs 90 N		0.53	0.45	0.64
0 N vs 30 N		0.67	0.18	0.86
30N vs 90 N		0.27	0.36	0.0659
Pea vs Flax - 0 N vs 30 N		0.68	0.0227	0.44
Pea vs Flax - 30 N vs 90 N		0.031	0.4	0.11
Pea at 30 N vs Flax 90 N		0.89	0.15	0.46
Pea at 0 N vs Flax at 30 N		0.19	0.0391	0.81
Pea at 0 N vs Flax at 90 N		0.47	0.23	0.93
C.V. (%)		5.6	3.5	6.0

* Ammonium nitrate

** Controlled-release urea

Table M.8. Mixograph peak band width (% torque) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	20.7	25.7
Durum	50	24.6	25.6
Durum	78	28.5	26.5
Pea	34	25.5	24.6
Pea	50	26.7	25.6
Pea	78	30.4	24.6
LSD (P=0.05)		2.9	ns
Stubble			
Durum		24.6	25.9
Pea		27.6	25.0
LSD (P=0.05)		1.7	ns
	N Applied (kg ha^{-1})		
	34	23.1	25.1
	50	25.7	25.6
	78	29.4	25.6
	LSD (P=0.05)	2.0	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0018	0.19
N Applied (kg ha^{-1})	2	<0.0001	0.83
N*S	2	0.26	0.55
Contrasts			
Pea vs Durum at 34N		0.003	0.38
Pea vs Durum at 50N		0.12	0.98
Pea vs Durum at 78N		0.15	0.15
34 N vs 50 N		0.0171	0.59
50 N vs 78 N		0.0016	0.95
34 N vs 78 N		<0.0001	0.63
Pea vs Durum - 34 N vs 50 N		0.18	0.52
Pea vs Durum - 50 N vs 78 N		0.92	0.29
Durum at 50 N vs Pea at 34 N		0.48	0.42
Durum at 78 N vs Pea at 50 N		0.23	0.49
Durum at 78 N vs Pea at 34 N		0.0473	0.14
C.V. (%)		6.2	5.7

Table M.9. Mixograph dough breakdown resistance at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	5.3	5.4	5.0
Flax	30 AN*	5.6	4.8	4.7
Flax	30 CRU**	5.1	5.4	4.3
Flax	90 AN	5.7	5.4	5.0
Flax	90 CRU	5.6	5.5	6.8
Pea	0	6.3	5.8	5.0
Pea	30 AN	6.2	5.2	5.1
Pea	30 CRU	6.3	4.8	5.1
Pea	90 AN	6.4	4.9	7.5
Pea	90 CRU	7.5	5.1	7.8
LSD (P=0.05)		ns	ns	1.4
Stubble				
Flax		5.5	5.3	5.2
Pea		6.6	5.2	6.1
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	5.8	5.6	5.0
	30 AN	5.9	5.0	4.9
	30 CRU	5.7	5.1	4.7
	90 AN	6.1	5.1	6.3
	90 CRU	6.5	5.3	7.3
	LSD (P=0.05)	ns	ns	0.9
ANOVA	df		Pr>F	
Stubble (S)	1	0.0783	0.73	0.15
N Applied (kg ha^{-1}) (N)	4	0.44	0.39	<0.0001
N*S	4	0.63	0.45	0.0856
Contrasts				
Pea vs Flax at 0 N		0.13	0.43	0.97
Pea vs Flax at 30 N		0.0629	0.84	0.23
Pea vs Flax at 90 N		0.0091	0.25	0.0013
AN vs CRU		0.69	0.47	0.21
AN vs CRU - 30 N vs 90 N		0.32	0.91	0.0485
0 N vs 30 N		0.98	0.066	0.56
30N vs 90 N		0.14	0.42	<0.0001
Pea vs Flax - 0 N vs 30 N		0.87	0.43	0.46
Pea vs Flax - 30 N vs 90 N		0.52	0.48	0.0718
Pea at 30 N vs Flax 90 N		0.18	0.23	0.1
Pea at 0 N vs Flax at 30 N		0.1	0.1	0.38
Pea at 0 N vs Flax at 90 N		0.23	0.41	0.14
C.V. (%)		1.0	0.7	0.9

* Ammonium nitrate

** Controlled-release urea

[a] Breakdown resistance is calculated as (peak dough resistance 2 min after peak (%) divided by peak dough resistance (%))*100.

Table M.10. Mixograph dough breakdown resistance at the Swift Current-00 and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	3.1	7.6
Durum	50	3.6	8.8
Durum	78	5.5	9.9
Pea	34	4.4	10.1
Pea	50	5.1	10.2
Pea	78	7.2	9.0
LSD (P=0.05)		1.8	1.6
Stubble			
Durum		4.1	8.8
Pea		5.6	9.8
LSD (P=0.05)		1.1	0.9
	N Applied (kg ha^{-1})		
	34	3.8	8.8
	50	4.4	9.5
	78	6.3	9.5
	LSD (P=0.05)	1.3	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0094	0.0334
N Applied (kg ha^{-1})	2	0.0027	0.39
N*S	2	0.94	0.0205
Contrasts			
Pea vs Durum at 34N		0.15	0.0058
Pea vs Durum at 50N		0.1	0.0662
Pea vs Durum at 78N		0.0661	0.25
34 N vs 50 N		0.33	0.23
50 N vs 78 N		0.0066	0.97
34 N vs 78 N		0.001	0.25
Pea vs Durum - 34 N vs 50 N		0.85	0.37
Pea vs Durum - 50 N vs 78 N		0.88	0.0416
Durum at 50 N vs Pea at 34 N		0.37	0.1
Durum at 78 N vs Pea at 50 N		0.69	0.67
Durum at 78 N vs Pea at 34 N		0.23	0.84
C.V. (%)		1.1	1.0

[a] Breakdown resistance is calculated as (peak dough resistance 2 min after peak (%) divided by peak dough resistance (%))*100.

Table M.11. Mixograph dough strength index at the Carman-00, Carman-01, and Brandon-01 sites.[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	130	135	125
Flax	30 AN*	126	136	124
Flax	30 CRU**	125	120	119
Flax	90 AN	120	121	96
Flax	90 CRU	118	125	97
Pea	0	109	116	114
Pea	30 AN	107	127	104
Pea	30 CRU	109	124	101
Pea	90 AN	109	120	91
Pea	90 CRU	101	124	90
LSD (P=0.05)		13	12	11
Stubble				
Flax		124	127	112
Pea		107	122	100
LSD (P=0.05)		ns	ns	5
	N Applied (kg ha^{-1})			
	0	120	125	120
	30 AN	116	131	114
	30 CRU	117	122	110
	90 AN	115	120	93
	90 CRU	109	125	93
	LSD (P=0.05)	ns	ns	7
ANOVA	df		Pr>F	
Stubble (S)	1	0.057	0.046	0.0313
N Applied (kg ha^{-1}) (N)	4	0.1	0.16	<0.0001
N*S	4	0.79	0.0889	0.2
Contrasts				
Pea vs Flax at 0 N		0.0038	0.0026	0.0475
Pea vs Flax at 30 N		0.0006	0.55	<0.0001
Pea vs Flax at 90 N		0.0039	0.83	0.11
AN vs CRU		0.39	0.49	0.41
AN vs CRU - 30 N vs 90 N		0.24	0.0366	0.42
0 N vs 30 N		0.41	0.7	0.0191
30N vs 90 N		0.0705	0.2	<0.0001
Pea vs Flax - 0 N vs 30 N		0.68	0.0327	0.22
Pea vs Flax - 30 N vs 90 N		0.53	0.79	0.0196
Pea at 30 N vs Flax 90 N		0.0214	0.58	0.0924
Pea at 0 N vs Flax at 30 N		0.0069	0.0211	0.13
Pea at 0 N vs Flax at 90 N		0.0908	0.15	0.0005
C.V. (%)		6.3	6.8	6.6

* Ammonium nitrate

** Controlled-release urea

[a] Dough strength index equals dough development time*peak band width.

Table M.12. Mixograph dough strength index at the Swift Current-00, and Swift Current-01 sites.[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	113	80
Durum	50	107	77
Durum	78	105	68
Pea	34	91	63
Pea	50	94	66
Pea	78	103	67
LSD (P=0.05)		ns	ns
Stubble			
Durum		108	75
Pea		96	65
LSD (P=0.05)		10	7
	N Applied (kg ha^{-1})		
	34	102	71
	50	101	72
	78	104	68
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0166	0.0117
N Applied (kg ha^{-1})	2	0.88	0.53
N*S	2	0.22	0.18
Contrasts			
Pea vs Durum at 34N		0.0137	0.012
Pea vs Durum at 50N		0.12	0.0704
Pea vs Durum at 78N		0.79	0.84
34 N vs 50 N		0.84	0.97
50 N vs 78 N		0.62	0.33
34 N vs 78 N		0.77	0.35
Pea vs Durum - 34 N vs 50 N		0.4	0.5
Pea vs Durum - 50 N vs 78 N		0.34	0.23
Durum at 50 N vs Pea at 34 N		0.0548	0.0278
Durum at 78 N vs Pea at 50 N		0.21	0.72
Durum at 78 N vs Pea at 34 N		0.1	0.39
C.V. (%)		9.3	9.9

[a] Dough strength index equals dough development time*peak band width.

Table M.13. Mixograph dough development time (min) at the Carman-00, Carman-01, and Brandon-01 sites (with the addition of 2% salt).

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	5.62	4.80	5.10
Flax	30 AN*	5.42	5.03	4.87
Flax	30 CRU**	5.58	4.56	4.86
Flax	90 AN	5.01	4.57	3.91
Flax	90 CRU	4.60	4.84	3.80
Pea	0	4.36	4.08	5.17
Pea	30 AN	4.63	4.28	4.10
Pea	30 CRU	4.41	4.79	4.11
Pea	90 AN	4.44	4.42	3.74
Pea	90 CRU	4.51	4.59	3.53
LSD (P=0.05)		0.47	ns	0.46
Stubble				
Flax		5.25	4.76	4.51
Pea		4.47	4.43	4.13
LSD (P=0.05)		0.18	ns	0.21
	N Applied (kg ha^{-1})			
	0	4.99	4.44	5.13
	30 AN	5.02	4.65	4.49
	30 CRU	5.00	4.67	4.49
	90 AN	4.72	4.50	3.83
	90 CRU	4.55	4.72	3.66
	LSD (P=0.05)	0.28	ns	0.33
ANOVA	df		Pr>F	
Stubble (S)	1	0.0264	0.0681	0.0209
N Applied (kg ha^{-1}) (N)	4	0.0063	0.56	<0.0001
N*S	4	0.0015	0.1	0.0598
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.015	0.75
Pea vs Flax at 30 N		<0.0001	0.19	<0.0001
Pea vs Flax at 90 N		0.0544	0.32	0.18
AN vs CRU		0.32	0.4	0.47
AN vs CRU - 30 N vs 90 N		0.47	0.47	0.47
0 N vs 30 N		0.87	0.2	0.0001
30N vs 90 N		0.0008	0.69	<0.0001
Pea vs Flax - 0 N vs 30 N		0.24	0.19	0.0067
Pea vs Flax - 30 N vs 90 N		0.0024	0.82	0.0266
Pea at 30 N vs Flax 90 N		0.0928	0.39	0.12
Pea at 0 N vs Flax at 30 N		<0.0001	0.0059	0.13
Pea at 0 N vs Flax at 90 N		0.0332	0.0144	<0.0001
C.V. (%)		5.6	8.6	7.5

* Ammonium nitrate

** Controlled-release urea

Table M.14. Mixograph dough development time (min) at the Swift Current-00 and Swift Current-01 sites (with the addition of 2% salt).

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	6.81	3.96
Durum	50	6.09	3.79
Durum	78	5.89	3.53
Pea	34	5.15	3.50
Pea	50	5.12	3.61
Pea	78	4.67	3.70
LSD (P=0.05)		ns	ns
Stubble			
Durum		6.20	3.76
Pea		4.98	3.60
LSD (P=0.05)		0.85	ns
	N Applied (kg ha^{-1})		
	34	5.82	3.73
	50	5.61	3.70
	78	5.28	3.61
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0094	0.21
N Applied (kg ha^{-1})	2	0.42	0.72
N*S	2	0.78	0.14
Contrasts			
Pea vs Durum at 34N		0.0436	0.0457
Pea vs Durum at 50N		0.17	0.39
Pea vs Durum at 78N		0.0858	0.44
34 N vs 50 N		0.46	0.83
50 N vs 78 N		0.49	0.57
34 N vs 78 N		0.18	0.44
Pea vs Durum - 34 N vs 50 N		0.49	0.36
Pea vs Durum - 50 N vs 78 N		0.78	0.25
Durum at 50 N vs Pea at 34 N		0.18	0.19
Durum at 78 N vs Pea at 50 N		0.26	0.72
Durum at 78 N vs Pea at 34 N		0.28	0.89
C.V. (%)		14.3	6.9

Table M.15. Mixograph work input to peak (% torque*min) at the Carman-00, Carman-01, and Brandon-01 sites (with the addition of 2% salt).

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	210.1	190.7	187.7
Flax	30 AN*	215.0	204.2	169.4
Flax	30 CRU**	214.1	189.9	169.7
Flax	90 AN	217.2	192.0	160.7
Flax	90 CRU	203.4	203.8	161.2
Pea	0	191.5	177.5	192.2
Pea	30 AN	204.6	179.6	161.7
Pea	30 CRU	196.3	197.5	160.8
Pea	90 AN	203.7	182.7	162.4
Pea	90 CRU	210.6	191.4	155.4
LSD (P=0.05)		ns	ns	20.3
Stubble				
Flax		212.0	196.1	169.8
Pea		201.3	185.7	166.5
LSD (P=0.05)		9.5	ns	ns
	N Applied (kg ha^{-1})			
	0	200.8	184.1	189.9
	30 AN	209.8	191.9	165.5
	30 CRU	205.2	193.7	165.2
	90 AN	210.5	187.4	161.5
	90 CRU	207.0	197.6	158.3
	LSD (P=0.05)	ns	ns	13.9
ANOVA	df		Pr>F	
Stubble (S)	1	0.0468	0.24	0.59
N Applied (kg ha^{-1}) (N)	4	0.68	0.63	0.0007
N*S	4	0.41	0.55	0.81
Contrasts				
Pea vs Flax at 0 N		0.073	0.34	0.65
Pea vs Flax at 30 N		0.056	0.38	0.24
Pea vs Flax at 90 N		0.65	0.26	0.77
AN vs CRU		0.44	0.37	0.72
AN vs CRU - 30 N vs 90 N		0.91	0.53	0.76
0 N vs 30 N		0.3	0.29	0.0003
30N vs 90 N		0.82	0.96	0.26
Pea vs Flax - 0 N vs 30 N		0.72	0.77	0.28
Pea vs Flax - 30 N vs 90 N		0.3	0.85	0.52
Pea at 30 N vs Flax 90 N		0.17	0.33	0.97
Pea at 0 N vs Flax at 30 N		0.0128	0.1	0.0136
Pea at 0 N vs Flax at 90 N		0.0384	0.09	0.0011
C.V. (%)		7.0	9.7	8.0

* Ammonium nitrate

** Controlled-release urea

Table M.16. Mixograph work inut to peak (% torque*min) at the Swift Current-00 and Swift Current-01 sites (with the addition of 2% salt).

Treatment		Year	
Stubble	N Applied ($kg\ ha^{-1}$)	2000	2001
Durum	34	213.6	150.9
Durum	50	208.2	152.0
Durum	78	226.2	156.4
Pea	34	189.1	152.2
Pea	50	198.6	167.7
Pea	78	200.3	163.7
LSD (P=0.05)		ns	ns
Stubble			
Durum		216.3	153.1
Pea		196.0	161.2
LSD (P=0.05)		ns	ns
	N Applied ($kg\ ha^{-1}$)		
	34	198.9	151.5
	50	203.4	159.9
	78	213.3	160.1
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.12	0.14
N Applied ($kg\ ha^{-1}$)	2	0.68	0.33
N*S	2	0.83	0.53
Contrasts			
Pea vs Durum at 34N		0.3	0.89
Pea vs Durum at 50N		0.64	0.1
Pea vs Durum at 78N		0.23	0.43
34 N vs 50 N		0.89	0.21
50 N vs 78 N		0.5	0.97
34 N vs 78 N		0.45	0.2
Pea vs Durum - 34 N vs 50 N		0.64	0.27
Pea vs Durum - 50 N vs 78 N		0.58	0.51
Durum at 50 N vs Pea at 34 N		0.37	0.99
Durum at 78 N vs Pea at 50 N		0.2	0.23
Durum at 78 N vs Pea at 34 N		0.0943	0.64
C.V. (%)		12.1	6.9

Table M.17. Mixograph peak dough resistance (% torque) at the Carman-00, Carman-01, and Brandon-01 sites (with the addition of 2% salt).

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	54.7	58.3	52.4
Flax	30 AN*	57.3	59.1	50.6
Flax	30 CRU**	56.3	61.0	50.8
Flax	90 AN	61.5	60.4	57.1
Flax	90 CRU	63.0	60.6	60.7
Pea	0	63.5	61.1	53.7
Pea	30 AN	62.8	60.7	55.6
Pea	30 CRU	64.1	60.0	55.2
Pea	90 AN	65.0	61.1	62.0
Pea	90 CRU	66.2	60.9	60.7
LSD (P=0.05)		2.9	ns	4.1
Stubble				
Flax		58.6	59.9	54.3
Pea		64.3	60.7	57.4
LSD (P=0.05)		0.8	ns	ns
	N Applied (kg ha^{-1})			
	0	59.1	59.7	53.0
	30 AN	60.1	59.9	53.1
	30 CRU	60.2	60.5	53.0
	90 AN	63.2	60.7	59.5
	90 CRU	64.6	60.7	60.7
	LSD (P=0.05)	1.3	ns	2.2
ANOVA	df		Pr>F	
Stubble (S)	1	0.0348	0.45	0.19
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.74	<0.0001
N*S	4	0.0004	0.41	0.0826
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.0797	0.51
Pea vs Flax at 30 N		<0.0001	0.81	0.0023
Pea vs Flax at 90 N		0.003	0.63	0.0945
AN vs CRU		0.1	0.65	0.47
AN vs CRU - 30 N vs 90 N		0.19	0.66	0.4
0 N vs 30 N		0.0737	0.58	0.98
30N vs 90 N		<0.0001	0.43	<0.0001
Pea vs Flax - 0 N vs 30 N		0.0644	0.16	0.0786
Pea vs Flax - 30 N vs 90 N		<0.0001	0.96	0.14
Pea at 30 N vs Flax 90 N		0.25	0.87	0.0197
Pea at 0 N vs Flax at 30 N		<0.0001	0.44	0.0917
Pea at 0 N vs Flax at 90 N		0.33	0.65	0.0054
C.V. (%)		2.1	3.3	3.8

* Ammonium nitrate

** Controlled-release urea

Table M.18. Mixograph peak dough resistance (% torque) at the Swift Current-00 and Swift Current-01 sites (with the addition of 2% salt).

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	43.1	53.7
Durum	50	48.9	56.3
Durum	78	55.4	62.9
Pea	34	52.3	62.9
Pea	50	55.6	64.9
Pea	78	60.8	61.4
LSD (P=0.05)		5.4	5.5
Stubble			
Durum		49.9	57.6
Pea		56.2	63.0
LSD (P=0.05)		3.2	3.2
	N Applied (kg ha^{-1})		
	34	48.6	58.3
	50	52.3	60.6
	78	58.1	62.2
	LSD (P=0.05)	5.8	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0012	0.0031
N Applied (kg ha^{-1})	2	0.0006	0.14
N*S	2	0.6	0.0196
Contrasts			
Pea vs Durum at 34N		0.0065	0.0036
Pea vs Durum at 50N		0.0193	0.0056
Pea vs Durum at 78N		0.0493	0.57
34 N vs 50 N		0.0308	0.23
50 N vs 78 N		0.0065	0.4
34 N vs 78 N		0.0002	0.0526
Pea vs Durum - 34 N vs 50 N		0.52	0.87
Pea vs Durum - 50 N vs 78 N		0.72	0.0161
Durum at 50 N vs Pea at 34 N		0.19	0.024
Durum at 78 N vs Pea at 50 N		0.92	0.45
Durum at 78 N vs Pea at 34 N		0.24	0.99
C.V. (%)		5.7	5.2

Table M.19. Mixograph peak band width (% torque) at the Carman-00, Carman-01, and Brandon-01 sites (with the addition of 2% salt).

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	42.7	39.7	39.0
Flax	30 AN*	40.0	38.8	41.7
Flax	30 CRU**	40.0	39.9	44.2
Flax	90 AN	38.6	41.4	41.8
Flax	90 CRU	38.7	39.4	42.1
Pea	0	40.5	38.8	39.9
Pea	30 AN	40.1	39.4	42.2
Pea	30 CRU	39.2	40.2	44.1
Pea	90 AN	39.0	40.6	38.4
Pea	90 CRU	37.2	39.3	37.9
LSD (P=0.05)		ns	ns	3.9
Stubble				
Flax		40.0	39.9	41.8
Pea		39.2	39.7	40.5
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	41.6	39.3	39.4
	30 AN	40.1	39.1	41.9
	30 CRU	39.6	40.1	44.1
	90 AN	38.8	41.0	40.1
	90 CRU	37.9	39.3	40.0
	LSD (P=0.05)	2.1	ns	2.8
ANOVA	df		Pr>F	
Stubble (S)	1	0.34	0.82	0.2
N Applied (kg ha^{-1}) (N)	4	0.0228	0.48	0.0125
N*S	4	0.69	0.96	0.24
Contrasts				
Pea vs Flax at 0 N		0.15	0.6	0.64
Pea vs Flax at 30 N		0.72	0.73	0.92
Pea vs Flax at 90 N		0.59	0.69	0.0089
AN vs CRU		0.37	0.69	0.29
AN vs CRU - 30 N vs 90 N		0.79	0.12	0.24
0 N vs 30 N		0.064	0.77	0.0055
30N vs 90 N		0.0604	0.49	0.0049
Pea vs Flax - 0 N vs 30 N		0.32	0.53	0.75
Pea vs Flax - 30 N vs 90 N		0.9	0.59	0.0519
Pea at 30 N vs Flax 90 N		0.36	0.61	0.4
Pea at 0 N vs Flax at 30 N		0.72	0.71	0.0727
Pea at 0 N vs Flax at 90 N		0.17	0.29	0.22
C.V. (%)		5.3	5.9	6.7

* Ammonium nitrate

** Controlled-release urea

Table M.20. Mixograph peak band width (% torque) at the Swift Current-00 and Swift Current-01 sites (with the addition of 2% salt).

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	32.0	35.4
Durum	50	35.6	37.6
Durum	78	40.1	35.8
Pea	34	38.3	34.2
Pea	50	39.1	35.7
Pea	78	39.6	36.8
LSD (P=0.05)		4.5	ns
Stubble			
Durum		36.4	36.3
Pea		39.0	35.6
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	35.7	34.8
	50	37.3	36.7
	78	39.8	36.3
	LSD (P=0.05)	4.1	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0525	0.49
N Applied (kg ha^{-1})	2	0.042	0.29
N*S	2	0.12	0.45
Contrasts			
Pea vs Durum at 34N		0.0175	0.48
Pea vs Durum at 50N		0.11	0.28
Pea vs Durum at 78N		0.81	0.54
34 N vs 50 N		0.17	0.14
50 N vs 78 N		0.11	0.76
34 N vs 78 N		0.0101	0.23
Pea vs Durum - 34 N vs 50 N		0.37	0.79
Pea vs Durum - 50 N vs 78 N		0.19	0.24
Durum at 50 N vs Pea at 34 N		0.21	0.0635
Durum at 78 N vs Pea at 50 N		0.63	0.98
Durum at 78 N vs Pea at 34 N		0.39	0.37
C.V. (%)		6.6	5.6

Table M.21. Mixograph dough breakdown resistance at the Carman-00, Carman-01, and Brandon-01 sites (with the addition of 2% salt).[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	3.6	4.2	5.4
Flax	30 AN*	3.9	4.3	3.4
Flax	30 CRU**	4.1	4.5	3.3
Flax	90 AN	4.3	4.0	6.3
Flax	90 CRU	4.3	4.8	4.3
Pea	0	3.8	4.4	5.3
Pea	30 AN	3.7	4.8	3.3
Pea	30 CRU	3.5	4.0	4.5
Pea	90 AN	3.9	4.0	4.6
Pea	90 CRU	4.6	4.2	5.0
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		4.0	4.4	4.5
Pea		3.9	4.3	4.5
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	3.7	4.3	5.3
	30 AN	3.8	4.5	3.3
	30 CRU	3.8	4.3	3.9
	90 AN	4.1	4.0	5.4
	90 CRU	4.4	4.5	4.6
	LSD (P=0.05)	ns	ns	1.4
ANOVA	df		Pr>F	
Stubble (S)	1	0.82	0.74	0.98
N Applied (kg ha^{-1}) (N)	4	0.56	0.92	0.0172
N*S	4	0.86	0.88	0.25
Contrasts				
Pea vs Flax at 0 N		0.74	0.82	0.9
Pea vs Flax at 30 N		0.45	0.95	0.45
Pea vs Flax at 90 N		0.98	0.58	0.47
AN vs CRU		0.63	0.81	0.78
AN vs CRU - 30 N vs 90 N		0.64	0.4	0.16
0 N vs 30 N		0.86	0.79	0.0066
30N vs 90 N		0.18	0.73	0.0064
Pea vs Flax - 0 N vs 30 N		0.45	0.83	0.57
Pea vs Flax - 30 N vs 90 N		0.58	0.73	0.27
Pea at 30 N vs Flax 90 N		0.2	0.96	0.0604
Pea at 0 N vs Flax at 30 N		0.81	0.93	0.0356
Pea at 0 N vs Flax at 90 N		0.5	0.94	0.99
C.V. (%)		1.0	1.3	1.4

* Ammonium nitrate

** Controlled-release urea

[a] Breakdown resistance is calculated as (peak dough resistance 2 min after peak (%) divided by peak dough resistance (%))*100.

Table M.22. Mixograph dough breakdown resistance at the Swift Current-00 and Swift Current-01 sites (with the addition of 2% salt).[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	n.d.*	5.5
Durum	50	n.d.	5.0
Durum	78	n.d.	5.3
Pea	34	n.d.	5.3
Pea	50	n.d.	5.3
Pea	78	n.d.	5.5
LSD (P=0.05)			ns
Stubble			
Durum		n.d.	5.3
Pea		n.d.	5.3
LSD (P=0.05)			ns
N Applied (kg ha^{-1})			
	34	n.d.	5.4
	50	n.d.	5.1
	78	n.d.	5.4
	LSD (P=0.05)		ns
ANOVA	df	Pr > F	
Stubble (S)	1	n.d.	0.86
N Applied (kg ha^{-1})	2	n.d.	0.85
N*S	2	n.d.	0.85
Contrasts			
Pea vs Durum at 34N		n.d.	0.74
Pea vs Durum at 50N		n.d.	0.65
Pea vs Durum at 78N		n.d.	0.86
34 N vs 50 N		n.d.	0.66
50 N vs 78 N		n.d.	0.6
34 N vs 78 N		n.d.	0.94
Pea vs Durum - 34 N vs 50 N		n.d.	0.58
Pea vs Durum - 50 N vs 78 N		n.d.	0.84
Durum at 50 N vs Pea at 34 N		n.d.	0.7
Durum at 78 N vs Pea at 50 N		n.d.	0.96
Durum at 78 N vs Pea at 34 N		n.d.	0.9
C.V. (%)		n.d.	0.9

[a] Breakdown resistance is calculated as (peak dough resistance 2 min after peak (%) divided by peak dough resistance (%))*100.

* No data.

Table M.23. Dough strength index at the Carman-00, Carman-01, and Brandon-01 sites. (with the addition of 2% salt).[a]

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	240	190	199
Flax	30 AN*	217	194	203
Flax	30 CRU**	223	182	214
Flax	90 AN	193	189	163
Flax	90 CRU	178	191	160
Pea	0	176	158	206
Pea	30 AN	186	168	173
Pea	30 CRU	173	193	181
Pea	90 AN	173	180	143
Pea	90 CRU	168	180	133
LSD (P=0.05)		24	ns	20
Stubble				
Flax		210	189	188
Pea		175	176	167
LSD (P=0.05)		9	ns	10
	N Applied (kg ha^{-1})			
	0	208	174	202
	30 AN	201	181	188
	30 CRU	198	187	198
	90 AN	183	185	153
	90 CRU	173	185	147
	LSD (P=0.05)	14	ns	15
ANOVA	df		Pr>F	
Stubble (S)	1	0.0402	0.0743	0.0049
N Applied (kg ha^{-1}) (N)	4	0.0001	0.7	<0.0001
N*S	4	0.0037	0.24	0.0662
Contrasts				
Pea vs Flax at 0 N		<0.0001	0.0242	0.47
Pea vs Flax at 30 N		<0.0001	0.43	0.0001
Pea vs Flax at 90 N		0.0802	0.29	0.0025
AN vs CRU		0.17	0.63	0.71
AN vs CRU - 30 N vs 90 N		0.5	0.71	0.13
0 N vs 30 N		0.17	0.25	0.15
30N vs 90 N		0.0001	0.93	<0.0001
Pea vs Flax - 0 N vs 30 N		0.0662	0.16	0.0049
Pea vs Flax - 30 N vs 90 N		0.0124	0.85	0.42
Pea at 30 N vs Flax 90 N		0.45	0.32	0.0398
Pea at 0 N vs Flax at 30 N		0.0002	0.0162	0.74
Pea at 0 N vs Flax at 90 N		0.37	0.011	<0.0001
C.V. (%)		7.0	10.6	8.2

* Ammonium nitrate

** Controlled-release urea

[a] Dough strength index equals dough development time*peak band width.

Table M.24. Dough strength index at the Swift Current-00, and Swift Current-01 sites (with the addition of 2% salt).[a]

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	217	140
Durum	50	212	142
Durum	78	237	126
Pea	34	197	120
Pea	50	200	129
Pea	78	185	137
LSD (P=0.05)		ns	ns
Stubble			
Durum		223	136
Pea		194	129
LSD (P=0.05)		28	ns
	N Applied (kg ha^{-1})		
	34	205	130
	50	206	136
	78	211	132
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0441	0.27
N Applied (kg ha^{-1})	2	0.96	0.8
N*S	2	0.42	0.18
Contrasts			
Pea vs Durum at 34N		0.42	0.1
Pea vs Durum at 50N		0.57	0.27
Pea vs Durum at 78N		0.0328	0.38
34 N vs 50 N		0.95	0.52
50 N vs 78 N		0.77	0.64
34 N vs 78 N		0.83	0.85
Pea vs Durum - 34 N vs 50 N		0.82	0.67
Pea vs Durum - 50 N vs 78 N		0.22	0.17
Durum at 50 N vs Pea at 34 N		0.49	0.0777
Durum at 78 N vs Pea at 50 N		0.11	0.83
Durum at 78 N vs Pea at 34 N		0.0909	0.59
C.V. (%)		12.6	10.8

[a] Dough strength index equals dough development time*peak band width.

8.14. APPENDIX N – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON MICRO-EXTENSION TEST ANALYSES AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table N.1. Maximum dough resistance to extension (Rmax) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---Rmax (g)---		
Flax	0	33.1	36.0	34.6
Flax	30 AN*	34.4	36.0	35.3
Flax	30 CRU**	31.4	35.1	33.6
Flax	90 AN	37.0	35.8	31.0
Flax	90 CRU	33.6	36.7	29.1
Pea	0	32.2	36.7	34.9
Pea	30 AN	34.1	36.6	32.5
Pea	30 CRU	34.7	36.6	34.1
Pea	90 AN	36.8	37.0	29.3
Pea	90 CRU	35.0	37.7	33.4
LSD (P=0.05)		ns	ns	3.1
Stubble				
Flax		33.9	35.9	32.7
Pea		34.6	36.9	32.8
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	32.7	36.3	34.7
	30 AN	34.3	36.3	33.9
	30 CRU	33.0	35.9	33.9
	90 AN	36.9	36.4	30.1
	90 CRU	34.3	37.2	31.3
	LSD (P=0.05)	2.7	ns	2.0
ANOVA	df		Pr>F	
Stubble (S)	1	0.035	0.16	0.91
N Applied (kg ha^{-1}) (N)	4	0.0307	0.8	0.0002
N*S	4	0.53	0.99	0.0096
Contrasts				
Pea vs Flax at 0 N		0.62	0.64	0.83
Pea vs Flax at 30 N		0.24	0.3	0.28
Pea vs Flax at 90 N		0.67	0.28	0.22
AN vs CRU		0.0508	0.81	0.43
AN vs CRU - 30 N vs 90 N		0.46	0.41	0.41
0 N vs 30 N		0.41	0.78	0.31
30N vs 90 N		0.0445	0.35	<0.0001
Pea vs Flax - 0 N vs 30 N		0.31	0.83	0.37
Pea vs Flax - 30 N vs 90 N		0.62	0.98	0.0755
Pea at 30 N vs Flax 90 N		0.45	0.7	0.0045
Pea at 0 N vs Flax at 30 N		0.67	0.4	0.74
Pea at 0 N vs Flax at 90 N		0.0514	0.72	0.0008
C.V. (%)		7.7	5.8	5.8

* Ammonium nitrate

** Controlled-release urea

Table N.2. Maximum dough resistance to extension (Rmax) at the Swift Current-00 and Swift Current-01 sites.

Treatment			Year	
Stubble	N Applied ($kg\ ha^{-1}$)		2000	2001
			----------Rmax (g)----------	
Durum	34		28.7	25.3
Durum	50		29.1	26.7
Durum	78		29.8	26.6
Pea	34		29.3	23.4
Pea	50		27.8	25.7
Pea	78		28.2	24.3
LSD (P=0.05)			ns	ns
Stubble				
Durum			29.3	26.2
Pea			28.4	24.5
LSD (P=0.05)			ns	ns
	N Applied ($kg\ ha^{-1}$)			
	34		29.1	24.3
	50		28.5	26.2
	78		29.0	25.5
	LSD (P=0.05)		ns	ns
ANOVA		df	Pr > F	
Stubble (S)		1	0.57	0.22
N Applied ($kg\ ha^{-1}$)		2	0.93	0.54
N*S		2	0.8	0.91
Contrasts				
Pea vs Durum at 34N			0.83	0.43
Pea vs Durum at 50N			0.57	0.69
Pea vs Durum at 78N			0.49	0.33
34 N vs 50 N			0.75	0.28
50 N vs 78 N			0.75	0.65
34 N vs 78 N			0.99	0.51
Pea vs Durum - 34 N vs 50 N			0.59	0.78
Pea vs Durum - 50 N vs 78 N			0.93	0.68
Durum at 50 N vs Pea at 34 N			0.94	0.18
Durum at 78 N vs Pea at 50 N			0.4	0.71
Durum at 78 N vs Pea at 34 N			0.83	0.19
C.V. (%)			9.3	11.3

Table N.3. Dough extensibility at Rmax (E_{Rmax}) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		-----------Extensibility at Rmax (mm)-----------		
Flax	0	76.8	91.9	75.8
Flax	30 AN*	83.3	90.5	77.3
Flax	30 CRU**	81.5	87.5	77.7
Flax	90 AN	87.9	89.3	85.8
Flax	90 CRU	91.9	94.4	91.7
Pea	0	92.6	89.0	77.9
Pea	30 AN	92.9	91.0	85.3
Pea	30 CRU	93.9	88.6	77.6
Pea	90 AN	92.1	92.3	89.9
Pea	90 CRU	98.0	89.7	89.4
LSD (P=0.05)		9.8	ns	2.2
Stubble				
Flax		84.3	90.7	81.6
Pea		93.9	90.1	84.0
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	84.7	90.4	76.8
	30 AN	88.1	90.7	81.3
	30 CRU	87.7	88.0	77.7
	90 AN	90.0	90.8	87.9
	90 CRU	95.0	92.0	90.6
	LSD (P=0.05)	5.9	ns	1.5
ANOVA	df		Pr>F	
Stubble (S)	1	0.0874	0.56	0.27
N Applied (kg ha^{-1}) (N)	4	0.0212	0.2	<0.0001
N*S	4	0.28	0.16	0.21
Contrasts				
Pea vs Flax at 0 N		0.0025	0.21	0.55
Pea vs Flax at 30 N		0.003	0.63	0.0925
Pea vs Flax at 90 N		0.14	0.58	0.71
AN vs CRU		0.27	0.53	0.75
AN vs CRU - 30 N vs 90 N		0.19	0.1	0.0547
0 N vs 30 N		0.21	0.44	0.17
30N vs 90 N		0.0323	0.0899	<0.0001
Pea vs Flax - 0 N vs 30 N		0.34	0.2	0.6
Pea vs Flax - 30 N vs 90 N		0.16	0.47	0.33
Pea at 30 N vs Flax 90 N		0.31	0.21	0.0036
Pea at 0 N vs Flax at 30 N		0.0193	0.99	0.93
Pea at 0 N vs Flax at 90 N		0.51	0.16	0.0005
C.V. (%)		6.4	3.6	5.4

* Ammonium nitrate

** Controlled-release urea

Table N.4. Dough extensibility at Rmax (E_{Rmax}) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
		Extensibility at Rmax (mm)	
Durum	34	63.8	89.6
Durum	50	78.6	88.6
Durum	78	79.9	97.8
Pea	34	82.1	100.2
Pea	50	87.0	99.7
Pea	78	96.5	94.2
LSD (P=0.05)		3.2	ns
Stubble			
Durum		75.4	92.0
Pea		88.5	98.0
LSD (P=0.05)		8.5	ns
N Applied (kg ha^{-1})			
	34	74.8	94.9
	50	82.8	94.2
	78	88.2	96.0
	LSD (P=0.05)	2.6	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0002	0.0596
N Applied (kg ha^{-1})	2	0.0021	0.88
N*S	2	0.27	0.11
Contrasts			
Pea vs Durum at 34N		0.0029	0.0583
Pea vs Durum at 50N		0.0783	0.0466
Pea vs Durum at 78N		0.0026	0.49
34 N vs 50 N		0.0112	0.85
50 N vs 78 N		0.0989	0.62
34 N vs 78 N		0.0006	0.76
Pea vs Durum - 34 N vs 50 N		0.15	0.93
Pea vs Durum - 50 N vs 78 N		0.2	0.061
Durum at 50 N vs Pea at 34 N		0.43	0.0409
Durum at 78 N vs Pea at 50 N		0.13	0.7
Durum at 78 N vs Pea at 34 N		0.62	0.65
C.V. (%)		6.4	6.5

Table N.5. Extensigram area at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		--------------Extensigram Area --------------		
Flax	0	517	626	540
Flax	30 AN*	570	624	547
Flax	30 CRU**	514	585	523
Flax	90 AN	637	610	520
Flax	90 CRU	594	654	513
Pea	0	579	633	539
Pea	30 AN	610	628	545
Pea	30 CRU	634	627	538
Pea	90 AN	651	648	506
Pea	90 CRU	646	645	581
LSD (P=0.05)		67	ns	ns
Stubble				
Flax		567	620	528
Pea		624	636	542
LSD (P=0.05)		30	ns	ns
	N Applied (kg ha^{-1})			
	0	548	630	539
	30 AN	590	626	546
	30 CRU	574	606	531
	90 AN	644	629	513
	90 CRU	620	650	547
	LSD (P=0.05)	48	ns	ns
ANOVA	df		Pr > F	
Stubble (S)	1	0.0275	0.0618	0.41
N Applied (kg ha^{-1}) (N)	4	0.0036	0.24	0.32
N*S	4	0.26	0.53	0.2
Contrasts				
Pea vs Flax at 0 N		0.069	0.79	1
Pea vs Flax at 30 N		0.002	0.19	0.72
Pea vs Flax at 90 N		0.17	0.42	0.15
AN vs CRU		0.24	0.96	0.45
AN vs CRU - 30 N vs 90 N		0.82	0.12	0.0608
0 N vs 30 N		0.11	0.39	0.93
30N vs 90 N		0.0057	0.0848	0.53
Pea vs Flax - 0 N vs 30 N		0.68	0.6	0.83
Pea vs Flax - 30 N vs 90 N		0.17	0.73	0.42
Pea at 30 N vs Flax 90 N		0.8	0.81	0.19
Pea at 0 N vs Flax at 30 N		0.2	0.19	0.84
Pea at 0 N vs Flax at 90 N		0.21	0.96	0.32
C.V. (%)		7.8	5.7	6.7

* Ammonium nitrate

** Controlled-release urea

Table N.6. Extensigram area at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
		----Extensigram Area----	
Durum	34	397	450
Durum	50	472	474
Durum	78	475	509
Pea	34	484	465
Pea	50	472	510
Pea	78	517	456
LSD (P=0.05)		ns	ns
Stubble			
Durum		454	478
Pea		491	477
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	450	458
	50	472	492
	78	496	482
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.15	0.98
N Applied (kg ha^{-1})	2	0.32	0.54
N*S	2	0.48	0.36
Contrasts			
Pea vs Durum at 34N		0.12	0.74
Pea vs Durum at 50N		0.97	0.43
Pea vs Durum at 78N		0.38	0.26
34 N vs 50 N		0.38	0.29
50 N vs 78 N		0.48	0.76
34 N vs 78 N		0.14	0.45
Pea vs Durum - 34 N vs 50 N		0.23	0.74
Pea vs Durum - 50 N vs 78 N		0.53	0.18
Durum at 50 N vs Pea at 34 N		0.79	0.84
Durum at 78 N vs Pea at 50 N		0.96	0.97
Durum at 78 N vs Pea at 34 N		0.84	0.34
C.V. (%)		11.9	11.4

Table N.7. Dough extensibility at point of dough rupture (E) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
		---------------Extensibility (mm)---------------		
Flax	0	83.3	100.2	83.2
Flax	30 AN*	90.4	99.0	85.4
Flax	30 CRU**	88.5	93.7	84.5
Flax	90 AN	94.0	97.1	93.5
Flax	90 CRU	99.4	102.2	101.1
Pea	0	99.0	95.8	84.0
Pea	30 AN	99.1	97.9	92.7
Pea	30 CRU	100.4	97.3	84.3
Pea	90 AN	97.7	102.9	98.1
Pea	90 CRU	103.9	96.7	98.4
LSD (P=0.05)		10.5	ns	7.4
Stubble				
Flax		91.1	98.4	89.5
Pea		100.0	98.1	91.5
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	91.1	98.0	83.6
	30 AN	94.7	98.4	89.1
	30 CRU	94.4	95.5	84.4
	90 AN	95.9	100.0	95.8
	90 CRU	101.7	99.4	99.7
	LSD (P=0.05)	6.3	ns	5.2
ANOVA	df		Pr>F	
Stubble (S)	1	0.12	0.82	0.33
N Applied (kg ha^{-1}) (N)	4	0.0308	0.22	<0.0001
N*S	4	0.28	0.0328	0.33
Contrasts				
Pea vs Flax at 0 N		0.0049	0.12	0.82
Pea vs Flax at 30 N		0.0085	0.53	0.17
Pea vs Flax at 90 N		0.26	0.94	0.73
AN vs CRU		0.21	0.22	0.83
AN vs CRU - 30 N vs 90 N		0.16	0.4	0.0244
0 N vs 30 N		0.2	0.55	0.17
30N vs 90 N		0.0647	0.0625	<0.0001
Pea vs Flax - 0 N vs 30 N		0.31	0.11	0.54
Pea vs Flax - 30 N vs 90 N		0.17	0.7	0.47
Pea at 30 N vs Flax 90 N		0.41	0.32	0.0018
Pea at 0 N vs Flax at 30 N		0.0412	0.82	0.76
Pea at 0 N vs Flax at 90 N		0.61	0.13	0.0002
C.V. (%)		6.4	4.0	5.6

* Ammonium nitrate

** Controlled-release urea

Table N.8. Dough extensibility at point of dough rupture (E) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
		----Extensibility (mm)----	
Durum	34	73.9	97.6
Durum	50	88.3	96.3
Durum	78	86.5	106.0
Pea	34	89.8	107.7
Pea	50	95.6	108.9
Pea	78	103.1	103.0
LSD (P=0.05)		12.6	ns
Stubble			
Durum		84.0	100.0
Pea		96.2	106.5
LSD (P=0.05)		8.5	ns
	N Applied (kg ha^{-1})		
	34	83.4	102.7
	50	91.9	102.6
	78	94.8	104.5
	LSD (P=0.05)	8.5	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0009	0.0519
N Applied (kg ha^{-1})	2	0.0128	0.85
N*S	2	0.38	0.12
Contrasts			
Pea vs Durum at 34N		0.0148	0.0788
Pea vs Durum at 50N		0.1634	0.0337
Pea vs Durum at 78N		0.0061	0.57
34 N vs 50 N		0.0193	0.99
50 N vs 78 N		0.42	0.62
34 N vs 78 N		0.0048	0.63
Pea vs Durum - 34 N vs 50 N		0.27	0.74
Pea vs Durum - 50 N vs 78 N		0.21	0.0571
Durum at 50 N vs Pea at 34 N		0.77	0.0512
Durum at 78 N vs Pea at 50 N		0.0917	0.59
Durum at 78 N vs Pea at 34 N		0.52	0.76
C.V. (%)		6.6	6.2

Table N.9. Ratio of Rmax to E_{Rmax} at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	0.44	0.39	0.46
Flax	30 AN*	0.41	0.40	0.46
Flax	30 CRU**	0.39	0.40	0.43
Flax	90 AN	0.42	0.40	0.36
Flax	90 CRU	0.37	0.39	0.32
Pea	0	0.35	0.41	0.45
Pea	30 AN	0.37	0.40	0.38
Pea	30 CRU	0.37	0.41	0.44
Pea	90 AN	0.40	0.40	0.33
Pea	90 CRU	0.36	0.42	0.37
LSD (P=0.05)		ns	ns	0.06
Stubble				
Flax		0.41	0.40	0.41
Pea		0.37	0.41	0.39
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	0.39	0.40	0.45
	30 AN	0.39	0.40	0.42
	30 CRU	0.38	0.41	0.44
	90 AN	0.41	0.40	0.34
	90 CRU	0.36	0.40	0.35
	LSD (P=0.05)	ns	ns	0.04
ANOVA	df		Pr>F	
Stubble (S)	1	0.12	0.21	0.61
N Applied (kg ha^{-1}) (N)	4	0.32	0.99	<0.0001
N*S	4	0.49	0.86	0.0198
Contrasts				
Pea vs Flax at 0 N		0.0136	0.32	0.73
Pea vs Flax at 30 N		0.16	0.64	0.11
Pea vs Flax at 90 N		0.47	0.27	0.5
AN vs CRU		0.0725	0.58	0.52
AN vs CRU - 30 N vs 90 N		0.27	0.91	0.58
0 N vs 30 N		0.67	1	0.17
30N vs 90 N		0.94	1	<0.0001
Pea vs Flax - 0 N vs 30 N		0.19	0.59	0.48
Pea vs Flax - 30 N vs 90 N		0.6	0.66	0.0898
Pea at 30 N vs Flax 90 N		0.26	0.43	0.0009
Pea at 0 N vs Flax at 30 N		0.0799	0.44	0.96
Pea at 0 N vs Flax at 90 N		0.13	0.31	0.0001
C.V. (%)		12.1	7.8	9.5

* Ammonium nitrate

** Controlled-release urea

Table N.10. Ratio of Rmax to E_{Rmax} at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	0.45	0.28
Durum	50	0.37	0.30
Durum	78	0.37	0.27
Pea	34	0.36	0.23
Pea	50	0.32	0.26
Pea	78	0.29	0.26
LSD (P=0.05)		0.07	ns
Stubble			
Durum		0.39	0.29
Pea		0.32	0.25
LSD (P=0.05)		0.04	ns
	N Applied (kg ha^{-1})		
	34	0.40	0.26
	50	0.35	0.28
	78	0.33	0.27
	LSD (P=0.05)	0.05	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0021	0.0528
N Applied (kg ha^{-1})	2	0.0219	0.54
N*S	2	0.49	0.72
Contrasts			
Pea vs Durum at 34N		0.0155	0.14
Pea vs Durum at 50N		0.19	0.14
Pea vs Durum at 78N		0.0246	0.58
34 N vs 50 N		0.023	0.29
50 N vs 78 N		0.6	0.49
34 N vs 78 N		0.0093	0.7
Pea vs Durum - 34 N vs 50 N		0.26	1
Pea vs Durum - 50 N vs 78 N		0.42	0.49
Durum at 50 N vs Pea at 34 N		0.75	0.0356
Durum at 78 N vs Pea at 50 N		0.13	0.58
Durum at 78 N vs Pea at 34 N		0.6	0.2
C.V. (%)		10.6	13.6

Table N.11. Ratio of Rmax to E at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	0.40	0.36	0.42
Flax	30 AN*	0.38	0.36	0.42
Flax	30 CRU**	0.36	0.37	0.40
Flax	90 AN	0.40	0.37	0.33
Flax	90 CRU	0.34	0.36	0.29
Pea	0	0.33	0.39	0.42
Pea	30 AN	0.35	0.37	0.35
Pea	30 CRU	0.35	0.38	0.41
Pea	90 AN	0.38	0.36	0.30
Pea	90 CRU	0.34	0.39	0.34
LSD (P=0.05)		ns	ns	0.05
Stubble				
Flax		0.38	0.37	0.37
Pea		0.35	0.38	0.36
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	0.37	0.37	0.42
	30 AN	0.36	0.37	0.38
	30 CRU	0.35	0.38	0.40
	90 AN	0.39	0.37	0.32
	90 CRU	0.34	0.38	0.31
	LSD (P=0.05)	ns	ns	0.04
ANOVA	df		Pr>F	
Stubble (S)	1	0.17	0.29	0.7
N Applied (kg ha^{-1}) (N)	4	0.34	0.97	<0.0001
N*S	4	0.48	0.79	0.0255
Contrasts				
Pea vs Flax at 0 N		0.0195	0.31	1
Pea vs Flax at 30 N		0.24	0.75	0.14
Pea vs Flax at 90 N		0.65	0.38	0.56
AN vs CRU		0.0901	0.53	0.49
AN vs CRU - 30 N vs 90 N		0.25	0.86	0.44
0 N vs 30 N		0.67	0.93	0.15
30N vs 90 N		0.71	0.86	<0.0001
Pea vs Flax - 0 N vs 30 N		0.18	0.52	0.36
Pea vs Flax - 30 N vs 90 N		0.6	0.69	0.13
Pea at 30 N vs Flax 90 N		0.29	0.47	0.0011
Pea at 0 N vs Flax at 30 N		0.12	0.43	0.71
Pea at 0 N vs Flax at 90 N		0.14	0.27	<0.0001
C.V. (%)		11.9	8.3	9.8

* Ammonium nitrate

** Controlled-release urea

Table N.12. Ratio of Rmax to E at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	0.39	0.26
Durum	50	0.33	0.28
Durum	78	0.34	0.25
Pea	34	0.33	0.22
Pea	50	0.29	0.24
Pea	78	0.27	0.24
LSD (P=0.05)		0.07	ns
Stubble			
Durum		0.35	0.26
Pea		0.30	0.23
LSD (P=0.05)		0.04	ns
N Applied (kg ha^{-1})			
	34	0.35	0.24
	50	0.31	0.26
	78	0.31	0.24
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0047	0.0542
N Applied (kg ha^{-1})	2	0.0607	0.67
N*S	2	0.62	0.71
Contrasts			
Pea vs Durum at 34N		0.0515	0.11
Pea vs Durum at 50N		0.22	0.19
Pea vs Durum at 78N		0.0238	0.57
34 N vs 50 N		0.039	0.39
50 N vs 78 N		0.93	0.58
34 N vs 78 N		0.0339	0.75
Pea vs Durum - 34 N vs 50 N		0.47	0.81
Pea vs Durum - 50 N vs 78 N		0.37	0.58
Durum at 50 N vs Pea at 34 N		0.91	0.0487
Durum at 78 N vs Pea at 50 N		0.0831	0.57
Durum at 78 N vs Pea at 34 N		0.49	0.19
C.V. (%)		10.6	14.3

8.15. APPENDIX O – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON BAKING QUALITY ANALYSES AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table O.1. Farinograph absorption (%) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	61.1	61.3	60.3
Flax	30 AN*	62.7	61.4	60.0
Flax	30 CRU**	61.4	61.9	59.6
Flax	90 AN	63.5	61.7	63.6
Flax	90 CRU	63.1	61.8	63.5
Pea	0	63.4	62.4	60.0
Pea	30 AN	64.1	62.3	62.1
Pea	30 CRU	64.2	62.4	62.6
Pea	90 AN	64.5	62.2	65.4
Pea	90 CRU	65.1	62.6	64.7
LSD (P=0.05)		1.4	ns	1.8
Stubble				
Flax		62.3	61.6	61.4
Pea		64.3	62.4	62.8
LSD (P=0.05)		ns	0.4	ns
	N Applied (kg ha^{-1})			
	0	62.2	61.8	60.2
	30 AN	63.4	61.9	61.0
	30 CRU	62.8	62.1	61.1
	90 AN	64.0	62.0	64.3
	90 CRU	64.1	62.2	64.1
	LSD (P=0.05)	0.8	ns	0.9
ANOVA	df		Pr>F	
Stubble (S)	1	0.0534	0.0029	0.11
N Applied (kg ha^{-1}) (N)	4	0.0003	0.74	<0.0001
N*S	4	0.18	0.87	0.0095
Contrasts				
Pea vs Flax at 0 N		0.0024	0.0189	0.69
Pea vs Flax at 30 N		0.0002	0.0419	<0.0001
Pea vs Flax at 90 N		0.0055	0.0322	0.0095
AN vs CRU		0.41	0.27	0.56
AN vs CRU - 30 N vs 90 N		0.24	0.85	0.43
0 N vs 30 N		0.0191	0.56	0.0154
30N vs 90 N		0.0027	0.81	<0.0001
Pea vs Flax - 0 N vs 30 N		0.75	0.45	0.0006
Pea vs Flax - 30 N vs 90 N		0.28	0.93	0.13
Pea at 30 N vs Flax 90 N		0.0893	0.0543	0.0391
Pea at 0 N vs Flax at 30 N		0.032	0.0713	0.79
Pea at 0 N vs Flax at 90 N		0.84	0.0868	<0.0001
C.V. (%)		1.3	1.0	1.3

* Ammonium nitrate

** Controlled-release urea

Table O.2. Farinograph absorption (%) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	58.2	60.6
Durum	50	59.5	60.7
Durum	78	61.1	62.7
Pea	34	61.2	63.3
Pea	50	62.1	63.2
Pea	78	61.9	62.6
LSD (P=0.05)		1.1	1.9
Stubble			
Durum		59.6	61.3
Pea		61.7	63.0
LSD (P=0.05)		0.7	1.1
	N Applied (kg ha^{-1})		
	34	59.7	61.9
	50	60.8	61.9
	78	61.5	62.6
	LSD (P=0.05)	0.8	ns
ANOVA	**df**	**Pr > F**	
Stubble (S)	1	<0.0001	0.0048
N Applied (kg ha^{-1})	2	0.0014	0.45
N*S	2	0.034	0.0716
Contrasts			
Pea vs Durum at 34N		<0.0001	<0.0001
Pea vs Durum at 50N		0.0004	0.0006
Pea vs Durum at 78N		0.13	0.8
34 N vs 50 N		0.012	0.99
50 N vs 78 N		0.0845	0.28
34 N vs 78 N		0.0004	0.28
Pea vs Durum - 34 N vs 50 N		0.54	0.8
Pea vs Durum - 50 N vs 78 N		0.0449	0.0586
Durum at 50 N vs Pea at 34 N		0.0081	0.0101
Durum at 78 N vs Pea at 50 N		0.0817	0.58
Durum at 78 N vs Pea at 34 N		0.8	0.46
C.V. (%)		1.1	1.7

Table O.3. GRL Mixer dough mixing time (min) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	8.0	8.2	7.7
Flax	30 AN*	7.9	8.0	7.4
Flax	30 CRU**	7.9	8.0	7.7
Flax	90 AN	7.8	8.0	6.9
Flax	90 CRU	7.8	7.9	6.8
Pea	0	7.5	7.7	7.5
Pea	30 AN	7.6	8.0	6.8
Pea	30 CRU	7.9	8.1	7.3
Pea	90 AN	7.7	7.8	6.5
Pea	90 CRU	7.7	8.0	6.8
LSD (P=0.05)		ns	ns	0.6
Stubble				
Flax		7.9	8.0	7.3
Pea		7.7	7.9	7.0
LSD (P=0.05)		ns	ns	0.3
	N Applied (kg ha^{-1})			
	0	7.7	7.9	7.6
	30 AN	7.8	8.0	7.1
	30 CRU	7.9	8.0	7.5
	90 AN	7.7	7.9	6.7
	90 CRU	7.7	8.0	6.8
	LSD (P=0.05)	ns	ns	0.5
ANOVA	df		Pr>F	
Stubble (S)	1	0.33	0.13	0.0332
N Applied (kg ha^{-1}) (N)	4	0.74	0.95	0.001
N*S	4	0.28	0.28	0.7
Contrasts				
Pea vs Flax at 0 N		0.019	0.0288	0.51
Pea vs Flax at 30 N		0.34	0.7	0.0236
Pea vs Flax at 90 N		0.72	0.82	0.39
AN vs CRU		0.62	0.54	0.14
AN vs CRU - 30 N vs 90 N		0.62	0.92	0.38
0 N vs 30 N		0.28	0.64	0.11
30N vs 90 N		0.36	0.68	0.0017
Pea vs Flax - 0 N vs 30 N		0.1	0.0555	0.42
Pea vs Flax - 30 N vs 90 N		0.62	0.68	0.34
Pea at 30 N vs Flax 90 N		0.93	0.7	0.33
Pea at 0 N vs Flax at 30 N		0.0179	0.14	0.89
Pea at 0 N vs Flax at 90 N		0.0829	0.14	0.014
C.V. (%)		3.2	4.2	6.2

* Ammonium nitrate

** Controlled-release urea

Table O.4. GRL Mixer dough mixing time (min) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	9.3	6.7
Durum	50	8.4	6.6
Durum	78	8.0	6.5
Pea	34	8.1	6.4
Pea	50	7.8	6.5
Pea	78	7.9	6.1
LSD (P=0.05)		ns	ns
Stubble			
Durum		8.6	6.6
Pea		7.9	6.3
LSD (P=0.05)		0.5	ns
	N Applied (kg ha^{-1})		
	34	8.7	6.5
	50	8.1	6.6
	78	7.9	6.3
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0206	0.25
N Applied (kg ha^{-1})	2	0.0519	0.56
N*S	2	0.24	0.8
Contrasts			
Pea vs Durum at 34N		0.0142	0.42
Pea vs Durum at 50N		0.18	0.87
Pea vs Durum at 78N		0.76	0.29
34 N vs 50 N		0.0538	0.91
50 N vs 78 N		0.66	0.33
34 N vs 78 N		0.0238	0.39
Pea vs Durum - 34 N vs 50 N		0.33	0.64
Pea vs Durum - 50 N vs 78 N		0.45	0.52
Durum at 50 N vs Pea at 34 N		0.54	0.57
Durum at 78 N vs Pea at 50 N		0.59	0.93
Durum at 78 N vs Pea at 34 N		0.82	0.74
C.V. (%)		6.2	7.4

Table O.5. GRL Mixer work input (Whr kg^{-1}) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	15.2	17.2	15.0
Flax	30 AN*	14.9	16.5	14.7
Flax	30 CRU**	15.2	16.7	15.3
Flax	90 AN	15.3	17.0	14.6
Flax	90 CRU	15.6	16.6	14.4
Pea	0	14.8	16.5	15.4
Pea	30 AN	15.3	16.3	14.2
Pea	30 CRU	15.9	17.5	14.7
Pea	90 AN	15.5	15.9	13.7
Pea	90 CRU	15.7	16.4	14.9
LSD (P=0.05)		ns	ns	ns
Stubble				
Flax		15.2	16.8	14.8
Pea		15.4	16.5	14.6
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	15.0	16.9	15.2
	30 AN	15.1	16.4	14.5
	30 CRU	15.5	17.1	15.0
	90 AN	15.4	16.4	14.2
	90 CRU	15.6	16.5	14.6
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.54	0.27	0.51
N Applied (kg ha^{-1}) (N)	4	0.64	0.37	0.41
N*S	4	0.82	0.26	0.66
Contrasts				
Pea vs Flax at 0 N		0.59	0.24	0.67
Pea vs Flax at 30 N		0.24	0.45	0.29
Pea vs Flax at 90 N		0.79	0.13	0.79
AN vs CRU		0.32	0.2	0.22
AN vs CRU - 30 N vs 90 N		0.82	0.31	0.97
0 N vs 30 N		0.43	0.77	0.33
30N vs 90 N		0.62	0.33	0.43
Pea vs Flax - 0 N vs 30 N		0.26	0.17	0.36
Pea vs Flax - 30 N vs 90 N		0.51	0.12	0.61
Pea at 30 N vs Flax 90 N		0.7	0.75	0.94
Pea at 0 N vs Flax at 30 N		0.71	0.87	0.58
Pea at 0 N vs Flax at 90 N		0.3	0.6	0.18
C.V. (%)		5.9	5.2	7.6

* Ammonium nitrate

** Controlled-release urea

Table O.6. GRL Mixer work input (Whr kg^{-1}) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied ($kg\ ha^{-1}$)	2000	2001
Durum	34	15.2	13.7
Durum	50	14.1	13.6
Durum	78	14.2	13.7
Pea	34	14.8	13.1
Pea	50	14.4	14.5
Pea	78	14.9	13.1
LSD (P=0.05)		ns	ns
Stubble			
Durum		14.5	13.6
Pea		14.7	13.6
LSD (P=0.05)		ns	ns
N Applied ($kg\ ha^{-1}$)			
	34	15.0	13.4
	50	14.2	14.0
	78	14.6	13.4
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.74	0.88
N Applied ($kg\ ha^{-1}$)	2	0.48	0.47
N*S	2	0.69	0.35
Contrasts			
Pea vs Durum at 34N		0.64	0.54
Pea vs Durum at 50N		0.75	0.28
Pea vs Durum at 78N		0.48	0.46
34 N vs 50 N		0.24	0.3
50 N vs 78 N		0.6	0.29
34 N vs 78 N		0.5	0.99
Pea vs Durum - 34 N vs 50 N		0.58	0.23
Pea vs Durum - 50 N vs 78 N		0.78	0.2
Durum at 50 N vs Pea at 34 N		0.43	0.62
Durum at 78 N vs Pea at 50 N		0.89	0.35
Durum at 78 N vs Pea at 34 N		0.54	0.5
C.V. (%)		7.6	7.6

Table O.7. Loaf Volume (cm^3) at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	1134	1174	1118
Flax	30 AN*	1134	1186	1062
Flax	30 CRU**	1132	1184	1101
Flax	90 AN	1214	1242	1184
Flax	90 CRU	1210	1173	1176
Pea	0	1180	1186	1104
Pea	30 AN	1195	1226	1156
Pea	30 CRU	1214	1190	1161
Pea	90 AN	1227	1208	1208
Pea	90 CRU	1241	1219	1228
LSD (P=0.05)		43	ns	52
Stubble				
Flax		1165	1192	1128
Pea		1211	1206	1169
LSD (P=0.05)		19	ns	19
	N Applied (kg ha^{-1})			
	0	1157	1180	1111
	30 AN	1164	1206	1109
	30 CRU	1173	1187	1131
	90 AN	1221	1225	1194
	90 CRU	1226	1196	1202
	LSD (P=0.05)	29	ns	64
ANOVA	df		Pr>F	
Stubble (S)	1	0.0308	0.0805	0.0366
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.17	<0.0001
N*S	4	0.18	0.25	0.0342
Contrasts				
Pea vs Flax at 0 N		0.037	0.66	0.54
Pea vs Flax at 30 N		<0.0001	0.22	<0.0001
Pea vs Flax at 90 N		0.14	0.73	0.032
AN vs CRU		0.52	0.0804	0.28
AN vs CRU - 30 N vs 90 N		0.87	0.69	0.46
0 N vs 30 N		0.35	0.32	0.53
30N vs 90 N		<0.0001	0.31	<0.0001
Pea vs Flax - 0 N vs 30 N		0.32	0.73	0.0033
Pea vs Flax - 30 N vs 90 N		0.023	0.54	0.12
Pea at 30 N vs Flax 90 N		0.61	0.98	0.19
Pea at 0 N vs Flax at 30 N		0.0159	0.99	0.27
Pea at 0 N vs Flax at 90 N		0.089	0.33	0.0008
C.V. (%)		2.4	3.1	2.8

* Ammonium nitrate

** Controlled-release urea

Table O.8. Loaf Volume (cm^3) at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied ($kg\ ha^{-1}$)	2000	2001
Durum	34	850	1191
Durum	50	950	1239
Durum	78	1000	1313
Pea	34	960	1258
Pea	50	1019	1337
Pea	78	1036	1288
LSD (P=0.05)		93	ns
Stubble			
Durum		933	1248
Pea		1005	1294
LSD (P=0.05)		54	ns
	N Applied ($kg\ ha^{-1}$)		
	34	905	1224
	50	985	1288
	78	1018	1300
	LSD (P=0.05)	66	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0132	0.12
N Applied ($kg\ ha^{-1}$)	2	0.0081	0.093
N*S	2	0.49	0.21
Contrasts			
Pea vs Durum at 34N		0.0243	0.19
Pea vs Durum at 50N		0.13	0.0646
Pea vs Durum at 78N		0.42	0.6
34 N vs 50 N		0.0218	0.0844
50 N vs 78 N		0.29	0.72
34 N vs 78 N		0.0028	0.044
Pea vs Durum - 34 N vs 50 N		0.51	0.66
Pea vs Durum - 50 N vs 78 N		0.59	0.0938
Durum at 50 N vs Pea at 34 N		0.82	0.71
Durum at 78 N vs Pea at 50 N		0.66	0.64
Durum at 78 N vs Pea at 34 N		0.37	0.27
C.V. (%)		5.4	4.6

Table O.9. Loaf volume per unit flour protein content at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	89.9	72.2	83.1
Flax	30 AN*	83.8	73.3	81.4
Flax	30 CRU**	87.0	73.2	84.2
Flax	90 AN	81.1	74.8	81.1
Flax	90 CRU	81.7	70.7	76.9
Pea	0	80.9	73.7	81.6
Pea	30 AN	77.4	74.1	81.8
Pea	30 CRU	80.3	72.7	82.5
Pea	90 AN	77.2	73.5	74.2
Pea	90 CRU	76.8	72.7	77.1
LSD (P=0.05)		4.8	ns	4.4
Stubble				
Flax		84.7	72.9	81.3
Pea		78.5	73.3	79.7
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	85.4	73.0	82.3
	30 AN	80.6	73.7	81.6
	30 CRU	83.7	73.0	83.3
	90 AN	79.2	74.2	78.2
	90 CRU	79.3	71.7	77.0
	LSD (P=0.05)	2.9	ns	3.4
ANOVA	df		Pr>F	
Stubble (S)	1	0.05	0.57	0.3
N Applied (kg ha^{-1}) (N)	4	0.0003	0.55	0.0005
N*S	4	0.43	0.79	0.19
Contrasts				
Pea vs Flax at 0 N		0.0007	0.49	0.48
Pea vs Flax at 30 N		0.0005	0.93	0.69
Pea vs Flax at 90 N		0.0141	0.84	0.0694
AN vs CRU		0.12	0.15	0.68
AN vs CRU - 30 N vs 90 N		0.15	0.41	0.21
0 N vs 30 N		0.0113	0.79	0.92
30N vs 90 N		0.0067	0.72	<0.0001
Pea vs Flax - 0 N vs 30 N		0.31	0.61	0.71
Pea vs Flax - 30 N vs 90 N		0.29	0.93	0.23
Pea at 30 N vs Flax 90 N		0.14	0.68	0.0498
Pea at 0 N vs Flax at 30 N		0.0368	0.8	0.52
Pea at 0 N vs Flax at 90 N		0.82	0.61	0.18
C.V. (%)		3.4	4.1	3.5

* Ammonium nitrate

** Controlled-release urea

Table O.10. Loaf volume per unit flour protein content at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	88.8	87.3
Durum	50	88.1	89.3
Durum	78	82.9	83.0
Pea	34	85.5	80.9
Pea	50	82.8	82.5
Pea	78	75.1	85.0
LSD (P=0.05)		6.3	ns
Stubble			
Durum		86.6	86.5
Pea		81.1	82.8
LSD (P=0.05)		3.6	3.3
	N Applied (kg ha^{-1})		
	34	87.1	84.1
	50	85.5	85.9
	78	79.0	84.0
	LSD (P=0.05)	4.4	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0062	0.0286
N Applied (kg ha^{-1})	2	0.0039	0.52
N*S	2	0.56	0.061
Contrasts			
Pea vs Durum at 34N		0.26	0.031
Pea vs Durum at 50N		0.0901	0.0229
Pea vs Durum at 78N		0.0184	0.47
34 N vs 50 N		0.43	0.34
50 N vs 78 N		0.0074	0.32
34 N vs 78 N		0.0017	0.98
Pea vs Durum - 34 N vs 50 N		0.64	0.91
Pea vs Durum - 50 N vs 78 N		0.54	0.0355
Durum at 50 N vs Pea at 34 N		0.37	0.0072
Durum at 78 N vs Pea at 50 N		0.99	0.84
Durum at 78 N vs Pea at 34 N		0.38	0.42
C.V. (%)		4.2	3.8

8.16. APPENDIX P – ANALYSIS OF VARIANCE, LSDs, AND CONTRASTS FOR THE EFFECTS OF PREVIOUS CROP AND FERTILIZER NITROGEN TREATMENTS ON PROTEIN QUALITY ANALYSES AT THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table P.1. Quantity (% of flour) of 50% 1-propanol soluble protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment			Site	
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	8.25	10.29	8.36
Flax	30 AN*	9.18	10.19	8.11
Flax	30 CRU**	8.97	10.32	8.21
Flax	90 AN	10.18	10.37	9.38
Flax	90 CRU	10.10	10.48	9.39
Pea	0	9.99	10.41	8.21
Pea	30 AN	10.50	10.52	8.82
Pea	30 CRU	10.30	10.41	8.62
Pea	90 AN	10.84	10.56	9.89
Pea	90 CRU	10.99	10.39	10.21
LSD (P=0.05)		1.09	ns	0.64
Stubble				
Flax		9.33	10.33	8.69
Pea		10.52	10.46	9.15
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	9.12	10.35	8.29
	30 AN	9.84	10.35	8.46
	30 CRU	9.63	10.37	8.42
	90 AN	10.51	10.46	9.63
	90 CRU	10.54	10.43	9.80
	LSD (P=0.05)	0.47	ns	0.37
ANOVA	df		Pr>F	
Stubble (S)	1	0.13	0.32	0.2
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.82	<0.0001
N*S	4	0.18	0.52	0.094
Contrasts				
Pea vs Flax at 0 N		0.0028	0.51	0.64
Pea vs Flax at 30 N		0.0015	0.1	0.0183
Pea vs Flax at 90 N		0.0479	0.69	0.006
AN vs CRU		0.61	0.93	0.64
AN vs CRU - 30 N vs 90 N		0.48	0.81	0.4
0 N vs 30 N		0.005	0.96	0.33
30N vs 90 N		<0.0001	0.29	<0.0001
Pea vs Flax - 0 N vs 30 N		0.3	0.65	0.03
Pea vs Flax - 30 N vs 90 N		0.1	0.34	0.68
Pea at 30 N vs Flax 90 N		0.49	0.75	0.0056
Pea at 0 N vs Flax at 30 N		0.0547	0.3	0.85
Pea at 0 N vs Flax at 90 N		0.75	0.94	0.0002
C.V. (%)		4.6	2.3	4.0

* Ammonium nitrate

** Controlled-release urea

Table P.2. Quantity (% of flour) of 50% 1-propanol soluble protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	6.36	8.90
Durum	50	7.29	9.29
Durum	78	8.19	10.10
Pea	34	7.39	9.81
Pea	50	8.27	10.23
Pea	78	9.36	9.75
LSD (P=0.05)		0.90	ns
Stubble			
Durum		7.28	9.43
Pea		8.34	9.93
LSD (P=0.05)		0.52	ns
	N Applied (kg ha^{-1})		
	34	6.88	9.36
	50	7.78	9.76
	78	8.78	9.93
	LSD (P=0.05)	0.64	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0008	0.0829
N Applied (kg ha^{-1})	2	0.0001	0.24
N*S	2	0.94	0.11
Contrasts			
Pea vs Durum at 34N		0.0145	0.0689
Pea vs Durum at 50N		0.028	0.0622
Pea vs Durum at 78N		0.0366	0.45
34 N vs 50 N		0.0092	0.23
50 N vs 78 N		0.0052	0.62
34 N vs 78 N		<0.0001	0.1
Pea vs Durum - 34 N vs 50 N		0.92	0.97
Pea vs Durum - 50 N vs 78 N		0.73	0.0682
Durum at 50 N vs Pea at 34 N		0.82	0.28
Durum at 78 N vs Pea at 50 N		0.85	0.78
Durum at 78 N vs Pea at 34 N		0.0781	0.54
C.V. (%)		6.5	5.8

Table P.3. Quantity of 50% 1-propanol soluble protein as a percentage of total flour protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	65.3	63.3	62.2
Flax	30 AN*	67.8	62.9	62.2
Flax	30 CRU**	68.6	63.7	62.7
Flax	90 AN	67.9	62.5	64.2
Flax	90 CRU	68.0	63.1	61.4
Pea	0	68.5	64.7	60.6
Pea	30 AN	67.9	63.6	62.3
Pea	30 CRU	68.1	63.6	61.2
Pea	90 AN	68.2	64.2	61.4
Pea	90 CRU	68.0	62.0	64.0
LSD (P=0.05)		ns	ns	2.2
Stubble				
Flax		67.5	63.1	62.5
Pea		68.2	63.6	61.9
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	66.9	64.0	61.4
	30 AN	67.9	63.2	62.2
	30 CRU	68.3	63.7	62.0
	90 AN	68.0	63.3	62.8
	90 CRU	68.0	62.6	62.7
	LSD (P=0.05)	ns	1.0	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.75	0.27	0.25
N Applied (kg ha^{-1}) (N)	4	0.85	0.0806	0.39
N*S	4	0.65	0.0482	0.0187
Contrasts				
Pea vs Flax at 0 N		0.16	0.0652	0.16
Pea vs Flax at 30 N		0.91	0.66	0.43
Pea vs Flax at 90 N		0.92	0.59	0.87
AN vs CRU		0.84	0.64	0.71
AN vs CRU - 30 N vs 90 N		0.79	0.11	0.88
0 N vs 30 N		0.31	0.2	0.3
30N vs 90 N		0.92	0.17	0.26
Pea vs Flax - 0 N vs 30 N		0.15	0.19	0.48
Pea vs Flax - 30 N vs 90 N		0.86	0.94	0.66
Pea at 30 N vs Flax 90 N		0.97	0.15	0.2
Pea at 0 N vs Flax at 30 N		0.82	0.0352	0.0644
Pea at 0 N vs Flax at 90 N		0.55	0.0048	0.0269
C.V. (%)		4.0	1.6	2.5

* Ammonium nitrate

** Controlled-release urea

Table P.4. Quantity of 50% 1-propanol soluble protein as a percentage of total flour protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	66.4	65.1
Durum	50	67.5	66.9
Durum	78	67.8	63.9
Pea	34	65.9	63.1
Pea	50	67.2	63.2
Pea	78	67.7	64.3
LSD (P=0.05)		ns	ns
Stubble			
Durum		67.3	65.3
Pea		66.9	63.5
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	66.2	64.1
	50	67.4	65.1
	78	67.7	64.1
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.76	0.18
N Applied (kg ha^{-1})	2	0.51	0.77
N*S	2	0.99	0.42
Contrasts			
Pea vs Durum at 34N		0.92	0.36
Pea vs Durum at 50N		0.78	0.11
Pea vs Durum at 78N		0.87	0.85
34 N vs 50 N		0.41	0.54
50 N vs 78 N		0.78	0.53
34 N vs 78 N		0.28	0.99
Pea vs Durum - 34 N vs 50 N		0.92	0.6
Pea vs Durum - 50 N vs 78 N		0.96	0.2
Durum at 50 N vs Pea at 34 N		0.43	0.1
Durum at 78 N vs Pea at 50 N		0.75	0.76
Durum at 78 N vs Pea at 34 N		0.34	0.71
C.V. (%)		3.5	4.1

Table P.5. Quantity (% of flour) of 50% 1-propanol insoluble glutenin at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	2.81	3.27	2.57
Flax	30 AN*	3.06	3.25	2.39
Flax	30 CRU**	2.91	3.27	2.44
Flax	90 AN	3.51	3.30	2.71
Flax	90 CRU	3.29	3.31	2.68
Pea	0	3.43	3.24	2.51
Pea	30 AN	3.53	3.32	2.50
Pea	30 CRU	3.51	3.33	2.54
Pea	90 AN	3.70	3.25	2.82
Pea	90 CRU	3.66	3.38	2.76
LSD (P=0.05)		0.36	ns	0.20
Stubble				
Flax		3.12	3.28	2.56
Pea		3.57	3.30	2.62
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	3.12	3.25	2.54
	30 AN	3.29	3.28	2.44
	30 CRU	3.21	3.30	2.49
	90 AN	3.61	3.27	2.76
	90 CRU	3.47	3.34	2.72
	LSD (P=0.05)	0.17	ns	0.12
ANOVA	df		Pr>F	
Stubble (S)	1	0.1	0.51	0.45
N Applied (kg ha^{-1}) (N)	4	<0.0001	0.52	<0.0001
N*S	4	0.0844	0.29	0.58
Contrasts				
Pea vs Flax at 0 N		0.0014	0.35	0.58
Pea vs Flax at 30 N		0.0002	0.96	0.15
Pea vs Flax at 90 N		0.0315	0.83	0.18
AN vs CRU		0.073	0.19	0.93
AN vs CRU - 30 N vs 90 N		0.68	0.38	0.3
0 N vs 30 N		0.0752	0.42	0.16
30N vs 90 N		<0.0001	0.74	<0.0001
Pea vs Flax - 0 N vs 30 N		0.49	0.47	0.13
Pea vs Flax - 30 N vs 90 N		0.043	0.91	0.93
Pea at 30 N vs Flax 90 N		0.37	0.91	0.0155
Pea at 0 N vs Flax at 30 N		0.007	0.25	0.26
Pea at 0 N vs Flax at 90 N		0.83	0.31	0.0378
C.V. (%)		4.9	3.0	4.5

* Ammonium nitrate

** Controlled-release urea

Table P.6. Quantity (% of flour) of 50% 1-propanol insoluble glutenin at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	1.99	2.50
Durum	50	2.25	2.61
Durum	78	2.60	2.87
Pea	34	2.20	2.73
Pea	50	2.46	2.87
Pea	78	2.85	2.69
LSD (P=0.05)		0.33	ns
Stubble			
Durum		2.28	2.66
Pea		2.50	2.76
LSD (P=0.05)		0.19	ns
	N Applied (kg ha^{-1})		
	34	2.09	2.61
	50	2.35	2.74
	78	2.73	2.78
	LSD (P=0.05)	0.24	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0263	0.23
N Applied (kg ha^{-1})	2	0.0003	0.25
N*S	2	0.98	0.088
Contrasts			
Pea vs Durum at 34N		0.13	0.14
Pea vs Durum at 50N		0.18	0.0911
Pea vs Durum at 78N		0.2	0.23
34 N vs 50 N		0.0338	0.22
50 N vs 78 N		0.0049	0.7
34 N vs 78 N		<0.0001	0.12
Pea vs Durum - 34 N vs 50 N		0.95	0.87
Pea vs Durum - 50 N vs 78 N		0.86	0.0483
Durum at 50 N vs Pea at 34 N		0.77	0.44
Durum at 78 N vs Pea at 50 N		0.36	1
Durum at 78 N vs Pea at 34 N		0.023	0.32
C.V. (%)		7.9	6.4

Table P.7. Quantity of 50% 1-propanol insoluble glutenin as a percentage of total flour protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	22.2	20.1	19.1
Flax	30 AN*	22.6	20.1	18.3
Flax	30 CRU**	22.3	20.2	18.6
Flax	90 AN	23.4	19.9	18.5
Flax	90 CRU	22.1	19.9	17.5
Pea	0	23.5	20.1	18.5
Pea	30 AN	22.8	20.0	17.7
Pea	30 CRU	23.2	20.3	18.0
Pea	90 AN	23.3	19.8	17.5
Pea	90 CRU	22.6	20.1	17.3
LSD (P=0.05)		ns	ns	0.9
Stubble				
Flax		22.5	20.0	18.4
Pea		23.1	20.1	17.8
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	22.9	20.1	18.8
	30 AN	22.7	20.0	18.0
	30 CRU	22.7	20.3	18.3
	90 AN	23.3	19.8	18.0
	90 CRU	22.4	20.0	17.4
	LSD (P=0.05)	ns	ns	0.7
ANOVA	df		Pr>F	
Stubble (S)	1	0.44	0.95	0.0619
N Applied (kg ha^{-1}) (N)	4	0.28	0.19	0.0039
N*S	4	0.48	0.21	0.73
Contrasts				
Pea vs Flax at 0 N		0.0839	0.28	0.24
Pea vs Flax at 30 N		0.3	0.42	0.0699
Pea vs Flax at 90 N		0.72	0.86	0.0699
AN vs CRU		0.14	0.31	0.55
AN vs CRU - 30 N vs 90 N		0.1	0.22	0.0493
0 N vs 30 N		0.69	0.24	0.0232
30N vs 90 N		0.67	0.35	0.0685
Pea vs Flax - 0 N vs 30 N		0.3	0.17	0.91
Pea vs Flax - 30 N vs 90 N		0.55	0.47	1
Pea at 30 N vs Flax 90 N		0.65	0.74	0.59
Pea at 0 N vs Flax at 30 N		0.1	0.27	0.8
Pea at 0 N vs Flax at 90 N		0.24	0.0482	0.19
C.V. (%)		3.7	3.9	3.6

* Ammonium nitrate

** Controlled-release urea

Table P.8. Quantity of 50% 1-propanol insoluble glutenin as a percentage of total flour protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	20.7	18.3
Durum	50	20.9	18.8
Durum	78	21.5	18.2
Pea	34	19.6	17.6
Pea	50	19.9	17.7
Pea	78	20.6	17.8
LSD (P=0.05)		ns	ns
Stubble			
Durum		21.0	18.4
Pea		20.1	17.7
LSD (P=0.05)		ns	ns
N Applied (kg ha^{-1})			
	34	20.2	17.9
	50	20.4	18.3
	78	21.1	18.0
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.15	0.0765
N Applied (kg ha^{-1})	2	0.51	0.71
N*S	2	0.99	0.79
Contrasts			
Pea vs Durum at 34N		0.44	0.31
Pea vs Durum at 50N		0.34	0.13
Pea vs Durum at 78N		0.42	0.52
34 N vs 50 N		0.74	0.46
50 N vs 78 N		0.43	0.51
34 N vs 78 N		0.27	0.94
Pea vs Durum - 34 N vs 50 N		0.9	0.7
Pea vs Durum - 50 N vs 78 N		0.98	0.51
Durum at 50 N vs Pea at 34 N		0.27	0.0844
Durum at 78 N vs Pea at 50 N		0.18	0.52
Durum at 78 N vs Pea at 34 N		0.11	0.38
C.V. (%)		6.6	4.4

Table P.9. Quantity (% of flour) of 50% 1-propanol insoluble residue protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	1.58	2.70	2.53
Flax	30 AN*	1.32	2.76	2.56
Flax	30 CRU**	1.18	2.60	2.46
Flax	90 AN	1.31	2.93	2.52
Flax	90 CRU	1.45	2.81	3.27
Pea	0	1.16	2.44	2.82
Pea	30 AN	1.42	2.72	2.82
Pea	30 CRU	1.32	2.64	2.92
Pea	90 AN	1.35	2.65	3.41
Pea	90 CRU	1.51	3.00	2.98
LSD (P=0.05)		ns	ns	0.45
Stubble				
Flax		1.37	2.76	2.67
Pea		1.35	2.69	2.99
LSD (P=0.05)		ns	ns	0.20
	N Applied (kg ha^{-1})			
	0	1.37	2.57	2.67
	30 AN	1.37	2.74	2.69
	30 CRU	1.25	2.62	2.69
	90 AN	1.33	2.79	2.97
	90 CRU	1.48	2.90	3.12
	LSD (P=0.05)	ns	ns	0.32
ANOVA	df		Pr>F	
Stubble (S)	1	0.97	0.5	0.045
N Applied (kg ha^{-1}) (N)	4	0.92	0.0575	0.0193
N*S	4	0.79	0.0853	0.0147
Contrasts				
Pea vs Flax at 0 N		0.32	0.12	0.19
Pea vs Flax at 30 N		0.68	0.68	0.0284
Pea vs Flax at 90 N		0.86	0.75	0.0596
AN vs CRU		0.93	0.46	0.47
AN vs CRU - 30 N vs 90 N		0.45	0.12	0.47
0 N vs 30 N		0.77	0.2	0.92
30N vs 90 N		0.58	0.11	0.0031
Pea vs Flax - 0 N vs 30 N		0.22	0.14	0.81
Pea vs Flax - 30 N vs 90 N		0.84	0.62	0.81
Pea at 30 N vs Flax 90 N		0.97	0.27	0.85
Pea at 0 N vs Flax at 30 N		0.82	0.1	0.11
Pea at 0 N vs Flax at 90 N		0.55	0.0061	0.69
C.V. (%)		36.8	10.7	10.9

* Ammonium nitrate

** Controlled-release urea

Table P.10. Quantity (% of flour) of 50% 1-propanol insoluble residue protein at the Swift Current-00 and Swift Current-01 sites.

Treatment			Year	
Stubble	N Applied ($kg\ ha^{-1}$)		2000	2001
Durum	34		1.23	2.28
Durum	50		1.25	1.98
Durum	78		1.28	2.85
Pea	34		1.63	3.03
Pea	50		1.59	3.10
Pea	78		1.65	2.73
LSD (P=0.05)			ns	ns
Stubble				
Durum			1.25	2.37
Pea			1.62	2.95
LSD (P=0.05)			ns	ns
	N Applied ($kg\ ha^{-1}$)			
	34		1.43	2.66
	50		1.42	2.54
	78		1.46	2.79
	LSD (P=0.05)		ns	ns
ANOVA		df	Pr > F	
Stubble (S)		1	0.0921	0.0572
N Applied ($kg\ ha^{-1}$)		2	0.98	0.76
N*S		2	0.99	0.21
Contrasts				
Pea vs Durum at 34N			0.3	0.14
Pea vs Durum at 50N			0.27	0.0376
Pea vs Durum at 78N			0.36	0.8
34 N vs 50 N			0.97	0.73
50 N vs 78 N			0.86	0.43
34 N vs 78 N			0.88	0.7
Pea vs Durum - 34 N vs 50 N			0.89	0.6
Pea vs Durum - 50 N vs 78 N			0.93	0.0916
Durum at 50 N vs Pea at 34 N			0.3	0.0484
Durum at 78 N vs Pea at 50 N			0.4	0.62
Durum at 78 N vs Pea at 34 N			0.33	0.71
C.V. (%)			29.7	22.0

Table P.11. Quantity of 50% 1-propanol insoluble residue protein as a percentage of total flour protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	12.5	16.6	18.7
Flax	30 AN*	9.6	17.0	19.6
Flax	30 CRU**	9.1	16.1	18.7
Flax	90 AN	8.7	17.7	17.2
Flax	90 CRU	9.9	16.9	21.1
Pea	0	7.9	15.1	20.9
Pea	30 AN	9.3	16.4	20.0
Pea	30 CRU	8.7	16.1	20.8
Pea	90 AN	8.5	16.1	21.2
Pea	90 CRU	9.3	17.9	18.7
LSD (P=0.05)		ns	ns	2.6
Stubble				
Flax		10.0	16.9	19.1
Pea		8.8	16.3	20.3
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	10.2	15.9	19.8
	30 AN	9.4	16.7	19.8
	30 CRU	8.9	16.1	19.7
	90 AN	8.6	16.9	19.2
	90 CRU	9.6	17.4	19.9
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.66	0.33	0.11
N Applied (kg ha^{-1}) (N)	4	0.88	0.0883	0.95
N*S	4	0.62	0.0687	0.0201
Contrasts				
Pea vs Flax at 0 N		0.12	0.0923	0.1
Pea vs Flax at 30 N		0.86	0.91	0.18
Pea vs Flax at 90 N		0.87	0.68	0.41
AN vs CRU		0.82	0.45	0.62
AN vs CRU - 30 N vs 90 N		0.52	0.12	0.56
0 N vs 30 N		0.48	0.19	0.96
30N vs 90 N		0.97	0.2	0.77
Pea vs Flax - 0 N vs 30 N		0.15	0.16	0.55
Pea vs Flax - 30 N vs 90 N		0.99	0.71	0.71
Pea at 30 N vs Flax 90 N		0.88	0.28	0.2
Pea at 0 N vs Flax at 30 N		0.57	0.0627	0.12
Pea at 0 N vs Flax at 90 N		0.58	0.0068	0.13
C.V. (%)		35.3	9.5	9.2

* Ammonium nitrate

** Controlled-release urea

Table P.12. Quantity of 50% 1-propanol insoluble residue protein as a percentage of total flour protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	12.8	16.6
Durum	50	11.6	14.3
Durum	78	10.6	18.0
Pea	34	14.5	19.4
Pea	50	12.9	19.1
Pea	78	11.7	18.0
LSD (P=0.05)		ns	ns
Stubble			
Durum		11.7	16.3
Pea		13.0	18.8
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	13.7	18.0
	50	12.2	16.7
	78	11.2	18.0
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.42	0.12
N Applied (kg ha^{-1})	2	0.47	0.71
N*S	2	0.98	0.47
Contrasts			
Pea vs Durum at 34N		0.7	0.32
Pea vs Durum at 50N		0.56	0.0951
Pea vs Durum at 78N		0.66	0.99
34 N vs 50 N		0.48	0.48
50 N vs 78 N		0.6	0.49
34 N vs 78 N		0.23	0.99
Pea vs Durum - 34 N vs 50 N		0.91	0.59
Pea vs Durum - 50 N vs 78 N		0.99	0.23
Durum at 50 N vs Pea at 34 N		0.33	0.0764
Durum at 78 N vs Pea at 50 N		0.44	0.69
Durum at 78 N vs Pea at 34 N		0.19	0.6
C.V. (%)		27.7	18.4

Table P.13. Quantity (% of flour) of 50% 1-propanol insoluble protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	4.39	5.96	5.09
Flax	30 AN*	4.37	6.01	4.94
Flax	30 CRU**	4.08	5.87	4.91
Flax	90 AN	4.82	6.23	5.23
Flax	90 CRU	4.74	6.12	5.95
Pea	0	4.60	5.69	5.33
Pea	30 AN	4.95	6.03	5.32
Pea	30 CRU	4.82	5.97	5.45
Pea	90 AN	5.06	5.90	6.23
Pea	90 CRU	5.17	6.38	5.74
LSD (P=0.05)		0.68	ns	0.50
Stubble				
Flax		4.48	6.04	5.22
Pea		4.92	5.99	5.61
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	4.49	5.82	5.21
	30 AN	4.66	6.02	5.13
	30 CRU	4.45	5.92	5.18
	90 AN	4.94	6.06	5.73
	90 CRU	4.96	6.25	5.85
	LSD (P=0.05)	ns	0.26	0.34
ANOVA	df		Pr>F	
Stubble (S)	1	0.0645	0.26	0.0799
N Applied (kg ha^{-1}) (N)	4	0.12	0.0309	0.0002
N*S	4	0.77	0.12	0.0174
Contrasts				
Pea vs Flax at 0 N		0.53	0.13	0.34
Pea vs Flax at 30 N		0.0099	0.63	0.013
Pea vs Flax at 90 N		0.17	0.77	0.0292
AN vs CRU		0.57	0.58	0.47
AN vs CRU - 30 N vs 90 N		0.5	0.11	0.76
0 N vs 30 N		0.75	0.16	0.68
30N vs 90 N		0.0274	0.2	<0.0001
Pea vs Flax - 0 N vs 30 N		0.29	0.19	0.44
Pea vs Flax - 30 N vs 90 N		0.34	0.93	0.79
Pea at 30 N vs Flax 90 N		0.67	0.17	0.25
Pea at 0 N vs Flax at 30 N		0.22	0.11	0.0652
Pea at 0 N vs Flax at 90 N		0.53	0.0035	0.23
C.V. (%)		10.0	4.2	6.0

* Ammonium nitrate

** Controlled-release urea

Table P.14. Quantity (% of flour) of 50% 1-propanol insoluble protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	3.88	4.78
Durum	50	3.21	4.59
Durum	78	3.50	5.73
Pea	34	4.50	5.76
Pea	50	3.83	5.97
Pea	78	4.04	5.42
LSD (P=0.05)		0.73	ns
Stubble			
Durum		3.53	5.03
Pea		4.12	5.72
LSD (P=0.05)		0.42	0.63
	N Applied (kg ha^{-1})		
	34	3.52	5.27
	50	3.77	5.28
	78	4.19	5.58
	LSD (P=0.05)	0.52	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0103	0.0367
N Applied (kg ha^{-1})	2	0.0462	0.64
N*S	2	0.98	0.0856
Contrasts			
Pea vs Durum at 34N		0.0909	0.0767
Pea vs Durum at 50N		0.0923	0.018
Pea vs Durum at 78N		0.14	0.56
34 N vs 50 N		0.31	0.97
50 N vs 78 N		0.11	0.43
34 N vs 78 N		0.0159	0.41
Pea vs Durum - 34 N vs 50 N		1	0.58
Pea vs Durum - 50 N vs 78 N		0.87	0.036
Durum at 50 N vs Pea at 34 N		0.0024	0.0392
Durum at 78 N vs Pea at 50 N		0.35	0.63
Durum at 78 N vs Pea at 34 N		0.012	0.94
C.V. (%)		10.8	11.5

Table P.15. Quantity of 50% 1-propanol insoluble protein as a percentage of total flour protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	34.7	36.7	37.8
Flax	30 AN*	32.2	37.1	37.8
Flax	30 CRU**	31.4	36.3	37.3
Flax	90 AN	32.1	37.5	35.8
Flax	90 CRU	32.0	36.9	38.6
Pea	0	31.5	35.3	39.4
Pea	30 AN	32.1	36.4	37.7
Pea	30 CRU	31.9	36.4	38.8
Pea	90 AN	31.8	35.8	38.6
Pea	90 CRU	32.0	38.0	36.0
LSD (P=0.05)		ns	1.5	2.2
Stubble				
Flax		32.5	36.9	37.5
Pea		31.8	36.4	38.1
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	33.1	36.0	38.6
	30 AN	32.1	36.8	37.8
	30 CRU	31.7	36.3	38.0
	90 AN	32.0	36.7	37.2
	90 CRU	32.0	37.4	37.3
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.76	0.27	0.25
N Applied (kg ha^{-1}) (N)	4	0.86	0.0806	0.39
N*S	4	0.65	0.0482	0.0187
Contrasts				
Pea vs Flax at 0 N		0.16	0.0652	0.16
Pea vs Flax at 30 N		0.91	0.66	0.43
Pea vs Flax at 90 N		0.92	0.59	0.87
AN vs CRU		0.83	0.64	0.71
AN vs CRU - 30 N vs 90 N		0.8	0.11	0.88
0 N vs 30 N		0.31	0.2	0.3
30N vs 90 N		0.92	0.17	0.26
Pea vs Flax - 0 N vs 30 N		0.15	0.19	0.48
Pea vs Flax - 30 N vs 90 N		0.86	0.94	0.66
Pea at 30 N vs Flax 90 N		0.96	0.15	0.2
Pea at 0 N vs Flax at 30 N		0.87	0.0352	0.0644
Pea at 0 N vs Flax at 90 N		0.76	0.0048	0.0269
C.V. (%)		8.4	2.7	4.1

* Ammonium nitrate

** Controlled-release urea

Table P.16. Quantity of 50% 1-propanol insoluble protein as a percentage of total flour protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	32.2	34.9
Durum	50	33.6	33.1
Durum	78	32.5	36.1
Pea	34	32.3	36.9
Pea	50	34.1	36.8
Pea	78	32.8	35.7
LSD (P=0.05)		ns	ns
Stubble			
Durum		32.7	34.7
Pea		33.1	36.5
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	33.8	35.9
	50	32.6	34.9
	78	32.3	35.9
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.76	0.18
N Applied (kg ha^{-1})	2	0.51	0.77
N*S	2	0.99	0.42
Contrasts			
Pea vs Durum at 34N		0.92	0.36
Pea vs Durum at 50N		0.78	0.11
Pea vs Durum at 78N		0.87	0.85
34 N vs 50 N		0.4	0.54
50 N vs 78 N		0.78	0.53
34 N vs 78 N		0.27	0.99
Pea vs Durum - 34 N vs 50 N		0.9	0.6
Pea vs Durum - 50 N vs 78 N		0.93	0.2
Durum at 50 N vs Pea at 34 N		0.55	0.1
Durum at 78 N vs Pea at 50 N		0.42	0.76
Durum at 78 N vs Pea at 34 N		0.94	0.71
C.V. (%)		7.2	7.3

Table P.17. Ratio of 50% 1-propanol soluble protein to 50% 1-propanol insoluble protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	2.94	3.15	3.27
Flax	30 AN*	3.00	3.14	3.40
Flax	30 CRU**	3.08	3.16	3.36
Flax	90 AN	2.90	3.14	3.46
Flax	90 CRU	3.08	3.17	3.51
Pea	0	2.91	3.21	3.27
Pea	30 AN	2.98	3.17	3.53
Pea	30 CRU	2.94	3.13	3.41
Pea	90 AN	2.93	3.25	3.51
Pea	90 CRU	3.01	3.08	3.69
LSD (P=0.05)		0.16	ns	0.19
Stubble				
Flax		3.00	3.15	3.40
Pea		2.95	3.17	3.48
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	2.93	3.18	3.27
	30 AN	2.99	3.16	3.46
	30 CRU	3.01	3.14	3.39
	90 AN	2.91	3.20	3.49
	90 CRU	3.04	3.12	3.60
	LSD (P=0.05)	ns	ns	0.14
ANOVA	df		Pr>F	
Stubble (S)	1	0.42	0.7	0.0933
N Applied (kg ha^{-1}) (N)	4	0.0808	0.44	0.0006
N*S	4	0.54	0.6	0.66
Contrasts				
Pea vs Flax at 0 N		0.7	0.72	0.96
Pea vs Flax at 30 N		0.15	0.25	0.19
Pea vs Flax at 90 N		0.64	0.87	0.0812
AN vs CRU		0.0514	0.22	0.72
AN vs CRU - 30 N vs 90 N		0.13	0.48	0.051
0 N vs 30 N		0.1	0.41	0.0112
30N vs 90 N		0.52	0.57	0.0159
Pea vs Flax - 0 N vs 30 N		0.55	0.29	0.48
Pea vs Flax - 30 N vs 90 N		0.44	0.43	0.75
Pea at 30 N vs Flax 90 N		0.58	0.77	0.77
Pea at 0 N vs Flax at 30 N		0.0658	0.79	0.17
Pea at 0 N vs Flax at 90 N		0.26	0.34	0.0109
C.V. (%)		3.4	3.0	3.8

* Ammonium nitrate

** Controlled-release urea

Table P.18. Ratio of 50% 1-propanol soluble protein to 50% 1-propanol insoluble protein of total flour protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied ($kg\ ha^{-1}$)	2000	2001
Durum	34	3.21	3.56
Durum	50	3.24	3.56
Durum	78	3.16	3.52
Pea	34	3.36	3.60
Pea	50	3.37	3.56
Pea	78	3.28	3.62
LSD (P=0.05)		ns	ns
Stubble			
Durum		3.20	3.55
Pea		3.34	3.59
LSD (P=0.05)		ns	ns
	N Applied ($kg\ ha^{-1}$)		
	34	3.28	3.58
	50	3.30	3.56
	78	3.22	3.57
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.0944	0.45
N Applied ($kg\ ha^{-1}$)	2	0.64	0.95
N*S	2	0.99	0.8
Contrasts			
Pea vs Durum at 34N		0.36	0.73
Pea vs Durum at 50N		0.27	0.97
Pea vs Durum at 78N		0.32	0.35
34 N vs 50 N		0.82	0.75
50 N vs 78 N		0.37	0.9
34 N vs 78 N		0.5	0.85
Pea vs Durum - 34 N vs 50 N		0.94	0.83
Pea vs Durum - 50 N vs 78 N		0.96	0.52
Durum at 50 N vs Pea at 34 N		0.37	0.68
Durum at 78 N vs Pea at 50 N		0.12	0.68
Durum at 78 N vs Pea at 34 N		0.15	0.44
C.V. (%)		4.7	3.3

Table P.19. Ratio of 50% 1-propanol soluble protein to 50% 1-propanol insoluble protein at the Carman-00, Carman-01, and Brandon-01 sites.

Treatment		Site		
Stubble	N Applied (kg ha^{-1})	Carman-00	Carman-01	Brandon-01
Flax	0	1.88	1.73	1.65
Flax	30 AN*	2.15	1.70	1.65
Flax	30 CRU**	2.20	1.76	1.68
Flax	90 AN	2.14	1.67	1.81
Flax	90 CRU	2.17	1.71	1.60
Pea	0	2.20	1.84	1.54
Pea	30 AN	2.15	1.74	1.67
Pea	30 CRU	2.16	1.74	1.59
Pea	90 AN	2.16	1.79	1.60
Pea	90 CRU	2.15	1.63	1.79
LSD (P=0.05)		ns	ns	0.16
Stubble				
Flax		2.11	1.71	1.68
Pea		2.16	1.75	1.64
LSD (P=0.05)		ns	ns	ns
	N Applied (kg ha^{-1})			
	0	2.04	1.78	1.60
	30 AN	2.15	1.72	1.66
	30 CRU	2.18	1.75	1.64
	90 AN	2.15	1.73	1.70
	90 CRU	2.16	1.67	1.69
	LSD (P=0.05)	ns	ns	ns
ANOVA	df		Pr>F	
Stubble (S)	1	0.8	0.26	0.31
N Applied (kg ha^{-1}) (N)	4	0.86	0.0813	0.32
N*S	4	0.65	0.0609	0.0203
Contrasts				
Pea vs Flax at 0 N		0.18	0.0574	0.18
Pea vs Flax at 30 N		0.92	0.63	0.5
Pea vs Flax at 90 N		0.98	0.54	0.89
AN vs CRU		0.86	0.58	0.66
AN vs CRU - 30 N vs 90 N		0.91	0.11	0.85
0 N vs 30 N		0.29	0.16	0.28
30N vs 90 N		0.9	0.2	0.23
Pea vs Flax - 0 N vs 30 N		0.16	0.19	0.47
Pea vs Flax - 30 N vs 90 N		0.95	0.93	0.71
Pea at 30 N vs Flax 90 N		0.99	0.15	0.21
Pea at 0 N vs Flax at 30 N		0.89	0.0266	0.0726
Pea at 0 N vs Flax at 90 N		0.82	0.004	0.0253
C.V. (%)		12.7	4.3	6.7

* Ammonium nitrate

** Controlled-release urea

Table P.20. Ratio of 50% 1-propanol soluble protein to 50% 1-propanol insoluble protein at the Swift Current-00 and Swift Current-01 sites.

Treatment		Year	
Stubble	N Applied (kg ha^{-1})	2000	2001
Durum	34	2.11	1.89
Durum	50	2.00	2.03
Durum	78	2.11	1.78
Pea	34	2.10	1.72
Pea	50	1.93	1.73
Pea	78	2.05	1.80
LSD (P=0.05)		ns	ns
Stubble			
Durum		2.07	1.90
Pea		2.03	1.75
LSD (P=0.05)		ns	ns
	N Applied (kg ha^{-1})		
	34	1.96	1.80
	50	2.08	1.88
	78	2.11	1.79
	LSD (P=0.05)	ns	ns
ANOVA	df	Pr > F	
Stubble (S)	1	0.67	0.16
N Applied (kg ha^{-1})	2	0.49	0.72
N*S	2	0.98	0.42
Contrasts			
Pea vs Durum at 34N		0.93	0.35
Pea vs Durum at 50N		0.72	0.1
Pea vs Durum at 78N		0.77	0.88
34 N vs 50 N		0.37	0.53
50 N vs 78 N		0.83	0.47
34 N vs 78 N		0.27	0.92
Pea vs Durum - 34 N vs 50 N		0.85	0.58
Pea vs Durum - 50 N vs 78 N		0.96	0.2
Durum at 50 N vs Pea at 34 N		0.57	0.092
Durum at 78 N vs Pea at 50 N		0.34	0.79
Durum at 78 N vs Pea at 34 N		0.97	0.74
C.V. (%)		10.4	11.4

8.17. APPENDIX Q – RESULTS OF CORRELATION ANALYSIS FOR THE CARMAN, BRANDON, AND SWIFT CURRENT EXPERIMENTAL SITES

Table Q.1. Significant coefficients of correlation (r) for selected quality attributes for the Carman-00 dataset (n = 40).[a]

	Flour Mineral Composition			Protein Composition						Mixograph						Micro-extension					Milling and Baking		
	Flour PC	Flour S	Flour N:S	SP	IG	RP	IP	SP:IG	SP:IP	MDT	PDR	WIP	PBW	BR	SI	Rmax	E at Rmax	E Area	E at Rupture	Rmax/E	FY	FAB	LV
Flour Mineral Composition																							
Flour PC	----																						
Flour S	0.98	----																					
Flour N:S	0.76	0.61	----																				
Protein Composition																							
SP	0.91	0.92	0.61	----																			
IG	0.90	0.91	0.60	0.93	----																		
RP	----	----	----	-0.35	----	----																	
IP	0.64	0.57	0.65	----	0.37	0.78	----																
SP:IG	----	----	----	----	----	----	----	----															
SP:IP	----	----	----	0.56	0.61	-0.94	-0.65	----	----														
Mixograph																							
MDT	-0.80	-0.78	-0.63	-0.72	-0.67	----	-0.53	----	----	----													
PDR	0.93	0.91	0.71	0.85	0.88	----	0.60	----	----	-0.85	----												
WIP	-0.39	-0.39	----	-0.37	----	----	----	----	----	0.79	-0.38	----											
PBW	----	----	0.44	----	----	----	0.34	----	----	-0.41	----	-0.32	----										
BR	0.63	0.60	0.52	0.57	0.60	----	0.41	----	----	-0.59	0.75	----	----	----									
SI	-0.70	-0.72	-0.43	-0.67	-0.62	----	-0.39	----	----	0.87	-0.75	0.69	----	-0.66	----								
Micro-extension																							
Rmax	0.50	0.46	0.48	0.35	0.42	----	0.52	----	----	----	0.44	----	----	----	----	----							
E at Rmax	0.73	0.68	0.65	0.75	0.70	----	0.30	----	0.35	-0.70	0.70	-0.51	----	0.56	-0.61		----						
E Area	0.81	0.75	0.76	0.70	0.74	----	0.60	----	----	-0.65	0.76	-0.32	----	0.49	-0.53	0.76	0.65	----					
E at Rupture	0.69	0.64	0.64	0.72	0.65	----	----	----	0.36	-0.66	.0.65	-0.50	----	0.54	-0.57	----	0.99	0.61	----				
Rmax/E	----	----	----	-0.40	----	----	----	----	-0.37	0.40	----	0.41	----	-0.32	0.36	0.57	-0.80	----	-0.81	----			
Milling and Baking																							
FY	-0.62	-0.56	-0.64	-0.40	-0.46	-0.42	-0.71	----	----	0.39	-0.53	----	0.47	-0.33	----	-0.45	-0.40	-0.58	-0.39	----	----		
FAB	0.83	0.76	0.80	0.77	0.75	----	0.53	----	----	-0.82	0.85	-0.49	----	0.56	-0.63	0.49	0.70	0.78	0.68	----	-0.52	----	
LV	0.74	0.76	0.46	0.68	0.67	----	0.46	----	----	-0.58	0.75	----	----	0.49	-0.56	0.48	0.38	0.60	0.31	----	-0.36	0.51	----

[a] Significant at $P < 0.05$.

[b] Flour PC = flour protein concentration, Flour S = flour S concentration, Flour N:S = flour N:S ratio, SP = flour soluble protein content, IG = flour insoluble glutenin content, RP = flour residue protein content, flour IP = flour insoluble glutenin content, SP:IG = ratio of SP to IG, SP:IP = ratio of SP to IP, MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak band width, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FY = flour yield. FAB = Farinograph water absorption, LV = loaf volume.

Table Q.2. Significant coefficients of correlation (r) for selected quality attributes at the Swift Current-00 site (n = 18).[a,b,c]

	Flour Mineral Composition			Protein Composition						Mixograph						Micro-extension					Baking		
	Flour PC	Flour S	Flour N:S	SP	IG	RP	IP	SP:IG	SP:IP	MDT	PDR	WIP	PBW	BR	SI	Rmax	E at Rmax	E Area	E at Rupture	Rmax/E	FY	FAB	LV
Flour Mineral Composition																							
Flour PC	----																						
Flour S	0.92	----																					
Flour N:S	0.54	----	----																				
Protein Composition																							
SP	0.98	0.87	0.54	----																			
IG	0.89	0.80	0.51	0.94	----																		
RP	0.48	----	----	----	----	----																	
IP	0.90	0.82	----	0.78	0.67	0.79	----																
SP:IG	----	----	----	----	----	0.53	----	----															
SP:IP	----	----	----	----	----	-0.80	----	----	----														
Mixograph																							
MDT	-0.76	-0.75	----	-0.72	-0.60	-0.50	-0.73	----	----	----													
PDR	0.96	0.89	0.52	0.92	0.82	0.53	0.89	----	----	-0.90	----												
WIP	----	-0.49	----	----	----	----	----	----	----	----	-0.62	----											
PBW	0.90	0.82	0.51	0.89	0.87	----	0.77	----	----	0.51	0.90	-0.49	----										
BR	0.94	0.90	----	0.90	0.80	0.54	0.89	----	----	-0.68	0.91	----	0.79	----									
SI	----	----	----	----	----	----	----	-0.60	----	0.68	----	0.80	----	----	----								
Micro-extension																							
Rmax	----	----	----	----	----	0.85	----	----	----	----	----	----	----	----	----	----							
E at Rmax	0.87	0.92	----	0.85	0.75	0.52	0.81	----	----	-0.82	0.89	-0.61	0.81	0.78	----	----	----						
E Area	0.68	0.75	----	0.67	0.62	----	0.62	----	----	-0.60	0.68	----	0.62	0.63	----	0.64	0.75	----					
E at Rupture	0.82	0.88	----	0.77	0.66	0.59	0.81	----	----	-0.79	0.84	-0.61	0.73	0.71	----	----	0.97	0.70	----				
Rmax/E	-0.64	-0.67	----	-0.59	-0.53	----	-0.65	----	----	0.73	-0.70	0.63	-0.64	-0.52	----	0.51	-0.84	----	-0.85	----			
Milling and Baking																							
FY	----	----	----	----	----	----	----	----	----	-0.74	0.57	-0.79	----	----	-0.76	----	----	----	----	-0.62	----		
FAB	0.78	0.71	0.48	0.80	0.70	----	0.63	----	----	-0.85	0.84	-0.76	0.73	0.65	-0.53	----	0.78	----	0.75	-0.69	0.70	----	
LV	0.86	0.77	0.55	0.84	0.77	----	0.78	----	----	-0.82	0.91	-0.54	0.76	0.78	----	----	0.77	0.59	0.76	-0.61	0.57	0.82	----

[a] Significant at $P < 0.05$.

[b] For correlations involving micro-extension tests, n = 17.

[c] Flour PC = flour protein concentration, Flour S = flour S concentration, Flour N:S = flour N:S ratio, SP = flour soluble protein content, IG = flour insoluble glutenin content, RP = flour residue protein content, flour IP = flour insoluble glutenin content, SP:IG = ratio of SP to IG, SP:IP = ratio of SP to IP, MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak band width, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FY = flour yield. FAB = Farinograph water absorption, LV = loaf volume.

Table Q.3. Significant coefficients of correlation (r) for selected quality attributes Carman-01 site (n = 40).[a,b]

	Flour Mineral Composition			Protein Composition						Mixograph						Micro-extension					Milling and Baking		
	Flour PC	Flour S	Flour N:S	SP	IG	RP	IP	SP:IG	SP:IP	MDT	PDR	WIP	PBW	BR	SI	Rmax	E at Rmax	E Area	E at Rupture	Rmax/E	FY	FAB	LV
Flour Mineral Composition																							
Flour PC	----																						
Flour S	0.88	----																					
Flour N:S	----	----	----																				
Protein Composition																							
SP	0.76	0.77	----	----																			
IG	----	----	----	----	----																		
RP	0.69	0.51	0.42	----	-0.71	----																	
IP	0.76	0.57	0.45	----	-0.52	0.97	----																
SP:IG	0.74	0.69	----	0.56	-0.68	0.66	0.57	----															
SP:IP	-0.33	----	-0.44	0.35	0.60	-0.88	-0.86		----														
Mixograph																							
MDT	-0.44	-0.44	----	-0.35	----	-0.31	-0.32	-0.42	----	----													
PDR	0.64	0.58	----	0.51	----	0.44	0.46	0.57	----	-0.63	----												
WIP	----	----	----	----	----	----	----	----	----	0.83	----	----											
PBW	----	----	----	----	-0.34	0.34	----	----	-0.40	----	----	----	----										
BR	----	----	----	----	-0.40	----	----	----	----	----	----	----	-0.76	----									
SI	----	----	----	-0.38	----	----	----	----	----	0.84	-0.55	0.69	0.56	-0.38	----								
Micro-extension																							
Rmax	----	----	----							----	----	----	----	----	----	----							
E at Rmax	0.39	0.45	----	0.46	0.46	----	----	0.35	----	----	0.38	----	----	----	----	----	----						
E Area	0.39	0.38	----	0.41	----	----	----	0.40	----	----	0.43	----	----	----	----	0.80	0.48	----					
E at Rupture	0.43	0.54	----	0.46	----	----	----	0.37	----	----	0.38	----	----	----	----	----	0.89	0.50	----				
Rmax/E	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.80	-0.65	----	-0.55	----			
Milling and Baking																							
FY	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-0.41	----	----	----	----	----	----		
FAB	0.44	0.43	----	0.39	0.39	----	----	0.33	----	-0.60	0.51	-0.49	----	----	-0.59	----	----	----	----	----	----	----	
LV	----	----	----	----	----	-0.37	-0.38	-0.41	----	----	----	----	----	----	----	0.32	----	----	----	----	----	----	----

[a] Significant at $P < 0.05$.

[b] Flour PC = flour protein concentration, Flour S = flour S concentration, Flour N:S = flour N:S ratio, SP = flour soluble protein content, IG = flour insoluble glutenin content, RP = flour residue protein content, flour IP = flour insoluble glutenin content, SP:IG = ratio of SP to IG, SP:IP = ratio of SP to IP, MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak band width, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FY = flour yield. FAB = Farinograph water absorption, LV = loaf volume.

Table Q.4. Significant coefficients of correlation (r) for selected quality attributes at the Brandon-01 site (n = 40).[a,b]

	Flour Mineral Composition			Protein Composition						Mixograph						Micro-extension					Milling and Baking		
	Flour PC	Flour S	Flour N:S	SP	IG	RP	IP	SP:IG	SP:IP	MDT	PDR	WIP	PBW	BR	SI	Rmax	E at Rmax	E Area	E at Rupture	Rmax/E	FY	FAB	LV
Flour Mineral Composition																							
Flour PC	----																						
Flour S	0.92	----																					
Flour N:S	0.68	0.40	----																				
Protein Composition																							
SP	0.89	0.86	0.50	----																			
IG	0.84	0.75	0.59	0.83	----																		
RP	0.60	0.50	0.57	----	----	----																	
IP	0.78	0.66	0.67	0.40	0.55	0.96	----																
SP:IG	0.45	0.54	----	0.67	----	----	----	----															
SP:IP	----	----	----	0.46	----	-0.78	-0.63	0.58	----														
Mixograph																							
MDT	-0.73	-0.77	-0.34	-0.73	-0.53	-0.34	-0.45	-0.60	----	----													
PDR	0.95	0.94	0.54	0.91	0.81	----	0.66	0.54	----	-0.84	----												
WIP	-0.50	-0.55	----	-0.53	----	----	----	-0.56	----	0.93	-0.62	----											
PBW	----	----	----	-0.36	----	----	----	----	-0.33	----	----	----	----										
BR	0.85	0.78	0.64	0.81	0.72	0.43	0.59	0.47	----	-0.52	0.79	----	-0.50	----									
SI	-0.73	-0.75	-0.40	-0.79	-0.57	----	-0.36	-0.65	----	0.89	-0.80	0.79	0.49	-0.67	----								
Micro-extension																							
Rmax	-0.38	-0.46	----	-0.53	-0.40	----	----	-0.41	-0.41	0.40	-0.42	----	0.42	-0.42	0.53	----							
E at Rmax	0.75	0.68	0.43	0.74	0.58	0.35	0.48	0.54	----	-0.62	0.74	-0.45	----	0.62	-0.59	-0.51	----						
E Area	----	----	0.34	----	----	0.32	----	----	-0.34	----	----	----	0.40	----	----	----	----	----					
E at Rupture	0.74	0.68	0.41	0.75	0.57	0.32	0.45	0.57	----	-0.59	0.72	-0.42	----	0.65	-0.58	-0.54	0.94	----	----				
Rmax/E	-0.61	-0.63	----	-0.70	-0.54	----	----	-0.53	-0.34	0.57	-0.64	0.43	0.32	-0.56	0.64	0.90	-0.83	0.53	-0.82	----			
Milling and Baking																							
FY	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----		
FAB	0.90	0.89	0.54	0.85	0.73	0.48	0.63	0.53	----	-0.53	0.92	-0.70	----	0.73	-0.86	-0.38	-0.38	----	0.62	-0.56	----	----	
LV	0.82	0.76	0.53	0.79	0.69	0.40	0.55	0.47	----	-0.79	0.86	-0.63	----	0.64	-0.77	-0.39	-0.40	----	0.62	-0.59	----	0.85	----

[a] Significant at $P < 0.05$.

[b] Flour PC = flour protein concentration, Flour S = flour S concentration, Flour N:S = flour N:S ratio, SP = flour soluble protein content, IG = flour insoluble glutenin content, RP = flour residue protein content, flour IP = flour insoluble glutenin content, SP:IG = ratio of SP to IG, SP:IP = ratio of SP to IP, MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak band width, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FY = flour yield. FAB = Farinograph water absorption, LV = loaf volume.

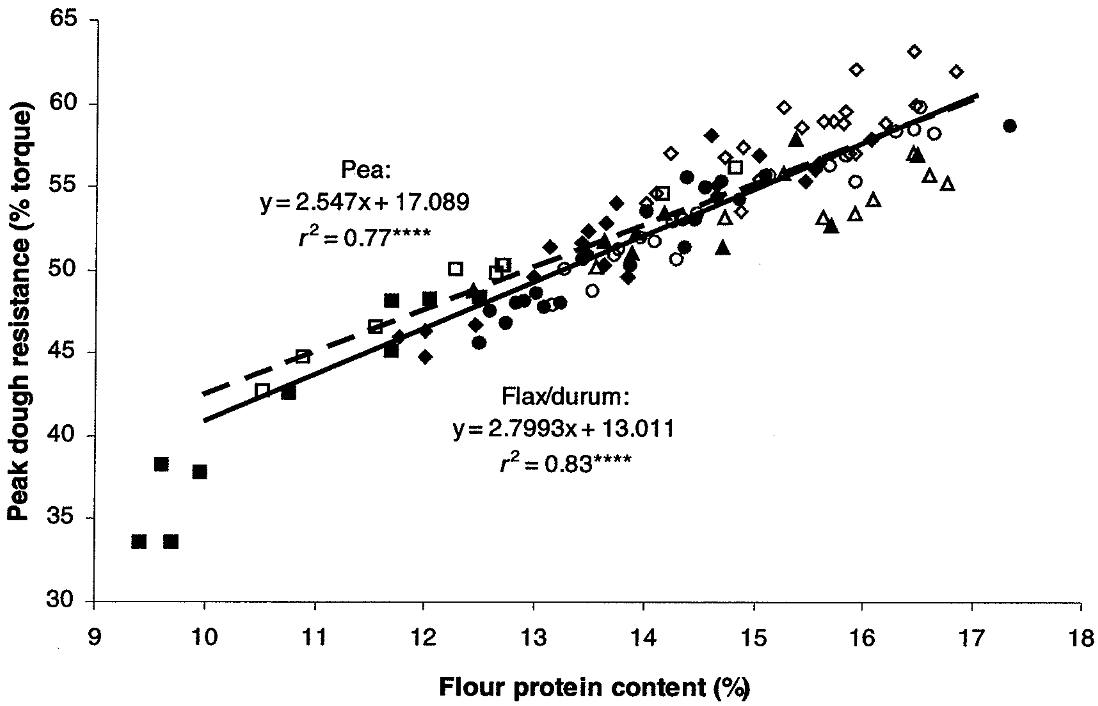
Table Q.5. Significant coefficients of correlation (r) for selected quality attributes at the Swift Current-01 site (n = 18).[a,b]

	Flour Mineral Composition			Protein Composition						Mixograph						Micro-extension					Milling and Baking		
	Flour PC	Flour S	Flour N:S	SP	IG	RP	IP	SP:IG	SP:IP	MDT	PDR	WIP	PBW	BR	SI	Rmax	E at Rmax	E Area	E at Rupture	Rmax/E	FY	FAB	LV
Flour Mineral Composition																							
Flour PC	----																						
Flour S	0.79	----																					
Flour N:S	0.71	----	----																				
Protein Composition																							
SP	0.87	0.66	0.66	----																			
IG	0.84	0.63	0.69	0.92	----																		
RP	0.77	0.65	0.49	----	----	----																	
IP	0.90	0.73	0.61	0.57	0.59	0.97	----																
SP:IG	----	----	----	----	----	----	----	----															
SP:IP	-0.55	----	----	----	----	-0.94	-0.85	----	----														
Mixograph																							
MDT	-0.89	-0.76	-0.54	-0.75	-0.61	-0.76	-0.83	----	0.55	----													
PDR	0.81	0.68	0.62	0.82	0.88	----	0.62	----	----	-0.61	----												
WIP	-0.74	-0.62	----	-0.62	----	-0.66	-0.68	----	----	0.92	----	----											
PBW	----	----	----	----	----	----	----	----	----	----	----	----	----										
BR	0.87	0.73	0.58	0.84	0.79	0.58	0.71	----	----	-0.86	0.74	-0.78	----	----									
SI	-0.81	-0.55	-0.62	-0.74	-0.58	-0.62	-0.70	----	----	0.90	-0.48	0.90	----	-0.83	----								
Micro-extension																							
Rmax	----	----	----	----	----	----	----	-0.62	----	----	----	----	----	----	----	----							
E at Rmax	0.52	0.57	----	----	----	0.51	0.55	----	----	-0.48	0.56	----	----	0.62	----	----	----						
E Area	----	----	----	----	----	----	----	-0.67	----	----	----	----	0.47	----	----	0.80	0.49	----					
E at Rupture	0.57	0.61	----	----	----	0.57	0.61	----	-0.49	-0.57	0.53	----	----	0.65	----	----	0.97	0.42	----				
Rmax/E	----	-0.48	----	----	----	----	----	----	----	----	----	0.49	----	----	----	0.85	-0.62	----	-0.66	----			
Milling and Baking																							
FY	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----		
FAB	0.83	0.51	0.78	0.69	0.63	0.69	0.77	----	-0.54	-0.80	0.70	-0.65	----	0.73	-0.66	----	----	----	0.49	----	----	----	
LV	0.85	0.60	0.63	0.81	0.75	0.58	0.70	----	----	-0.79	0.70	-0.67	----	0.75	----	----	----	----	----	----	----	0.78	----

[a] Significant at $P < 0.05$.

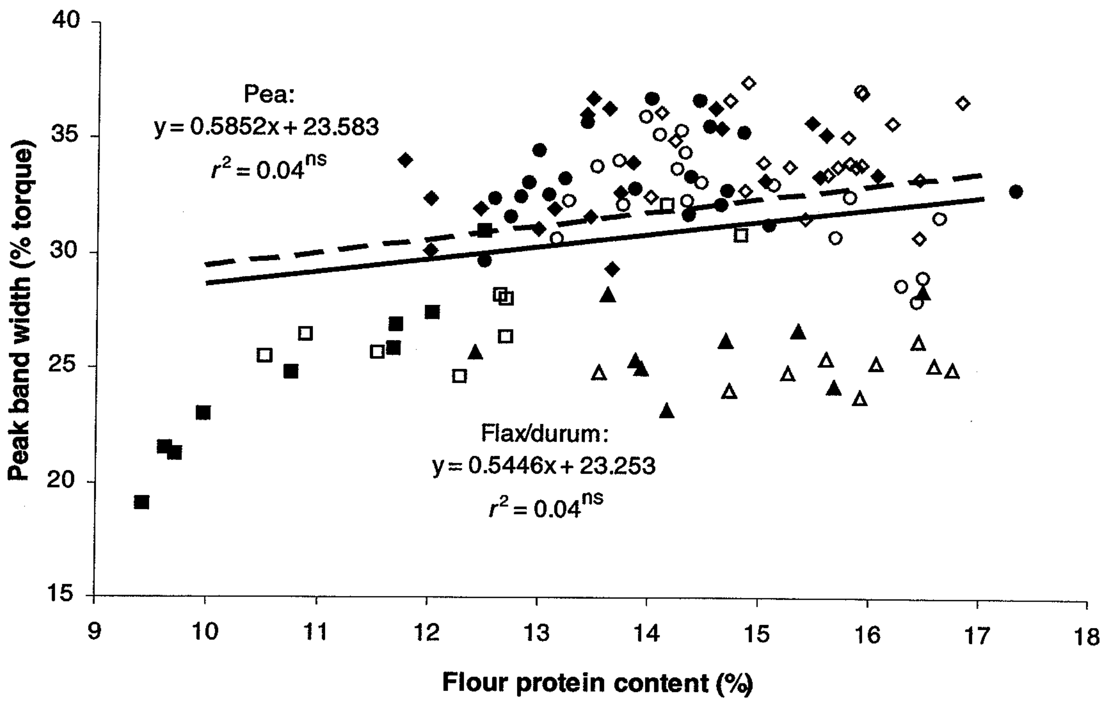
[b] Flour PC = flour protein concentration, Flour S = flour S concentration, Flour N:S = flour N:S ratio, SP = flour soluble protein content, IG = flour insoluble glutenin content, RP = flour residue protein content, flour IP = flour insoluble glutenin content, SP:IG = ratio of SP to IG, SP:IP = ratio of SP to IP, MDT = dough development time, PDR = peak dough resistance, WIP = work input-to-peak, PBW = peak band width, BR = breakdown resistance, SI = strength index. Rmax = maximum dough resistance to extension, E at Rmax = extensibility at Rmax, E Area = extensigram area, E = extensibility at dough rupture, Rmax/E = visco-elastic ratio, FY = flour yield. FAB = Farinograph water absorption, LV = loaf volume.

8.18. APPENDIX R – PLOTS OF SELECT END-USE QUALITY PARAMETERS VERSUS FLOUR PROTEIN CONTENT FOR THE CARMAN-00, SWIFT CURRENT-00, BRANDON-01, AND SWIFT CURRENT-01 SITES AS AFFECTED BY PREVIOUS CROP



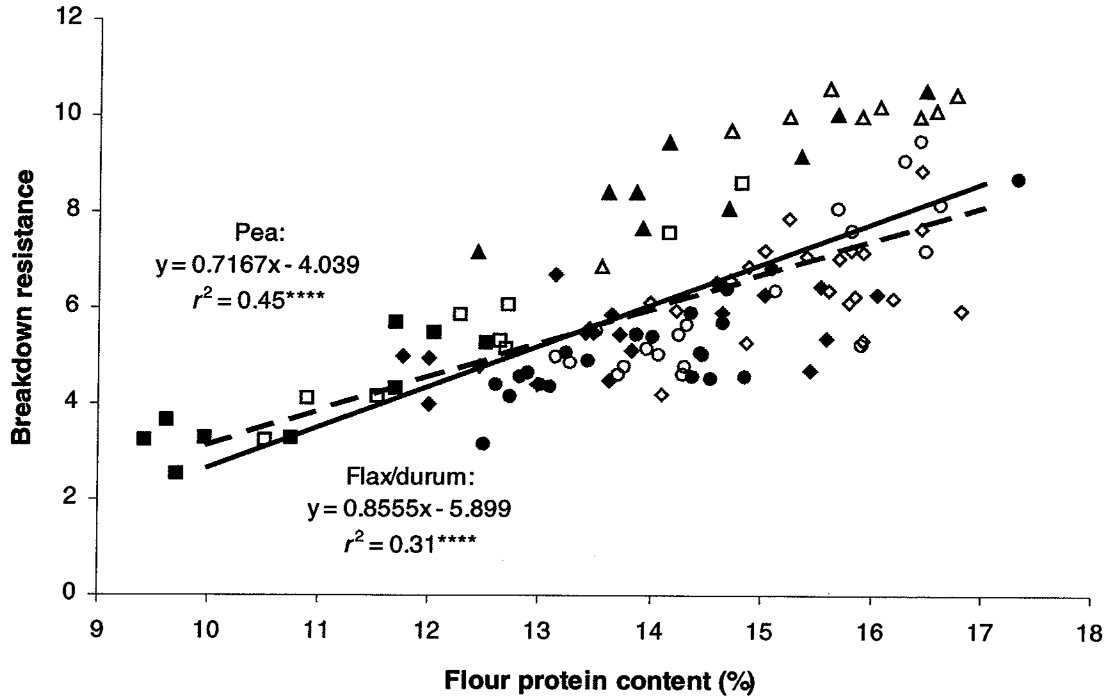
[a] **** = significant at $P < 0.0001$.

Figure R. 1. Effect of previous crop on Mixograph peak dough resistance. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



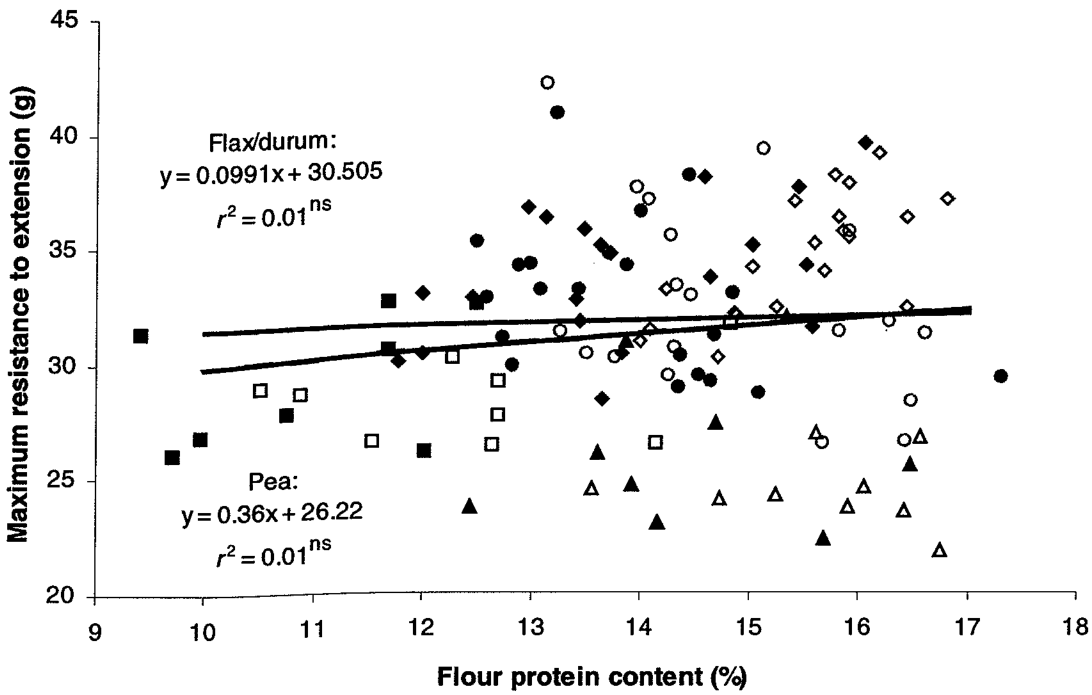
[a] ns = not significant.

Figure R. 2. Effect of previous crop on Mixograph peak band width. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



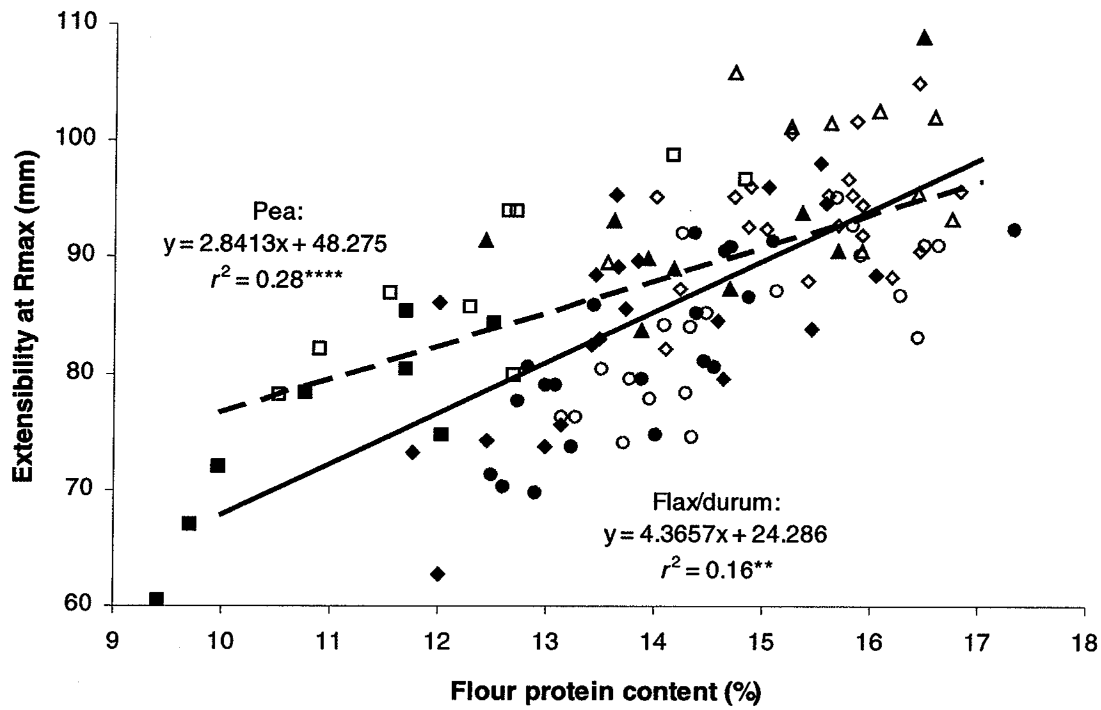
[a] **** = significant at $P < 0.0001$.

Figure R. 3. Effect of previous crop on Mixograph dough breakdown resistance. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (●), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



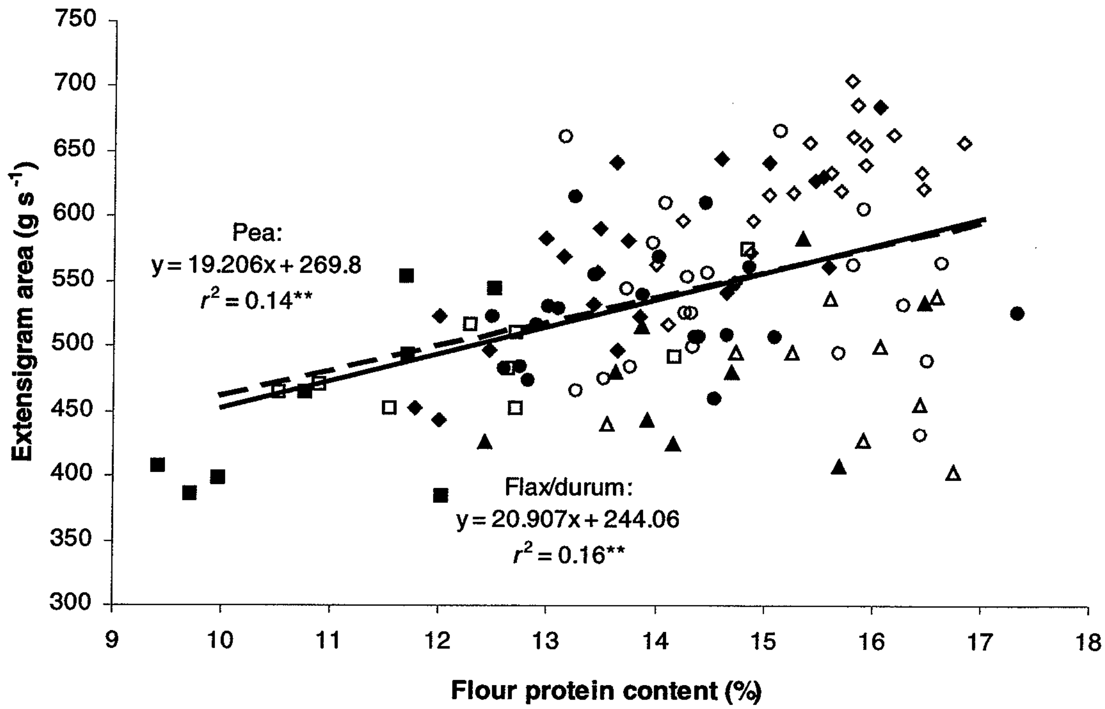
[a] ns = not significant.

Figure R. 4. Effect of previous crop on dough maximum resistance to extension. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



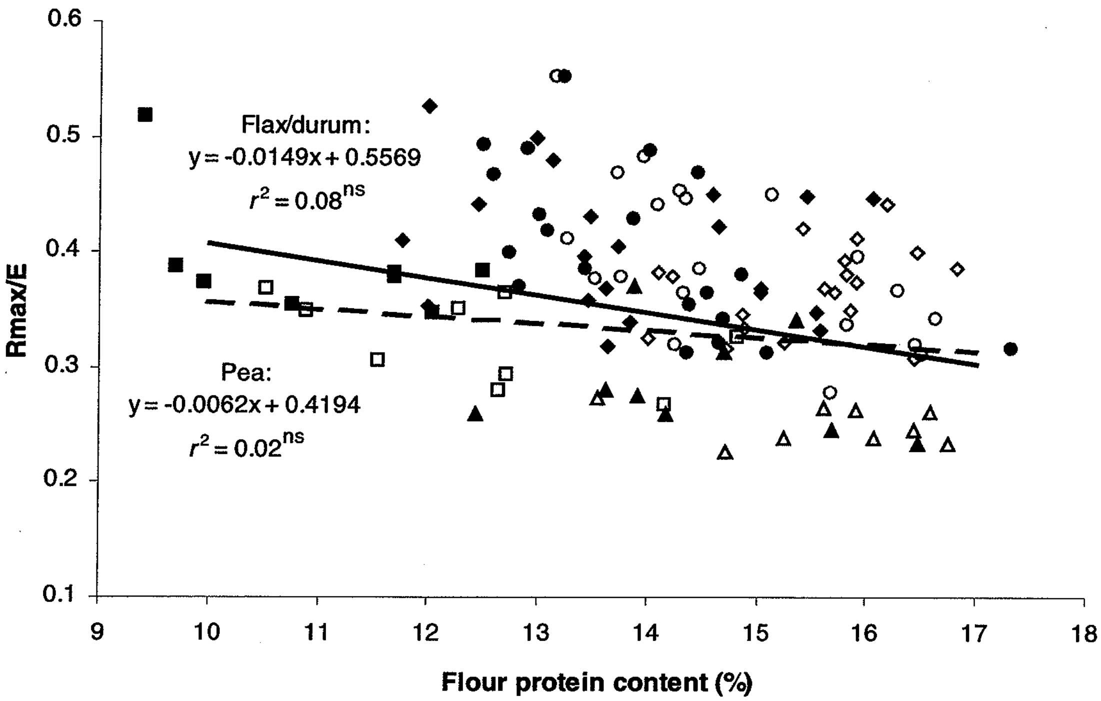
[a] **, **** = significant at $P < 0.01$ and 0.0001, respectively.

Figure R. 5. Effect of previous crop on dough extensibility at Rmax. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



[a] ** = significant at $P < 0.01$.

Figure R. 6. Effect of previous crop on extensigram area. Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]



[a] ns = not significant.

Figure R. 7. Effect of previous crop on dough visco-elastic ratio (Rmax/E). Closed symbols represent flax/durum stubble while open symbols represent pea stubble. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Brandon-01 (•), and Swift Current-01 (▲). The independent variable is flour protein content. Data falling outside the common range of flour protein content were excluded from analysis.[a]

8.19 APPENDIX S - DESCRIPTION OF SAMPLING METHODOLOGY AND LOCATION OF IMMATURE HEAD SAMPLES COLLECTED AT THE CARMAN-00, CARMAN-01, BRANDON-01, AND SWIFT CURRENT-01 SITES

As part of a separate study intended to evaluate the evolution of protein composition during kernel development, heads from main stems were collected on a weekly basis during the growing season at all sites excluding the Swift Current-00 site. Commencing 14 days after anthesis (DAA), 20 heads were randomly removed from main stems of each sub-plot with the sampling area until maturity. Care was taken to not collect heads from sub-plot edges. Samples were placed in re-sealable bags and placed in a cooler full of ice as son as possible after sampling in order to arrest kernel metabolic processes. Samples were stored in cold storage (-20°C) in the main building of the Department of Plant Science. Please contact Dr. M. H. Entz in the Department of Plant Science or Dr. D. N. Flaten in the Department of Soil Science for further information.

Labeling of sample bags was carried out using a simple numbering system, where the number represents plot number. Sampling date was as also placed on each sample bag as "TX", where "X" represents the number of weeks after anthesis. Therefore, "T0" represents the anthesis sampling date (0 weeks after anthesis), "T1" represents 1 week after anthesis, etc. The last sampling date at the Carman-00, Carman-01, and Swift Current-01 sites was designated as "T5" (5 weeks after anthesis), while heads were collected at the Brandon-01 site until 42 DAA (6 weeks after anthesis).

8.20. APPENDIX T – SCATTERPLOTS OF SELECT END-USE QUALITY PARAMETERS VERSUS SELECT PROTEIN COMPOSITION PARAMETERS FOR THE CARMAN-00, SWIFT CURRENT-00, CARMAN-01, BRANDON-01, AND SWIFT CURRENT-01 SITES

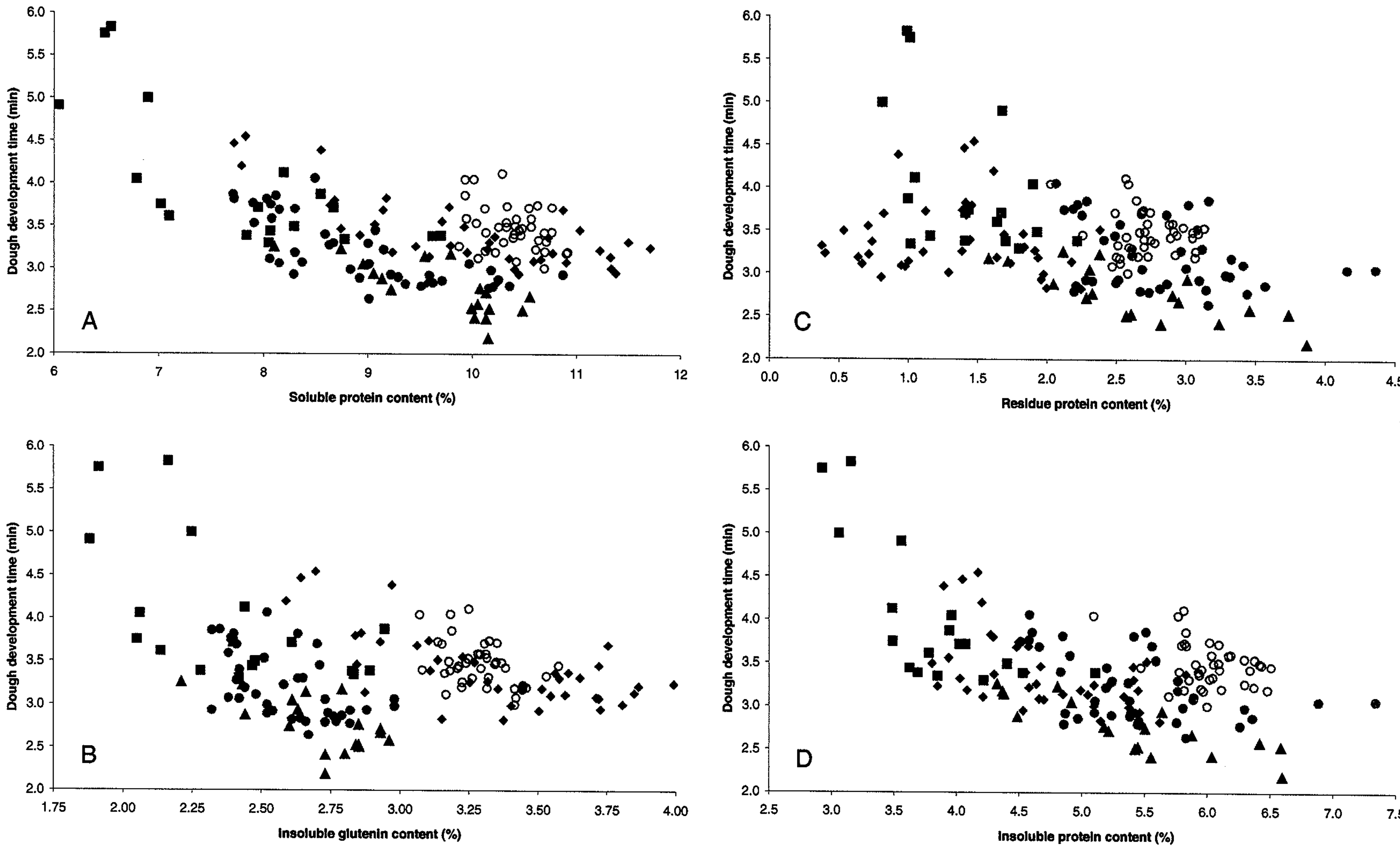


Figure T. 1. Scatterplots of Mixograph dough development time versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

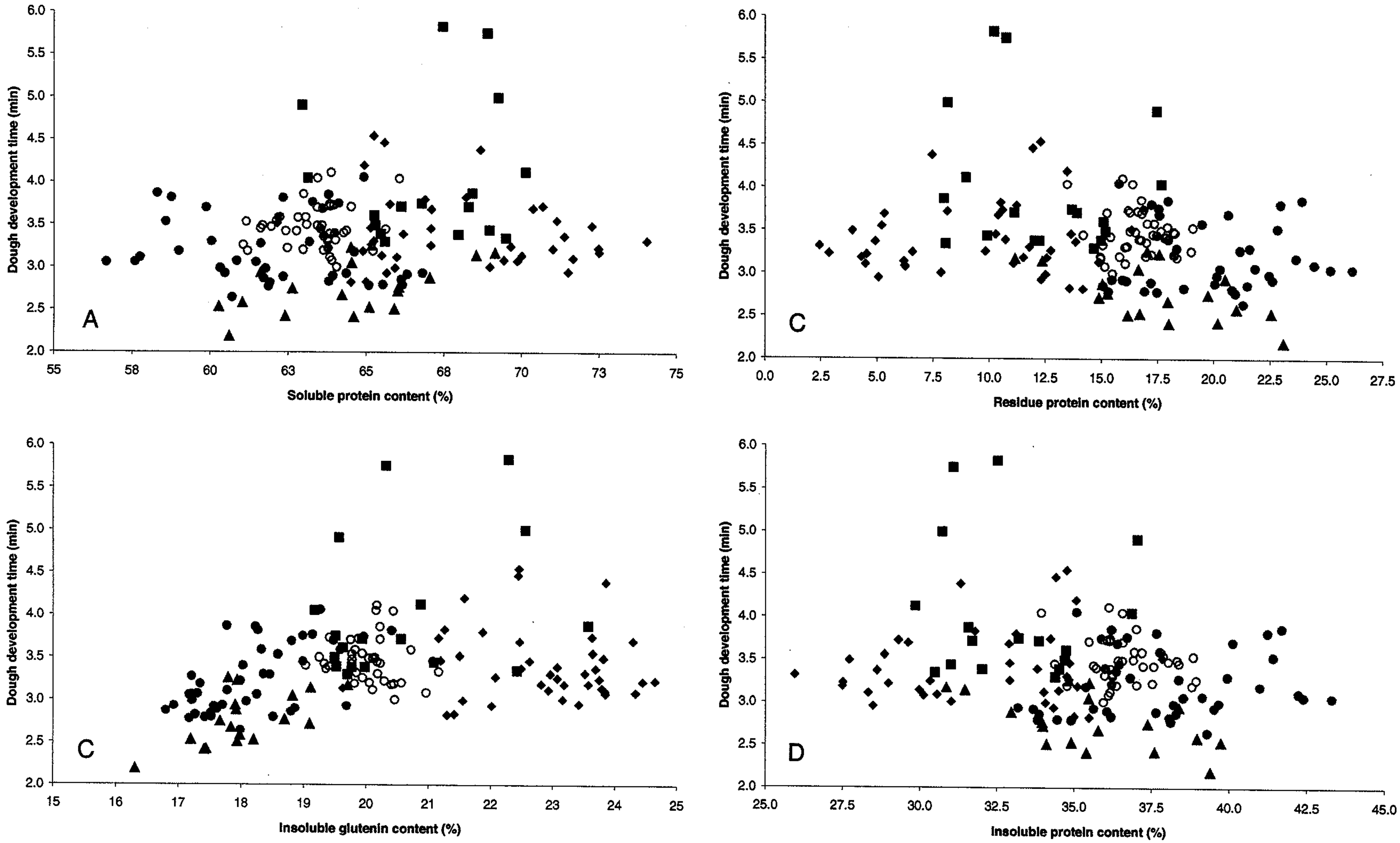


Figure T. 2. Scatterplots of Mixograph dough development time versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (●), and Swift Current-01 (▲).

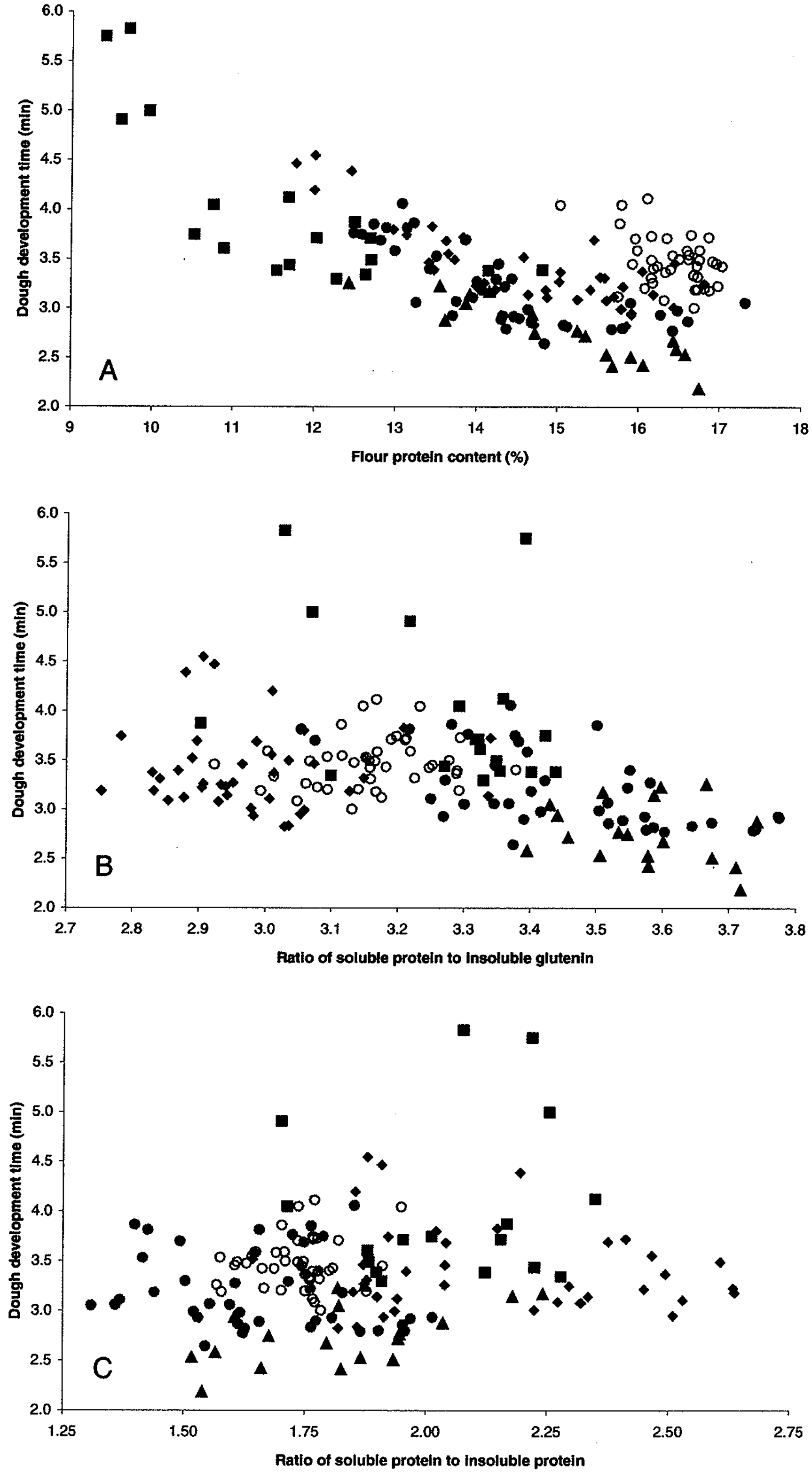


Figure T. 3. Scatterplots of Mixograph dough development time versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

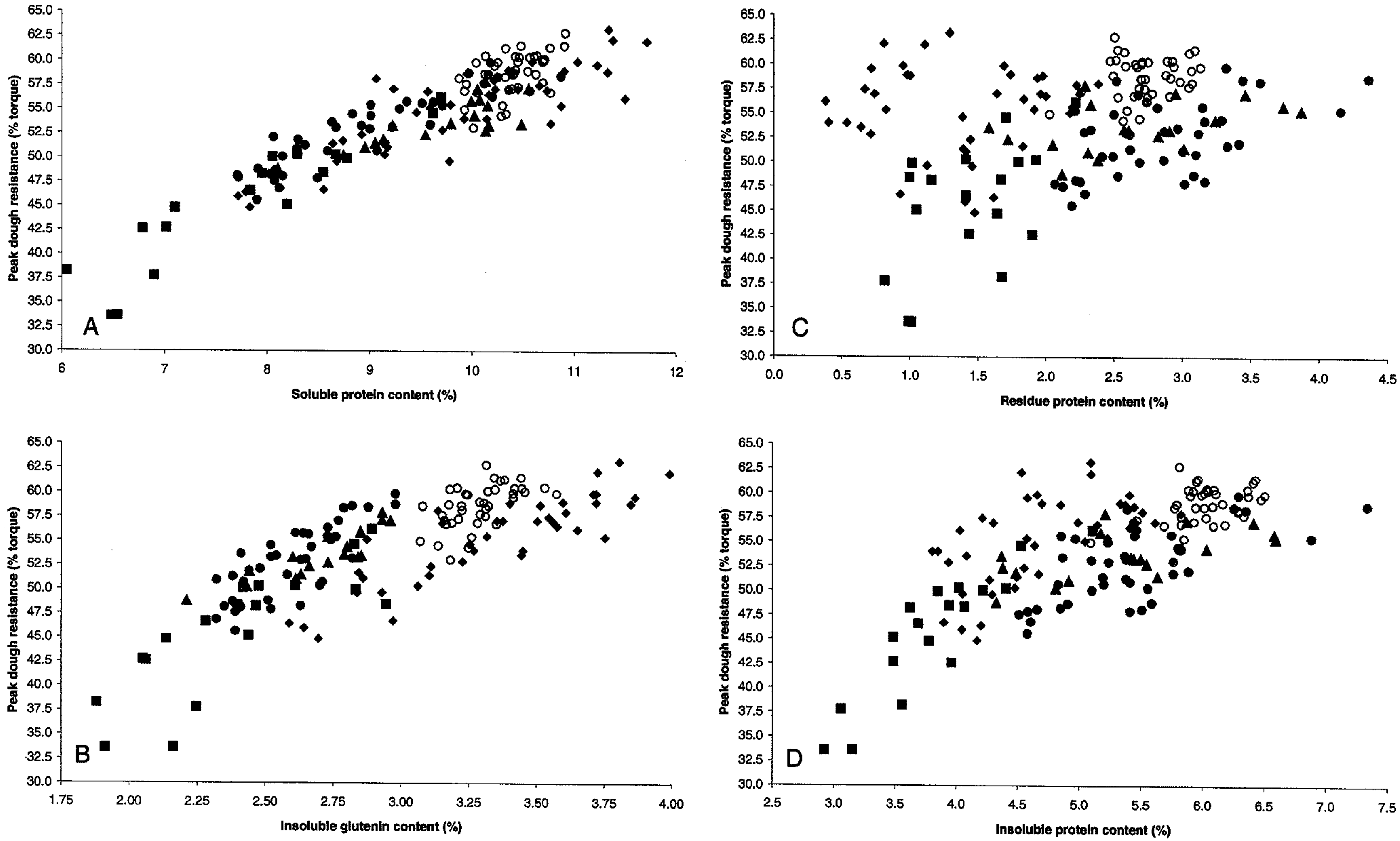


Figure T. 4. Scatterplots of Mixograph peak dough resistance versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

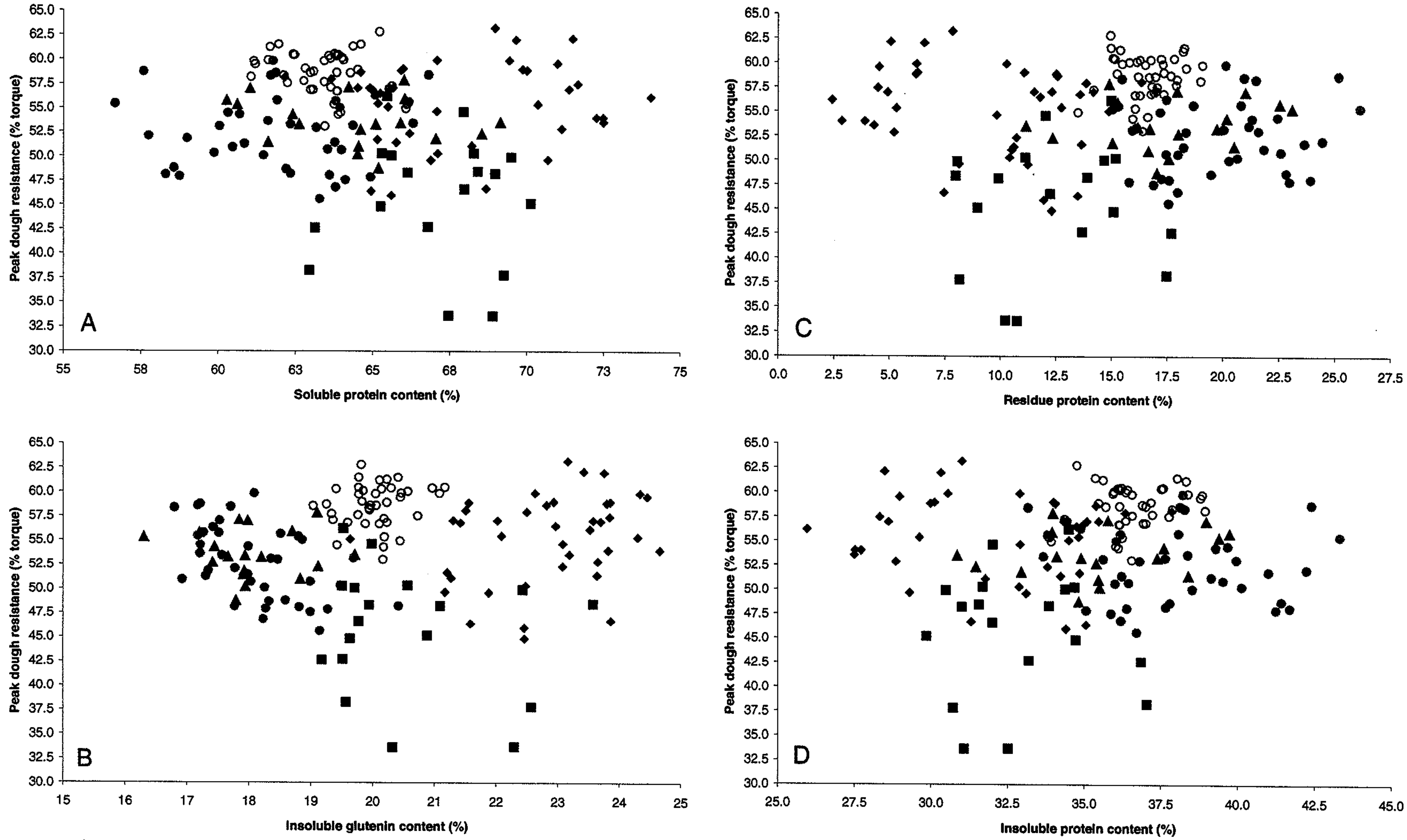


Figure T. 5. Scatterplots of Mixograph peak dough resistance versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

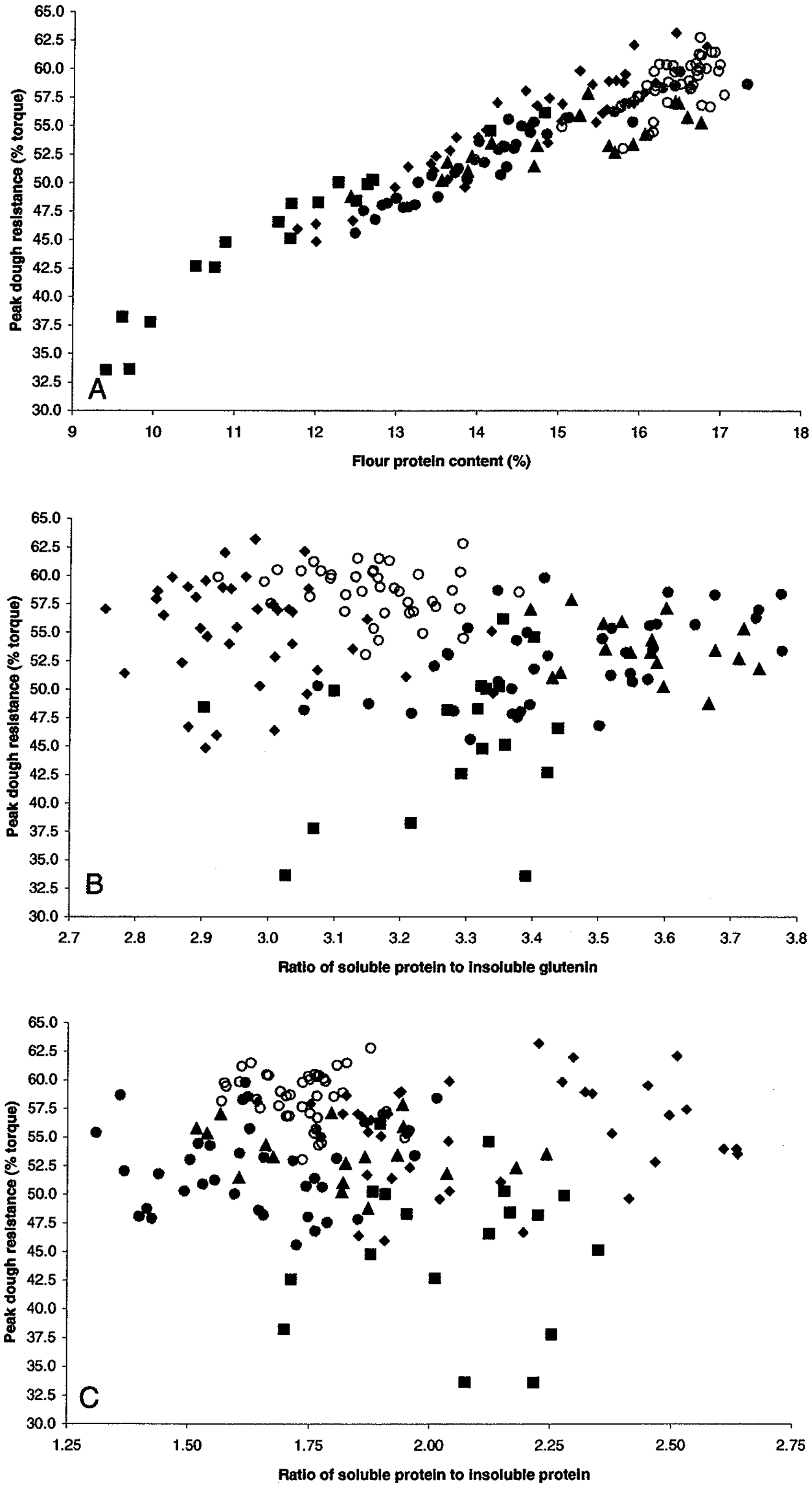


Figure T. 6. Scatterplots of Mixograph peak dough resistance versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

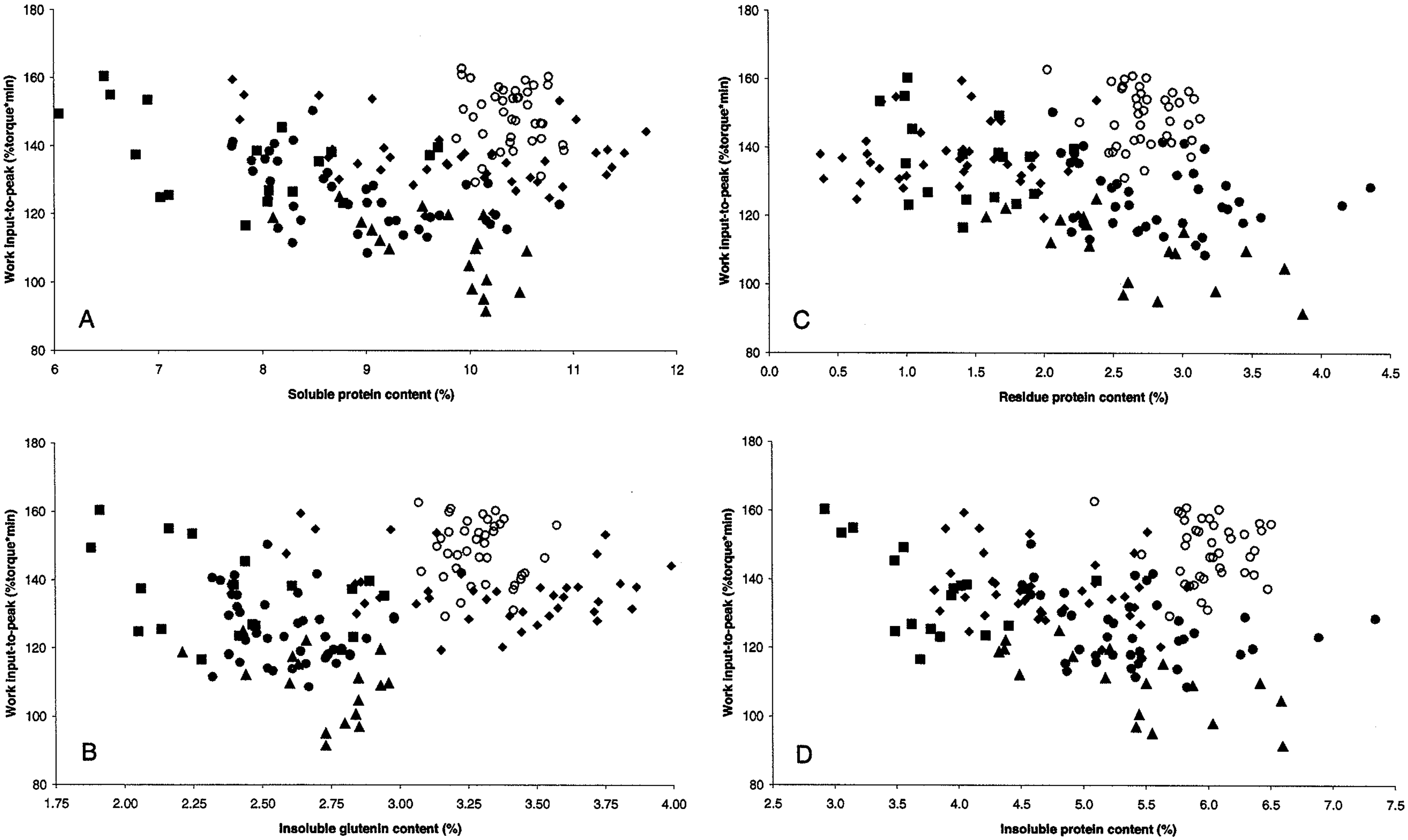


Figure T. 7. Scatterplots of Mixograph work input-to-peak versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

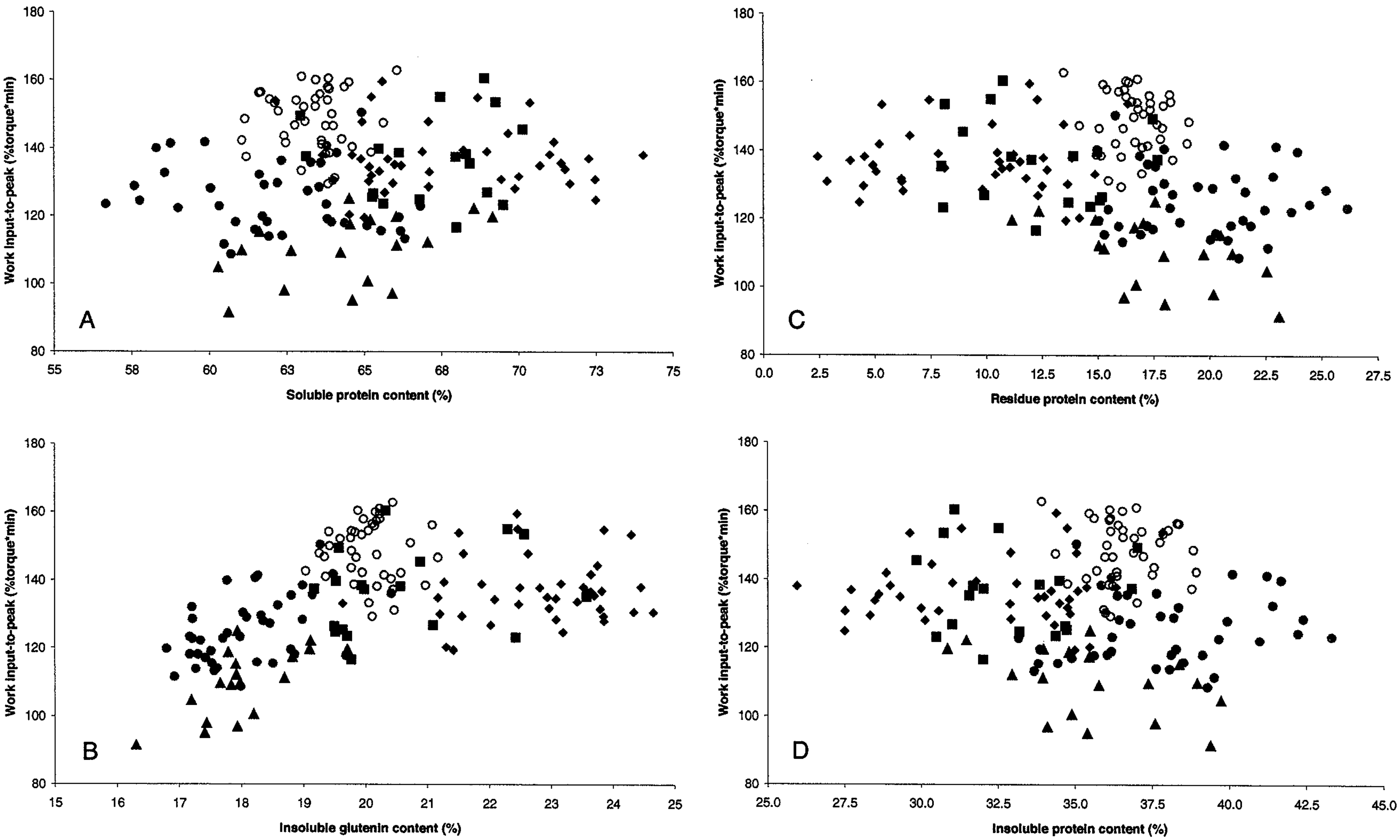


Figure T. 8. Scatterplots of Mixograph work input-to-peak versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

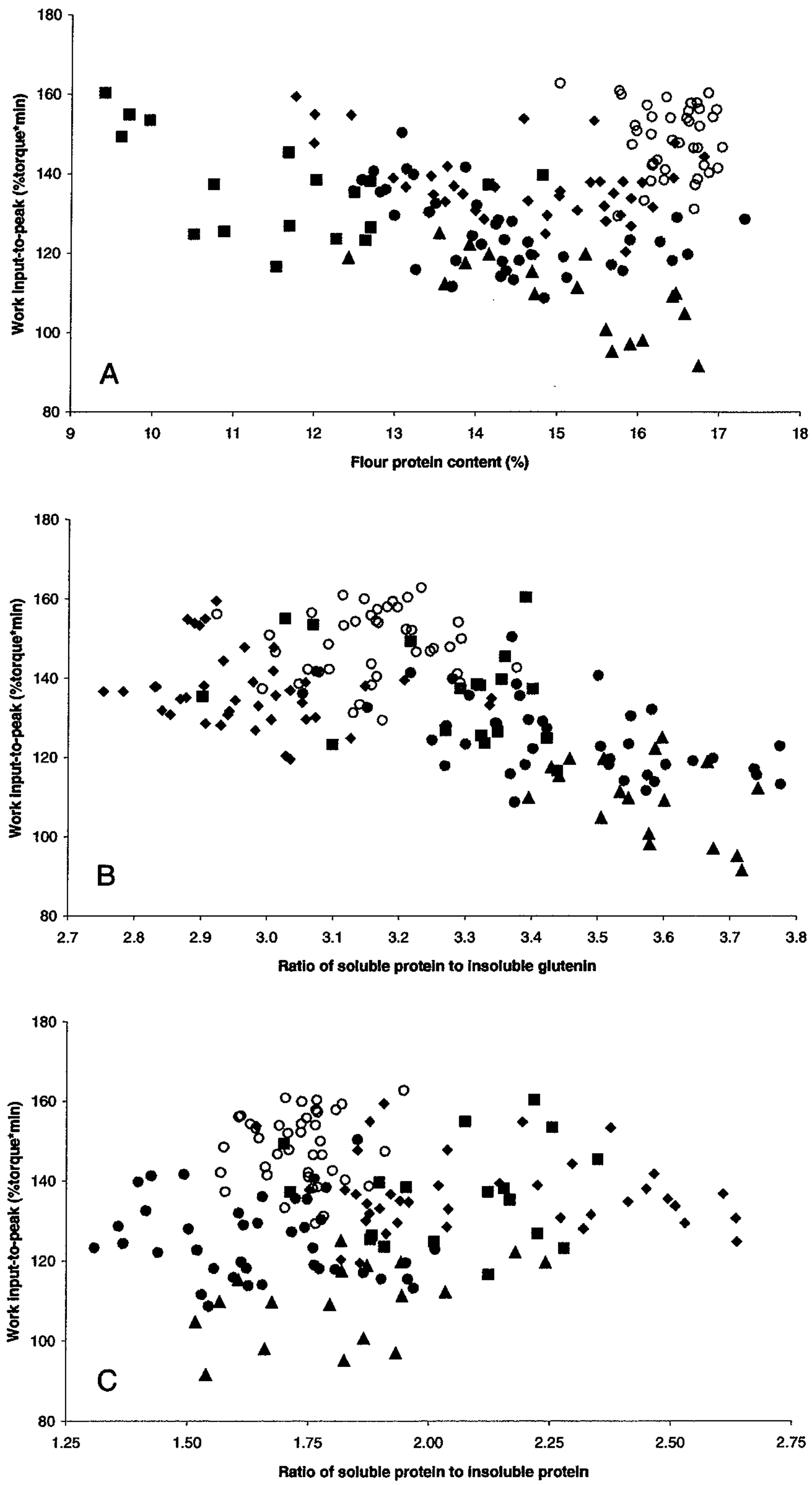


Figure T. 9. Scatterplots of Mixograph work input-to-peak versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

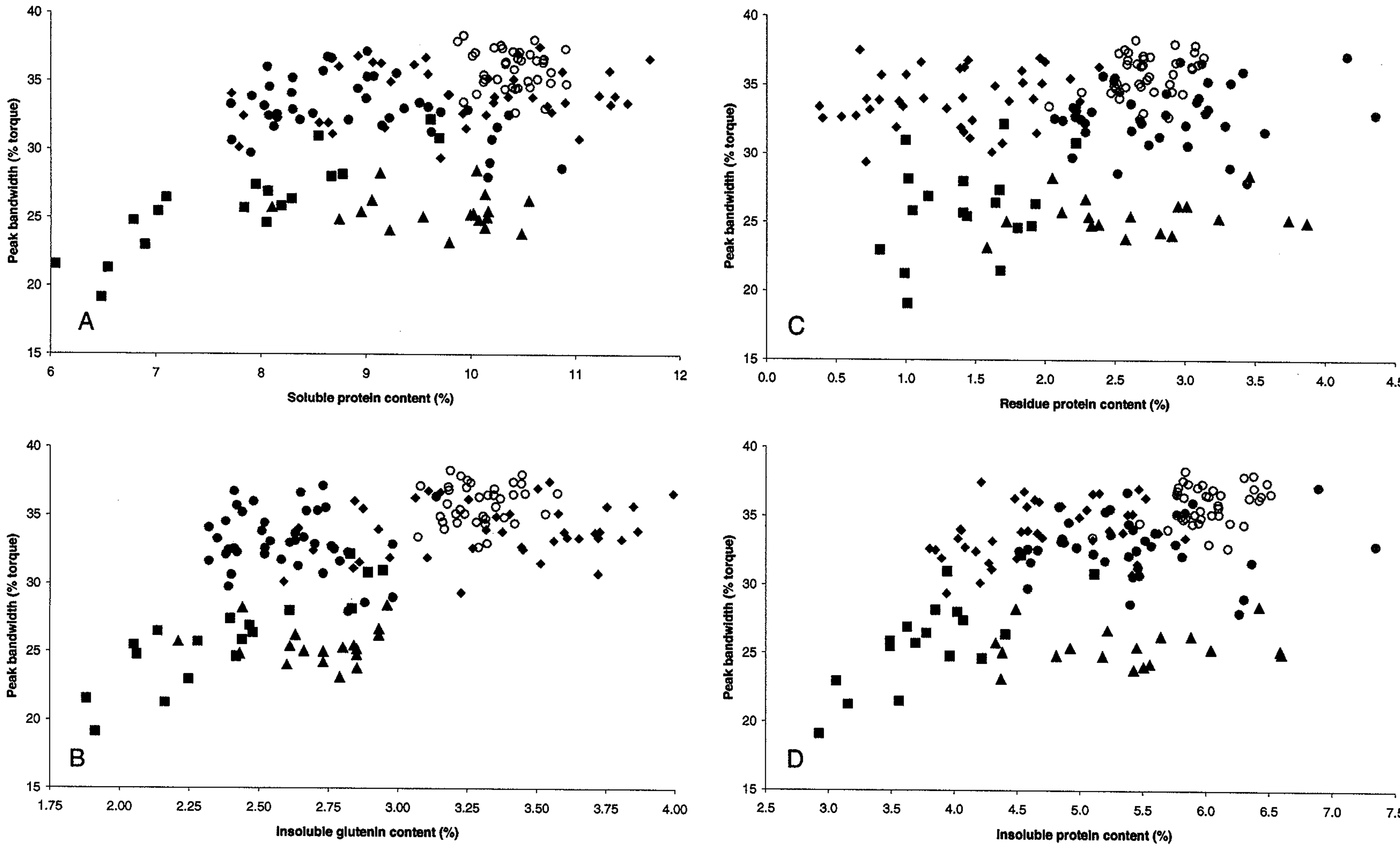


Figure T. 10. Scatterplots of Mixograph peak bandwidth versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

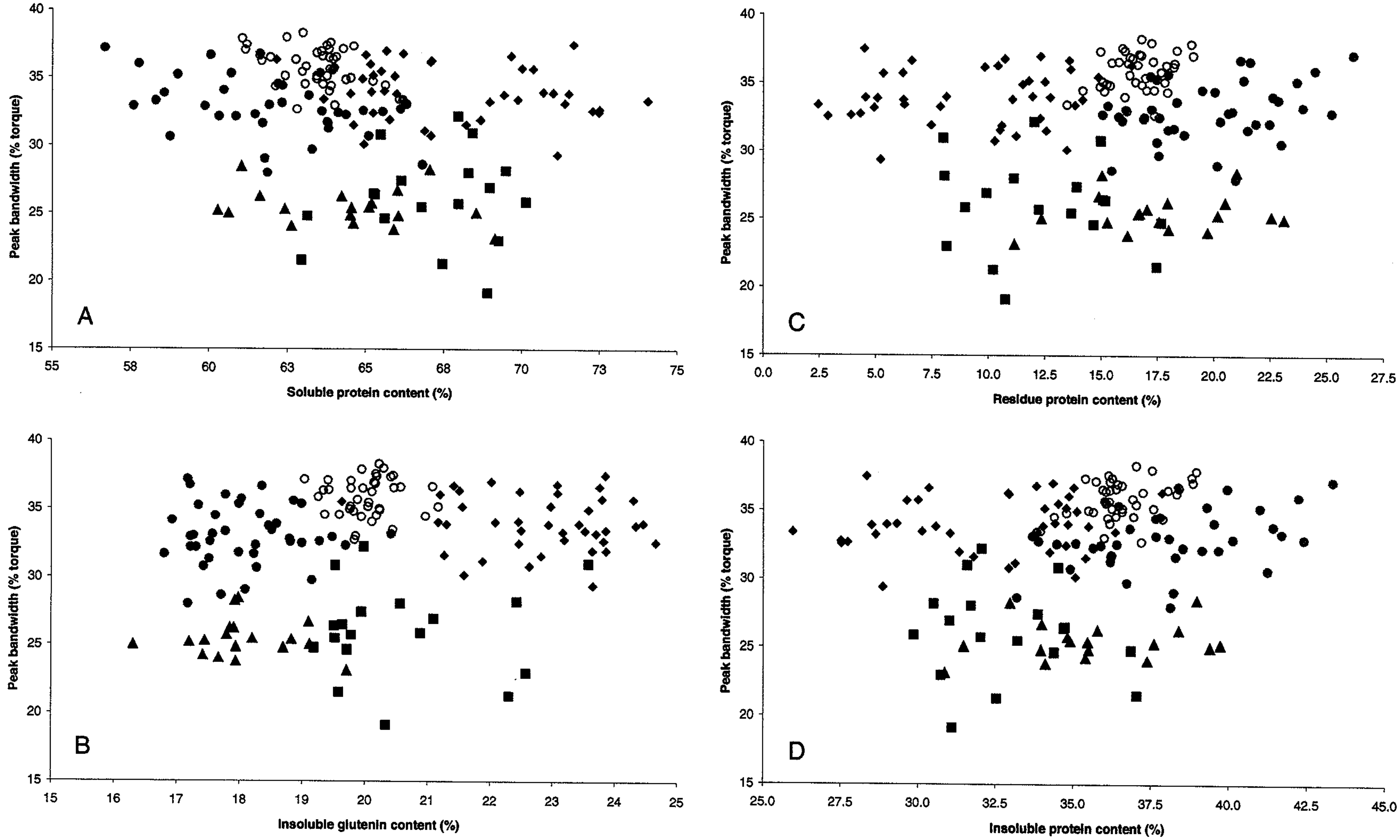


Figure T. 11. Scatterplots of Mixograph peak bandwidth versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

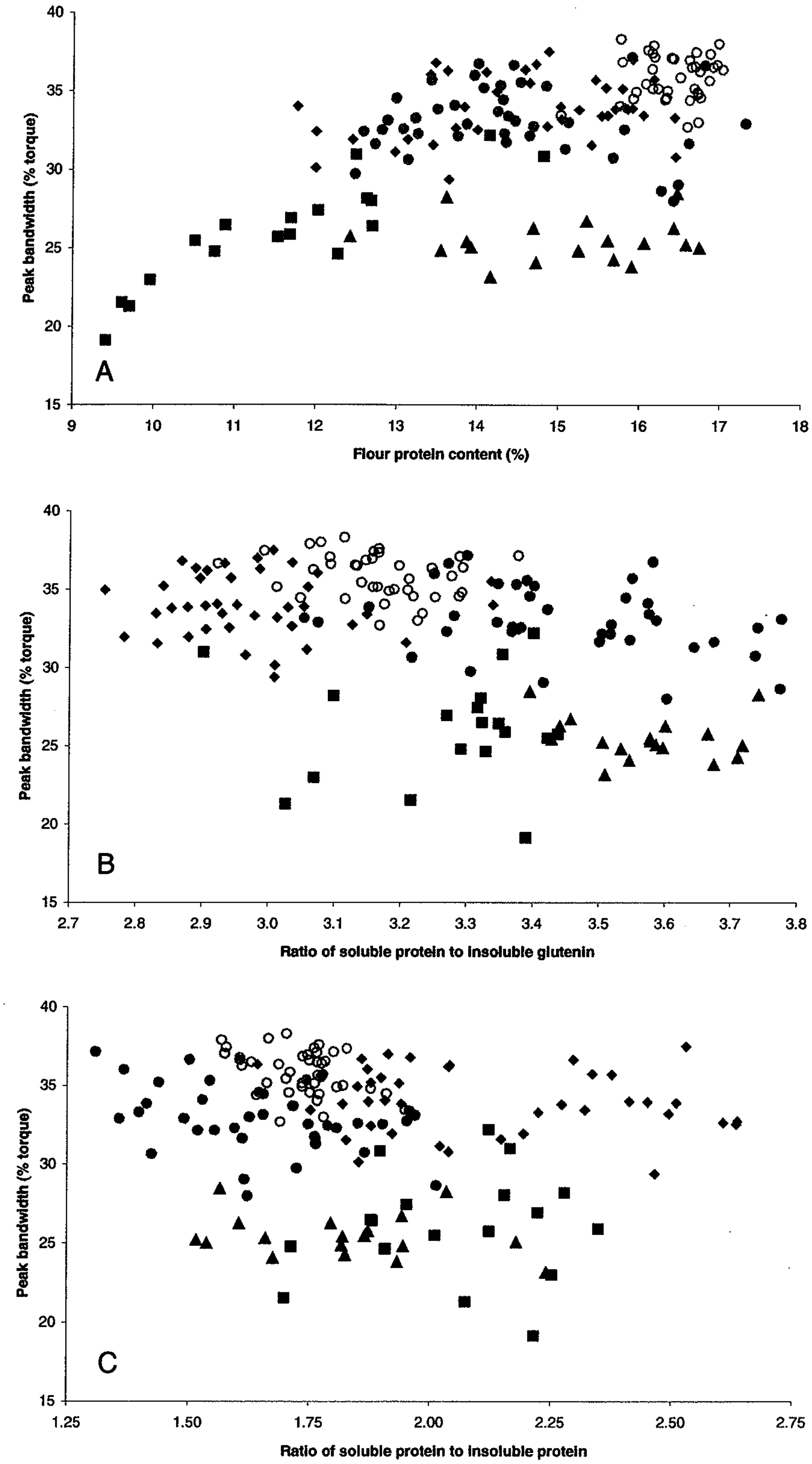


Figure T. 12. Scatterplots of Mixograph peak bandwidth versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

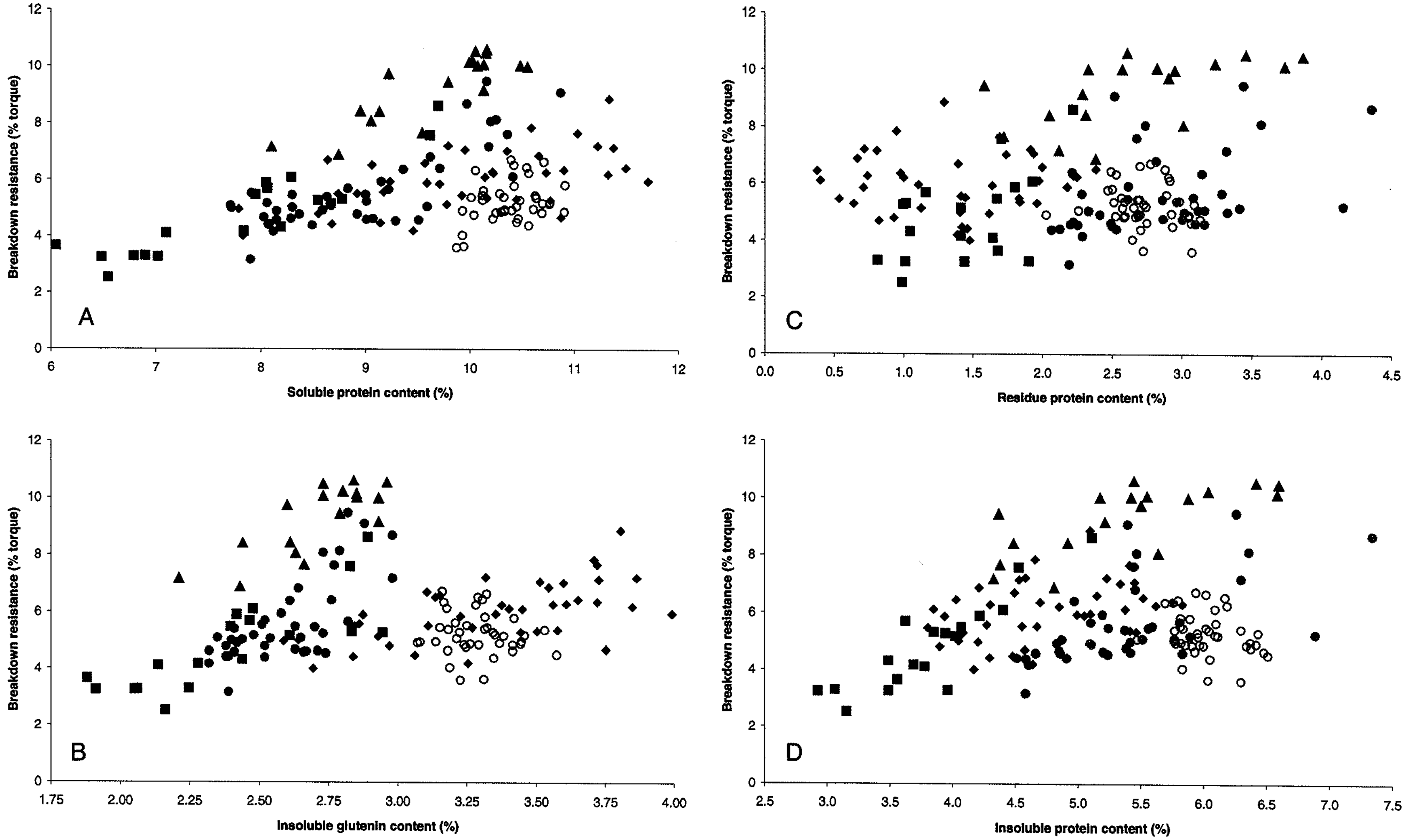


Figure T. 13. Scatterplots of Mixograph breakdown resistance versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

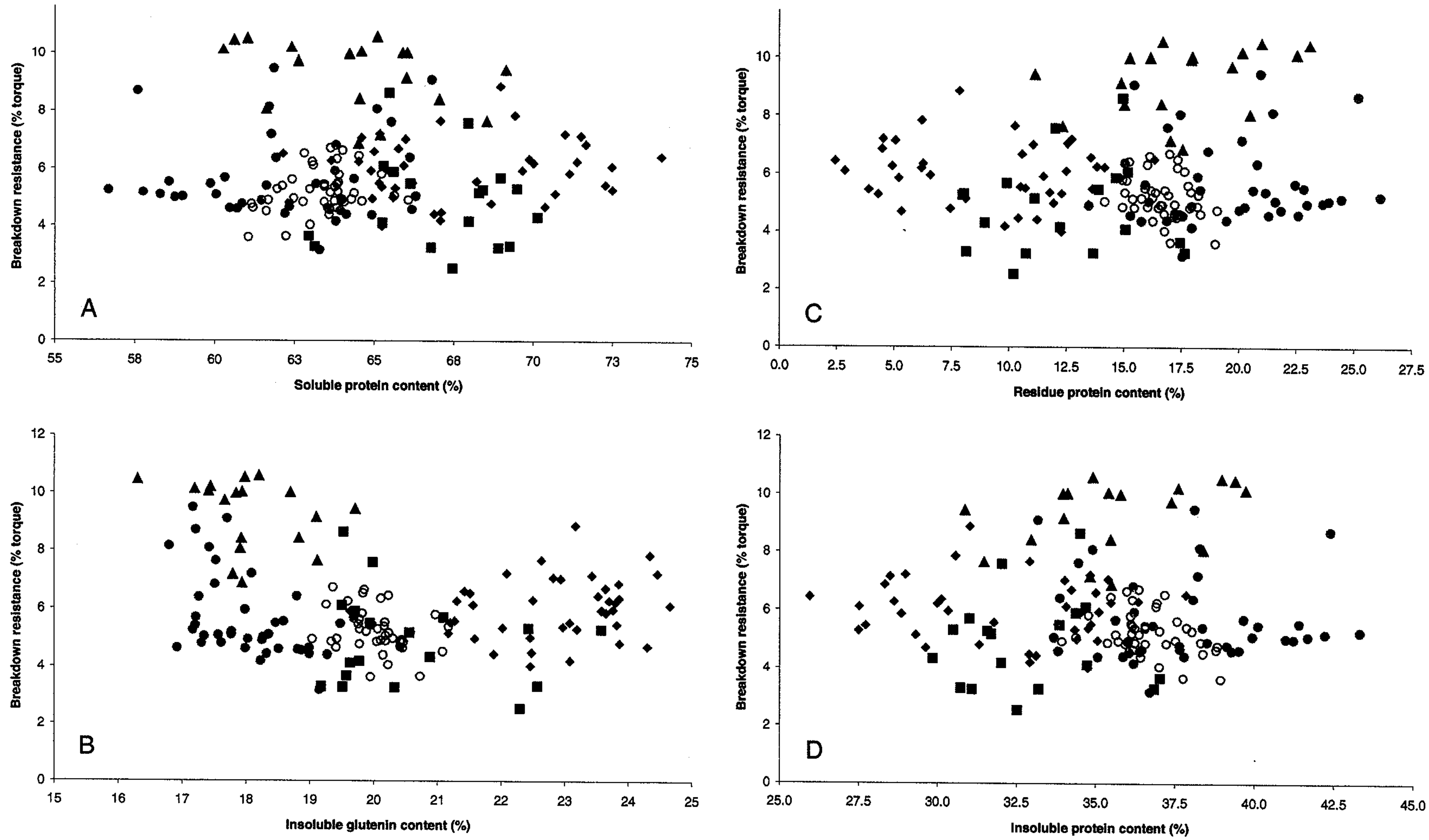


Figure T. 14. Scatterplots of Mixograph breakdown resistance versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

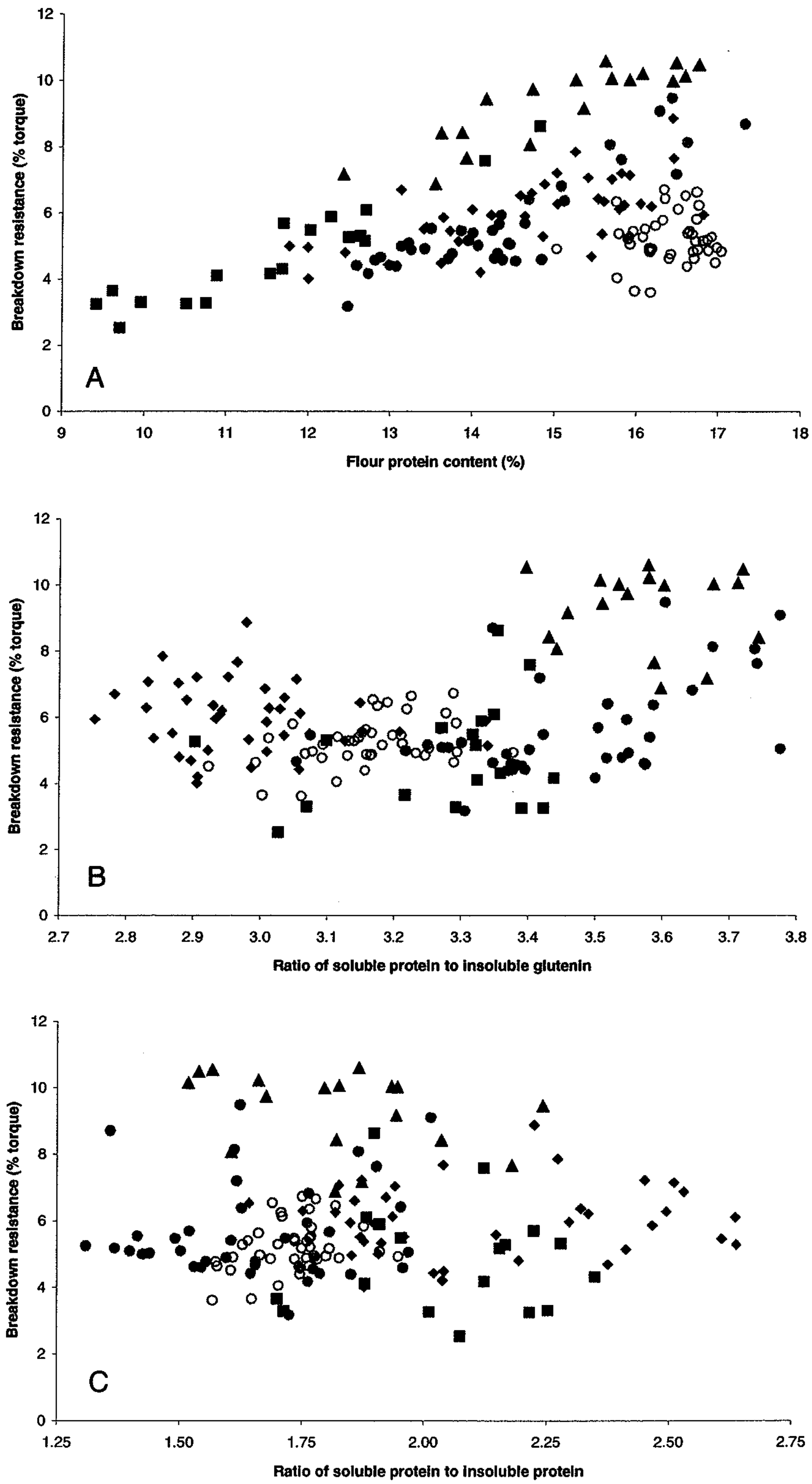


Figure T. 15. Scatterplots of Mixograph breakdown resistance versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

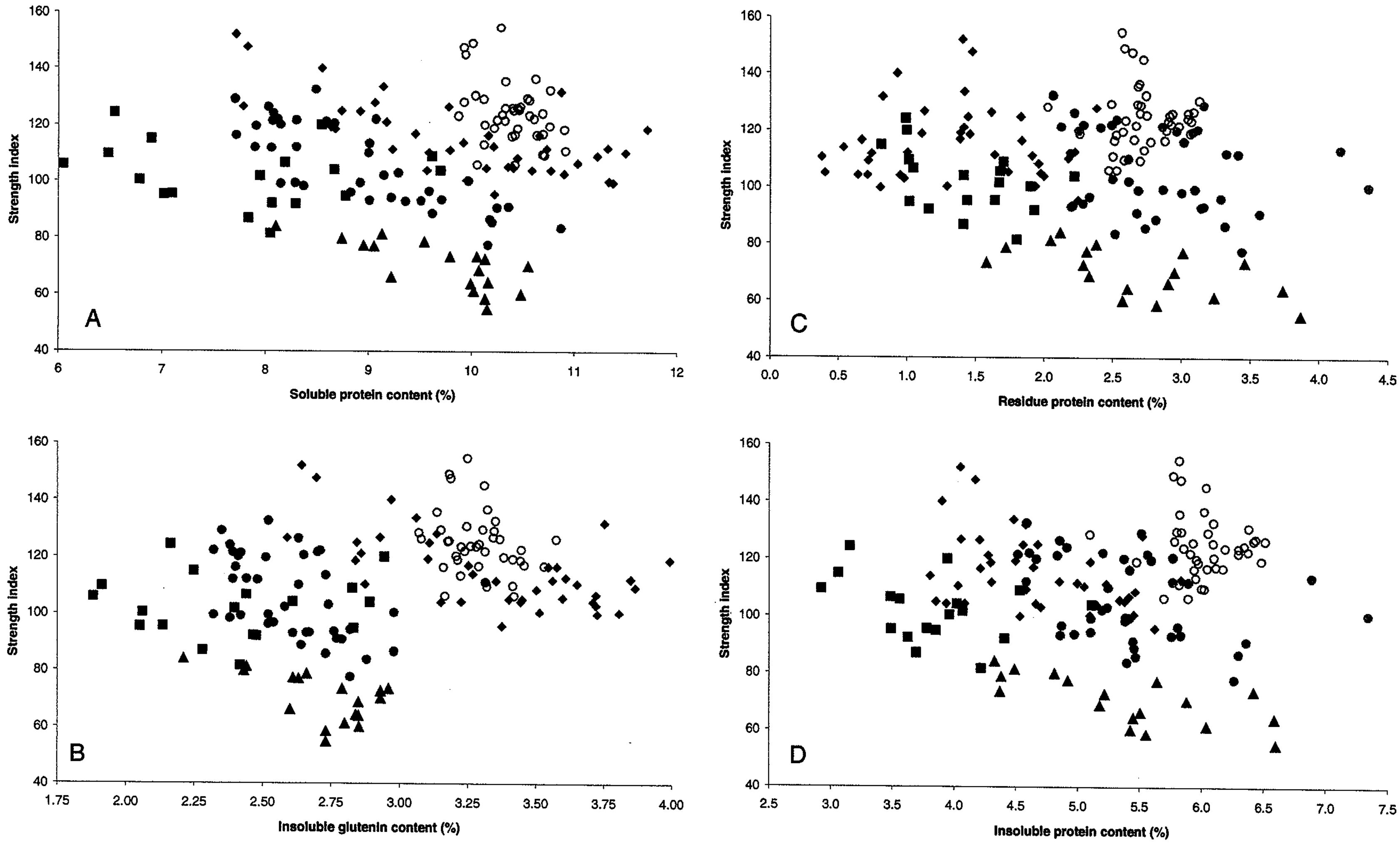


Figure T. 16. Scatterplots of Mixograph dough strength index versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

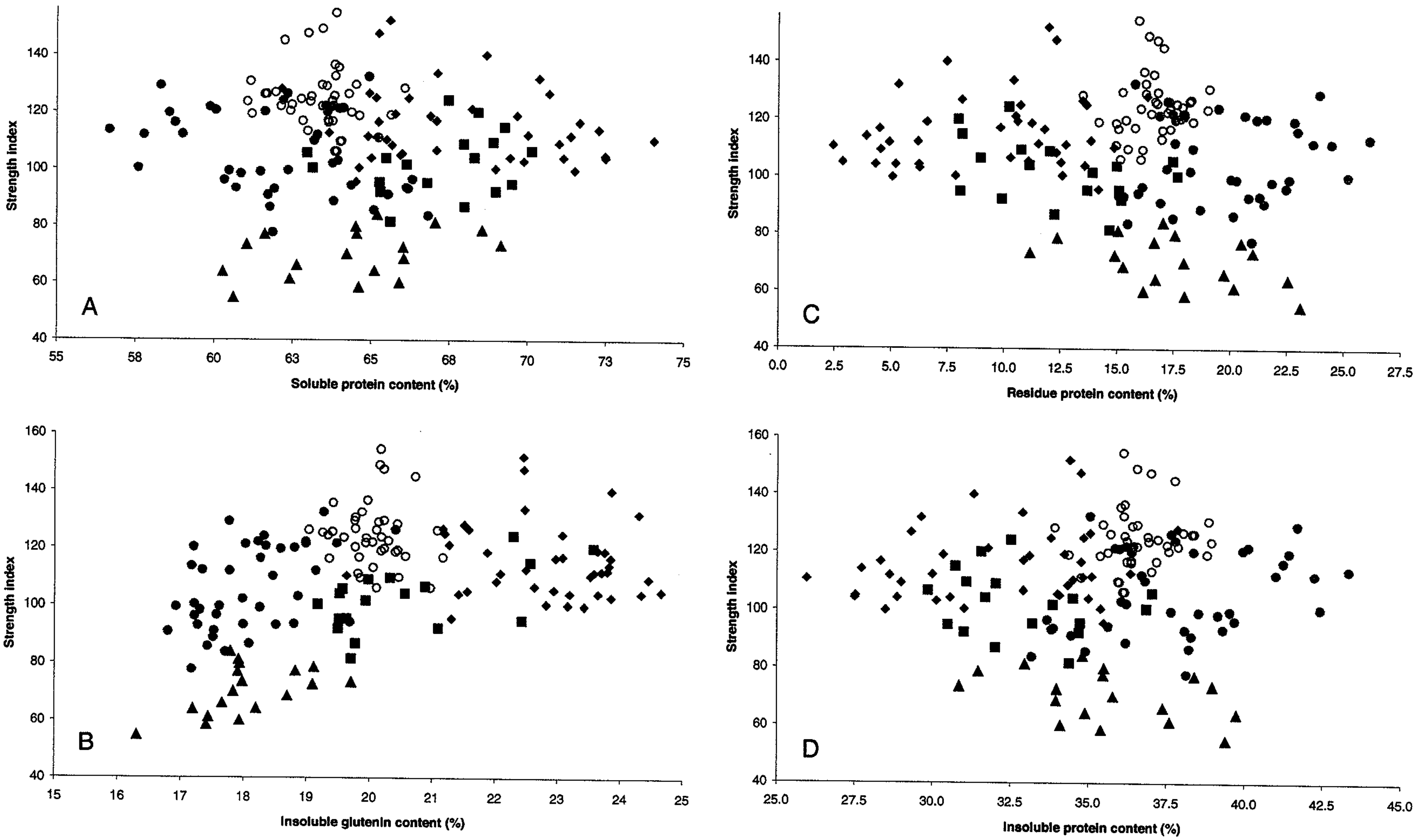


Figure T. 17. Scatterplots of Mixograph dough strength index versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

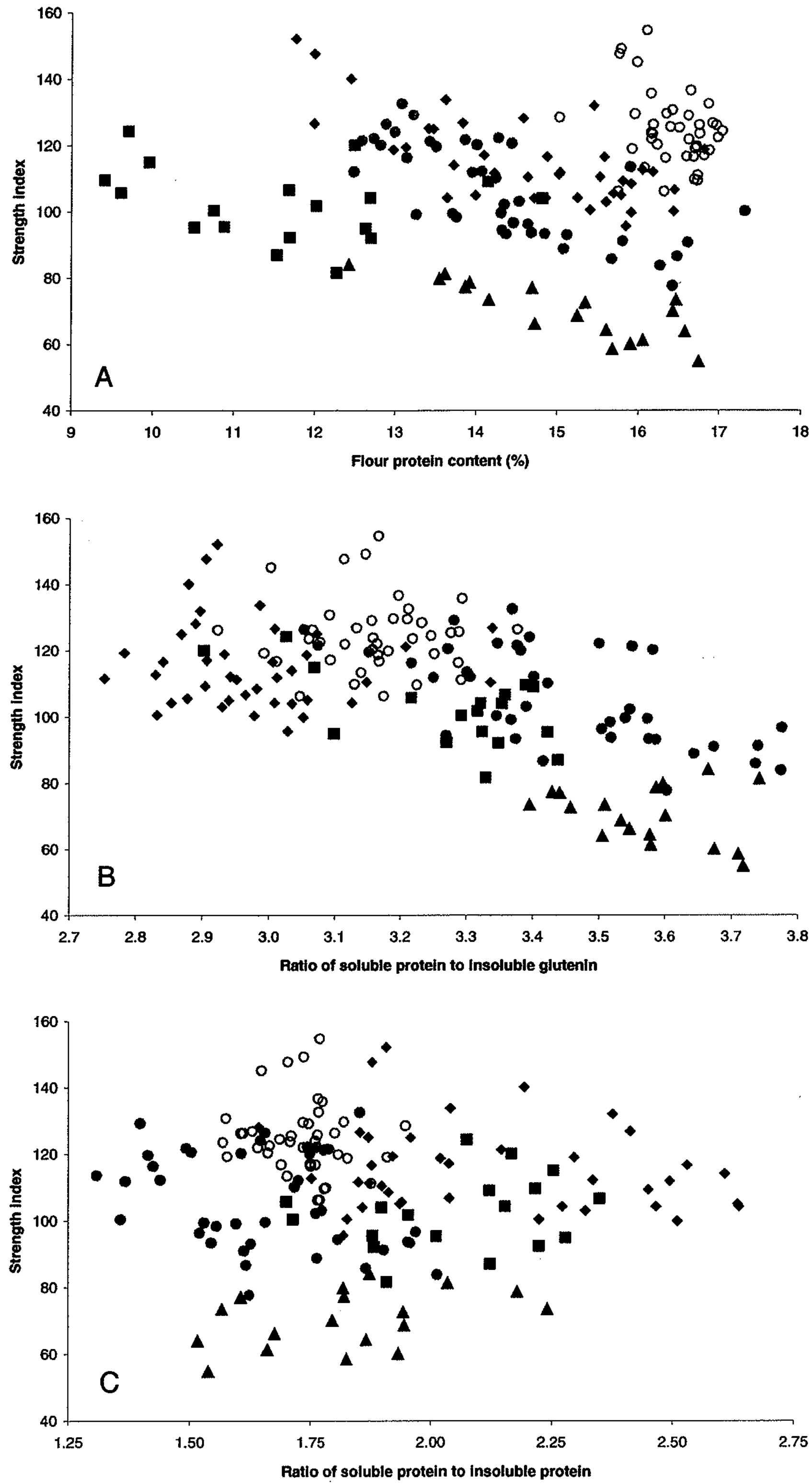


Figure T. 18. Scatterplots of Mixograph dough strength index versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

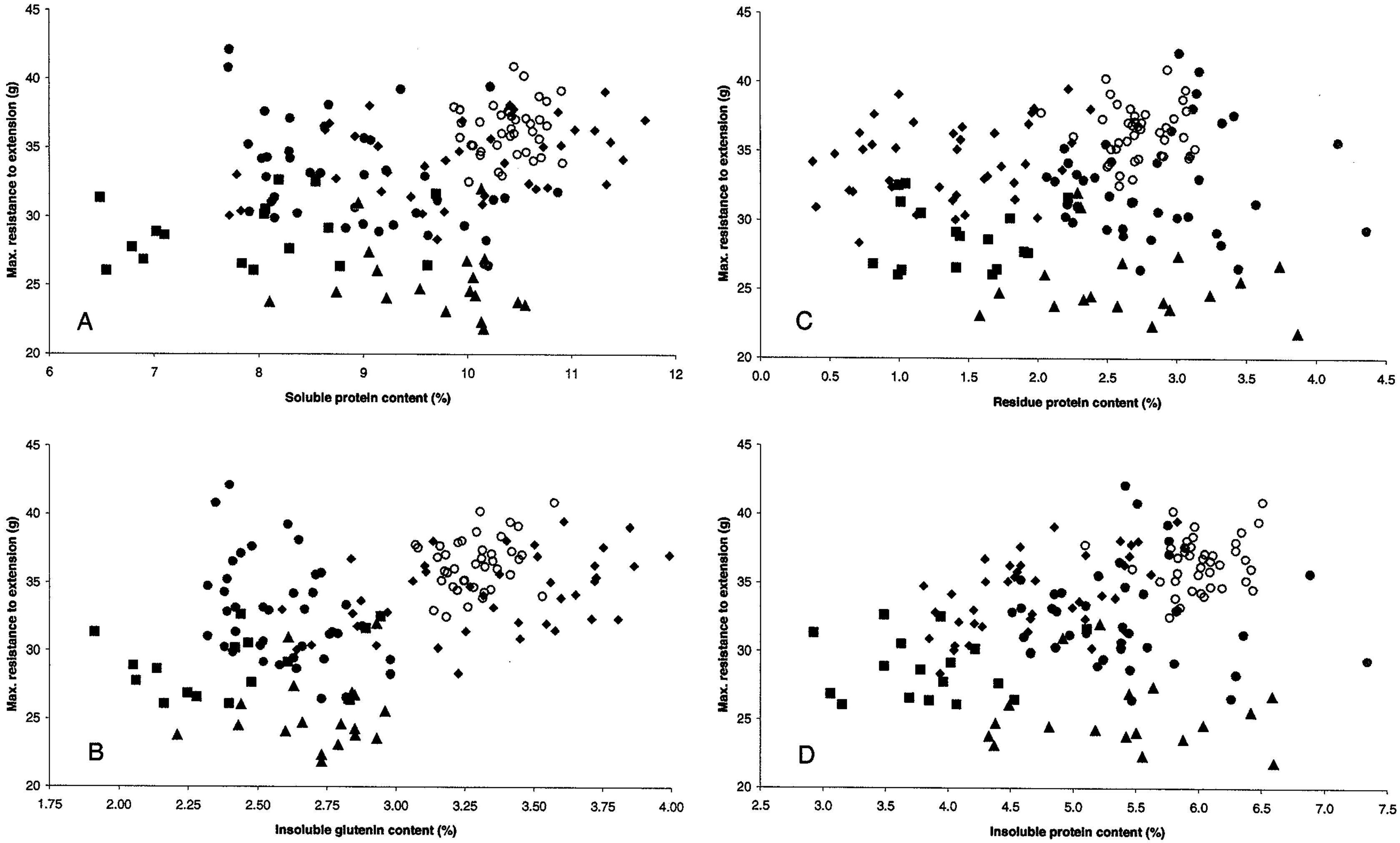


Figure T. 19. Scatterplots of dough maximum resistance to extension (Rmax) versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

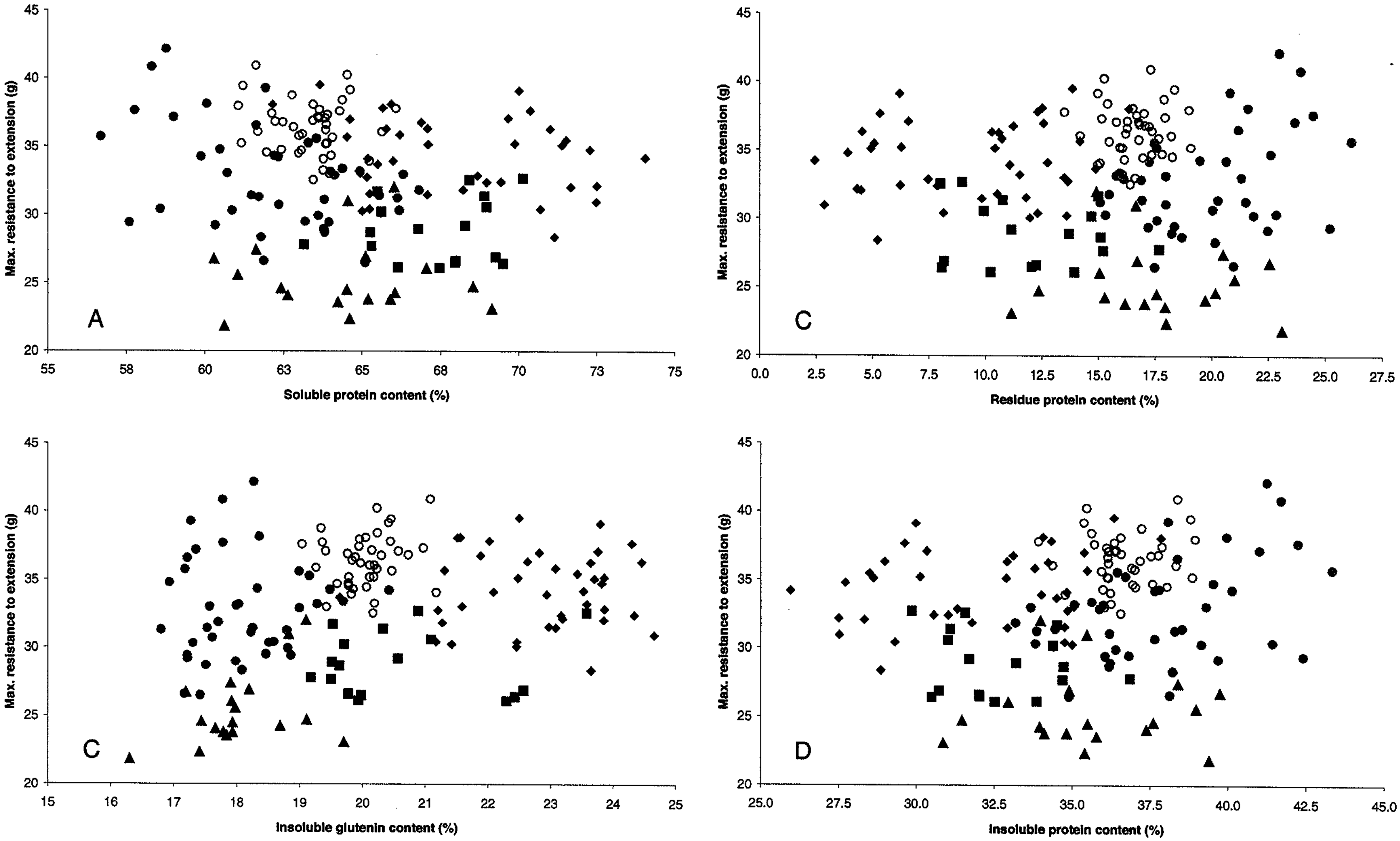


Figure T. 20. Scatterplots of dough maximum resistance to extension (Rmax) versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

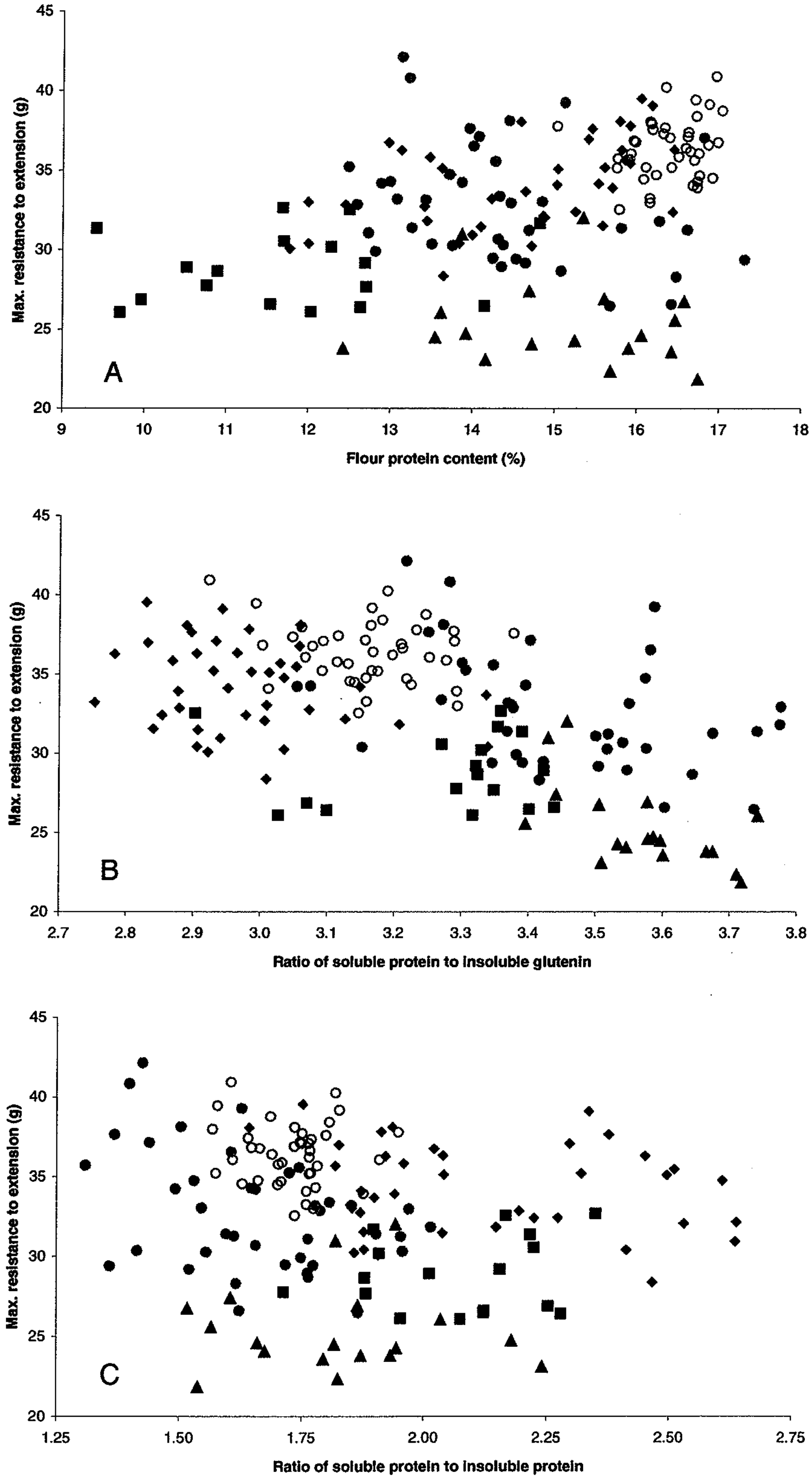


Figure T. 21. Scatterplots of dough maximum resistance to extension (Rmax) versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

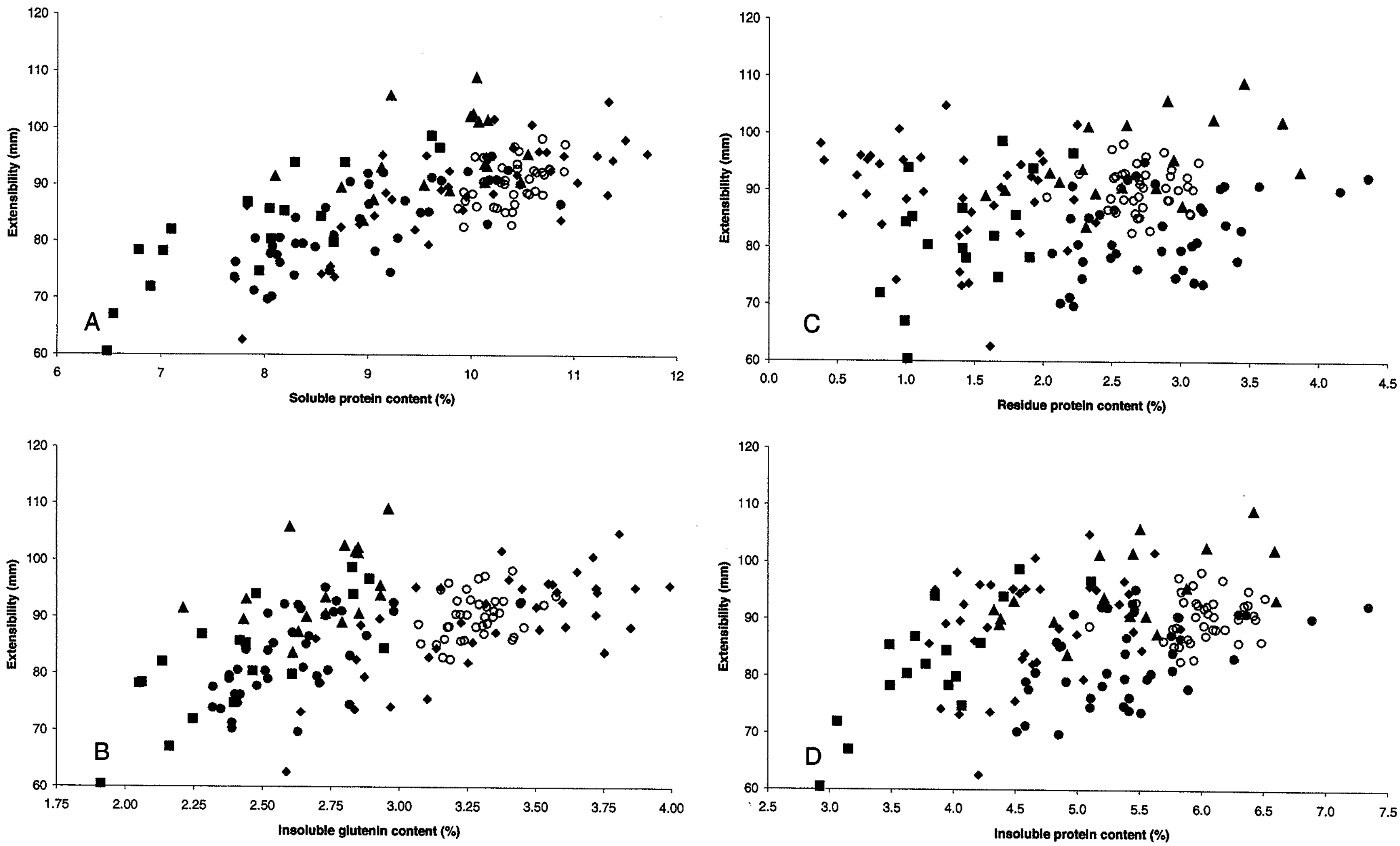


Figure T. 22. Scatterplots of dough extensibility at Rmax versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

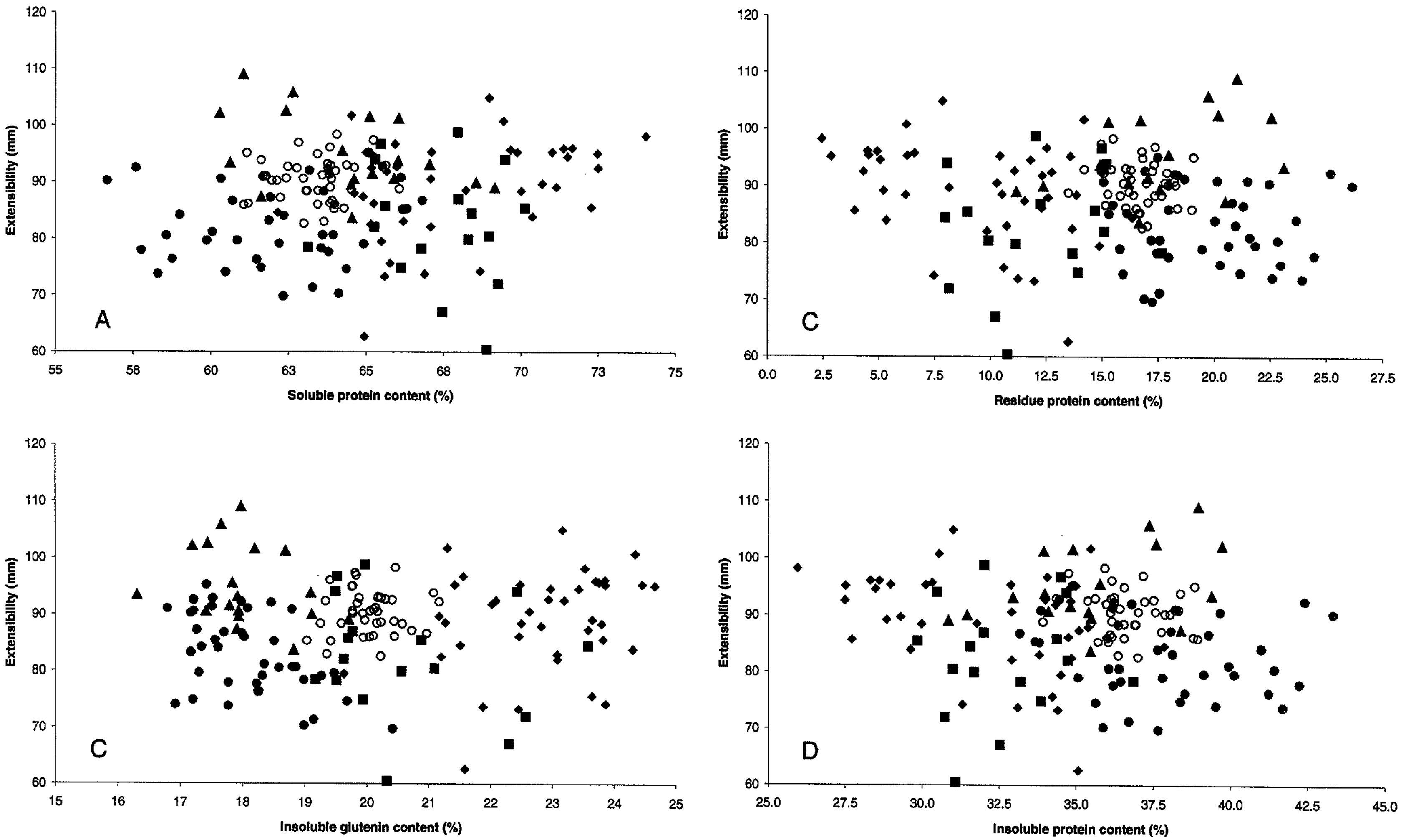


Figure T. 23. Scatterplots of dough extensibility at Rmax versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

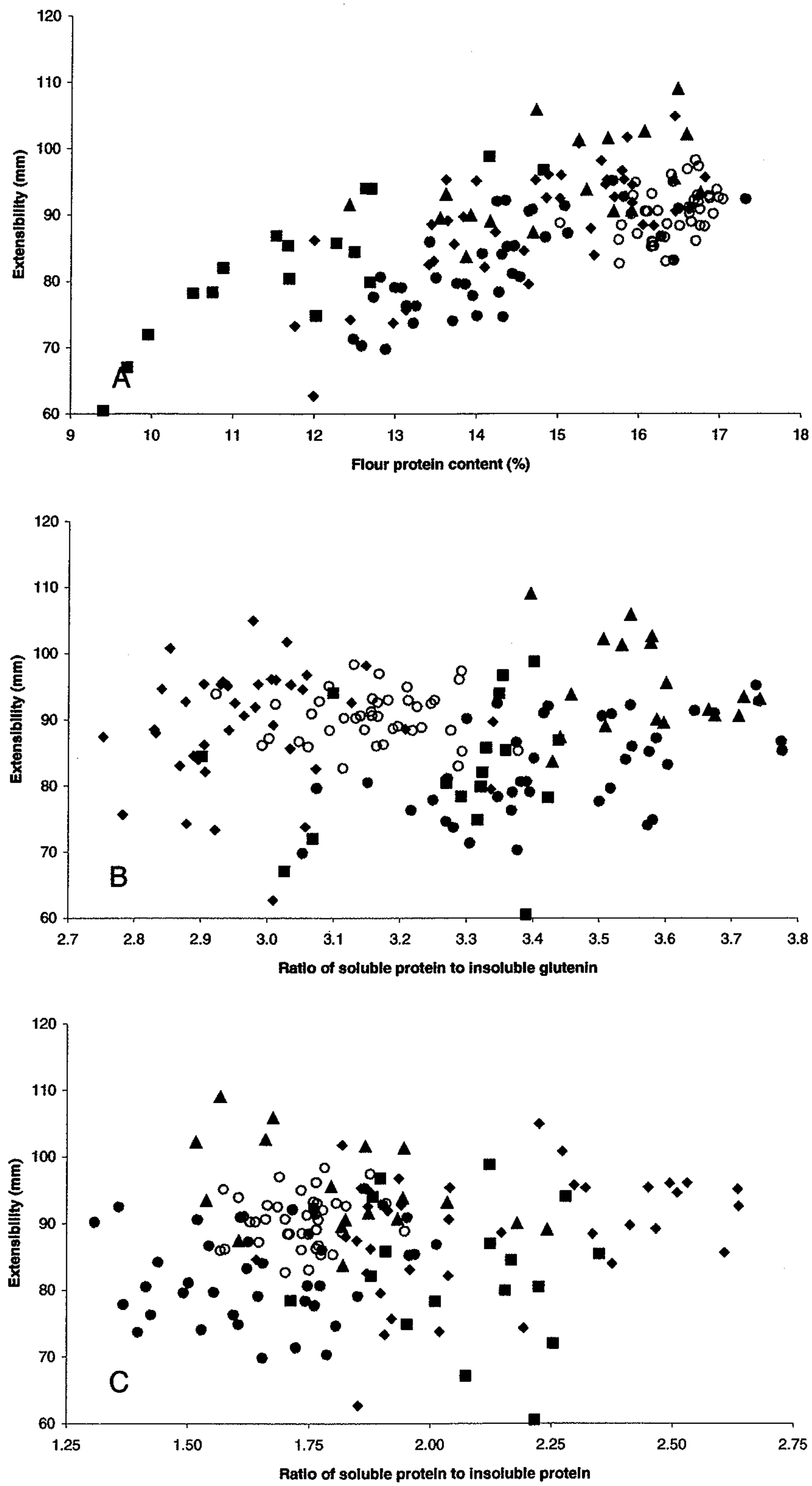


Figure T. 24. Scatterplots of dough extensibility at Rmax versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

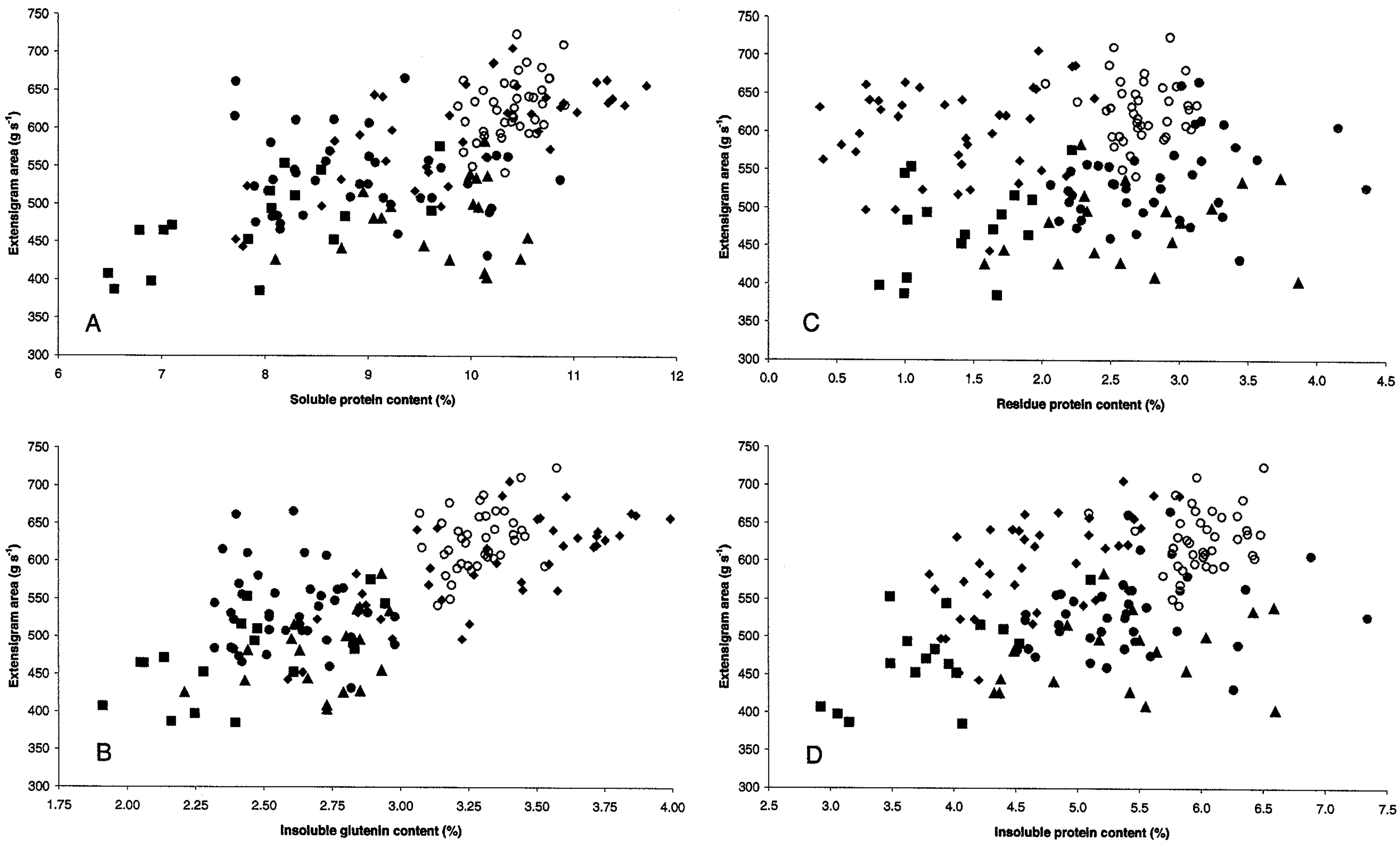


Figure T. 25. Scatterplots of extensigram area versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (●), and Swift Current-01 (▲).

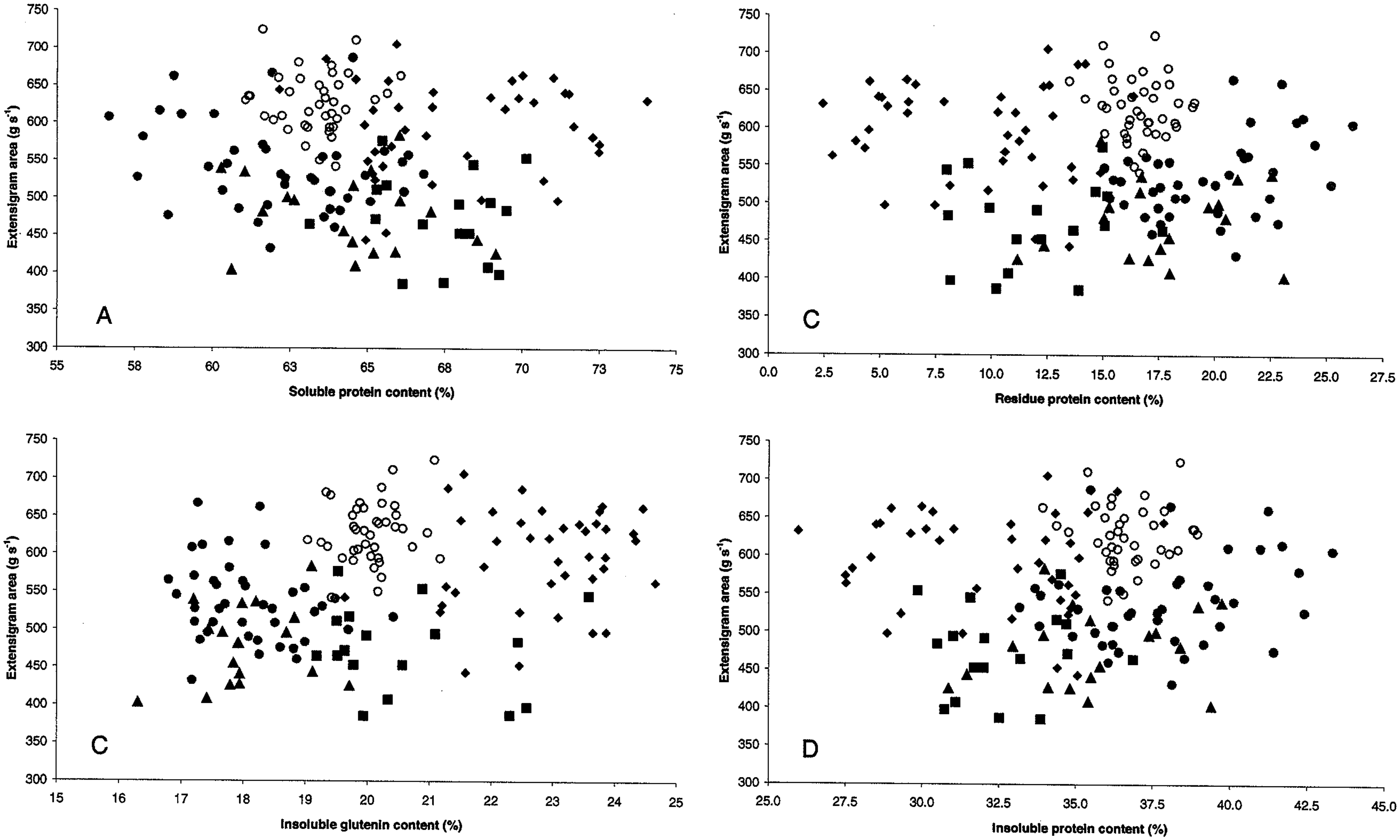


Figure T. 26. Scatterplots of extensigram area versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

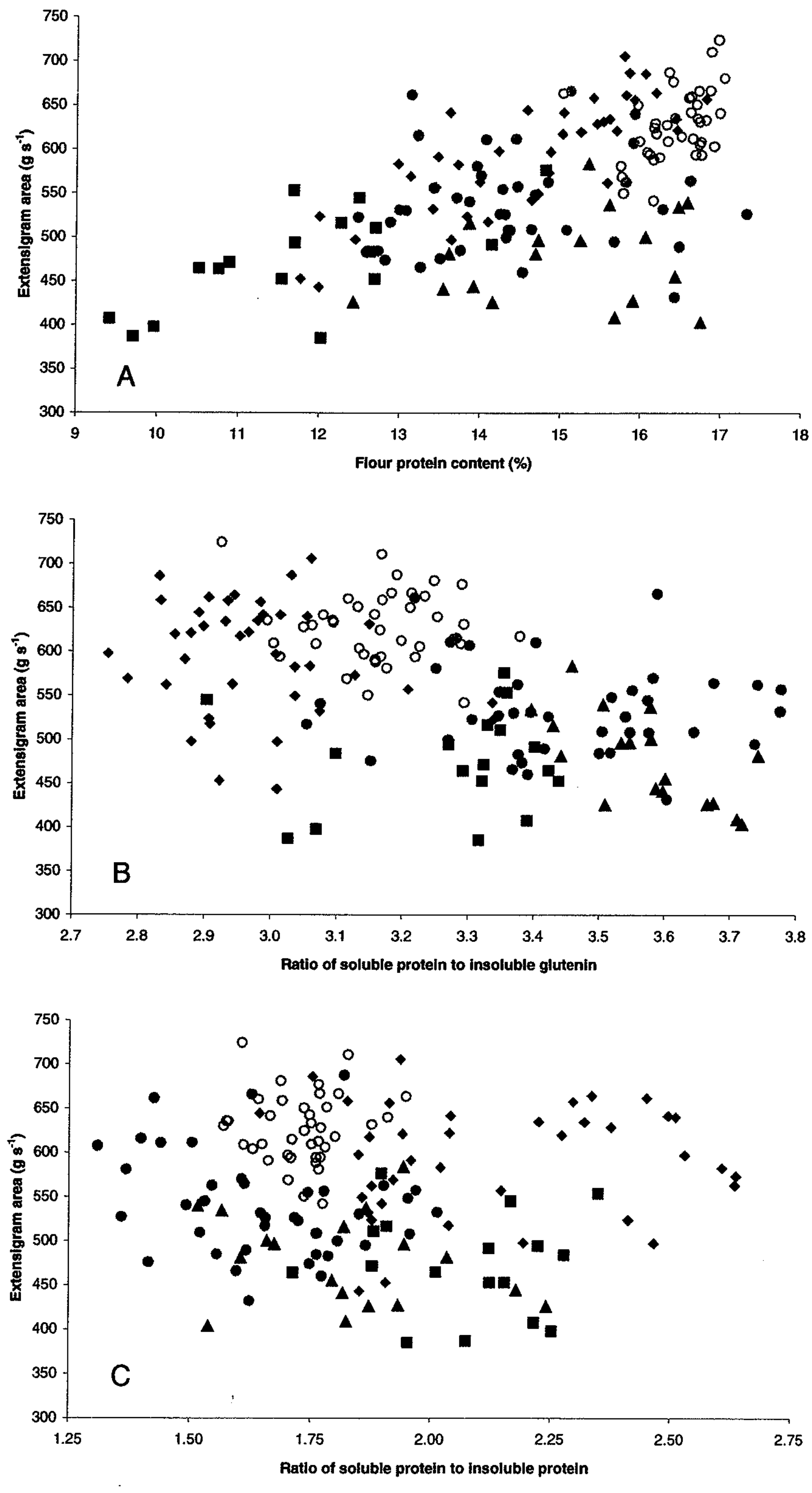


Figure T. 27. Scatterplots of extensigram area versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

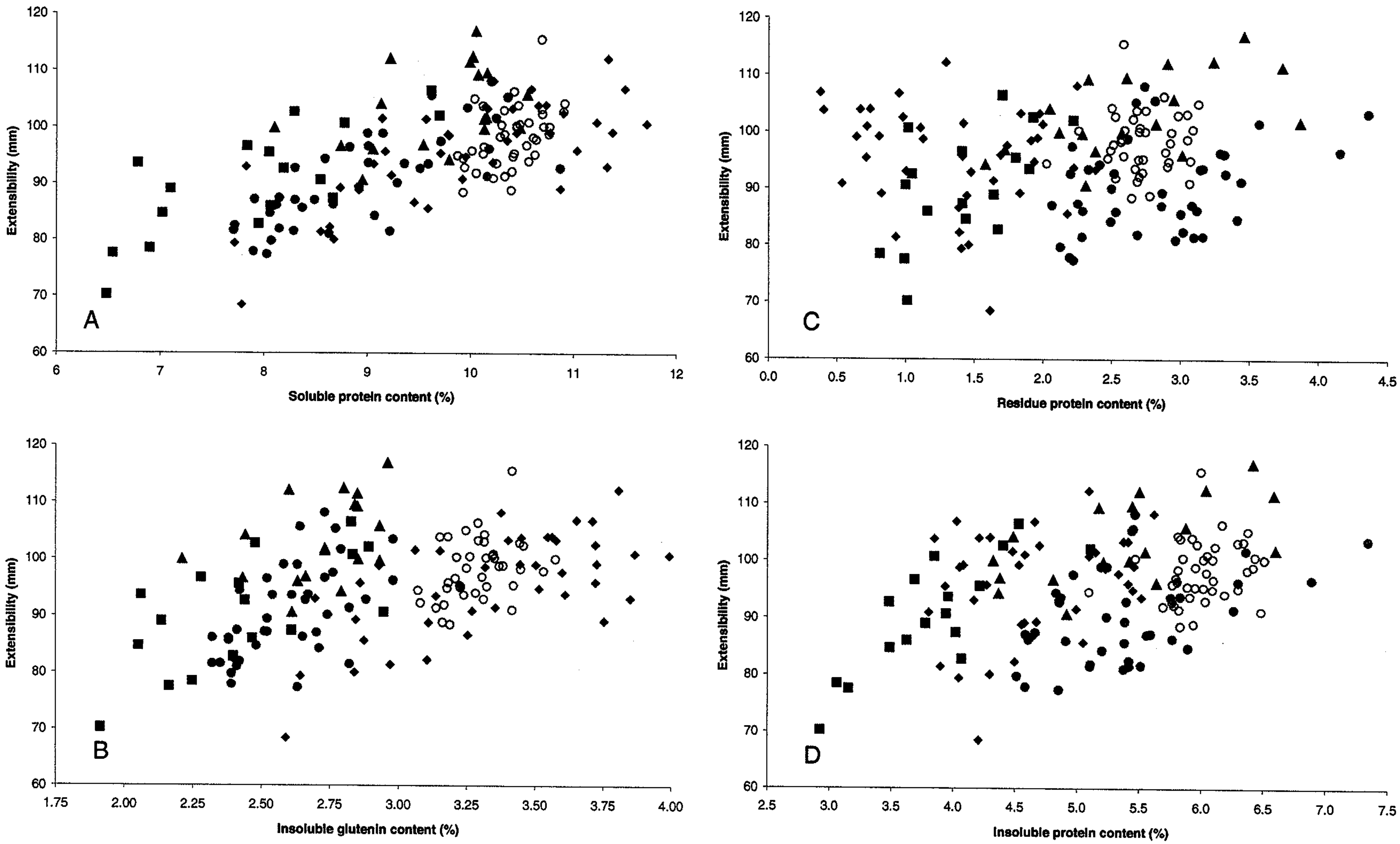


Figure T. 28. Scatterplots of extensibility at dough rupture versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

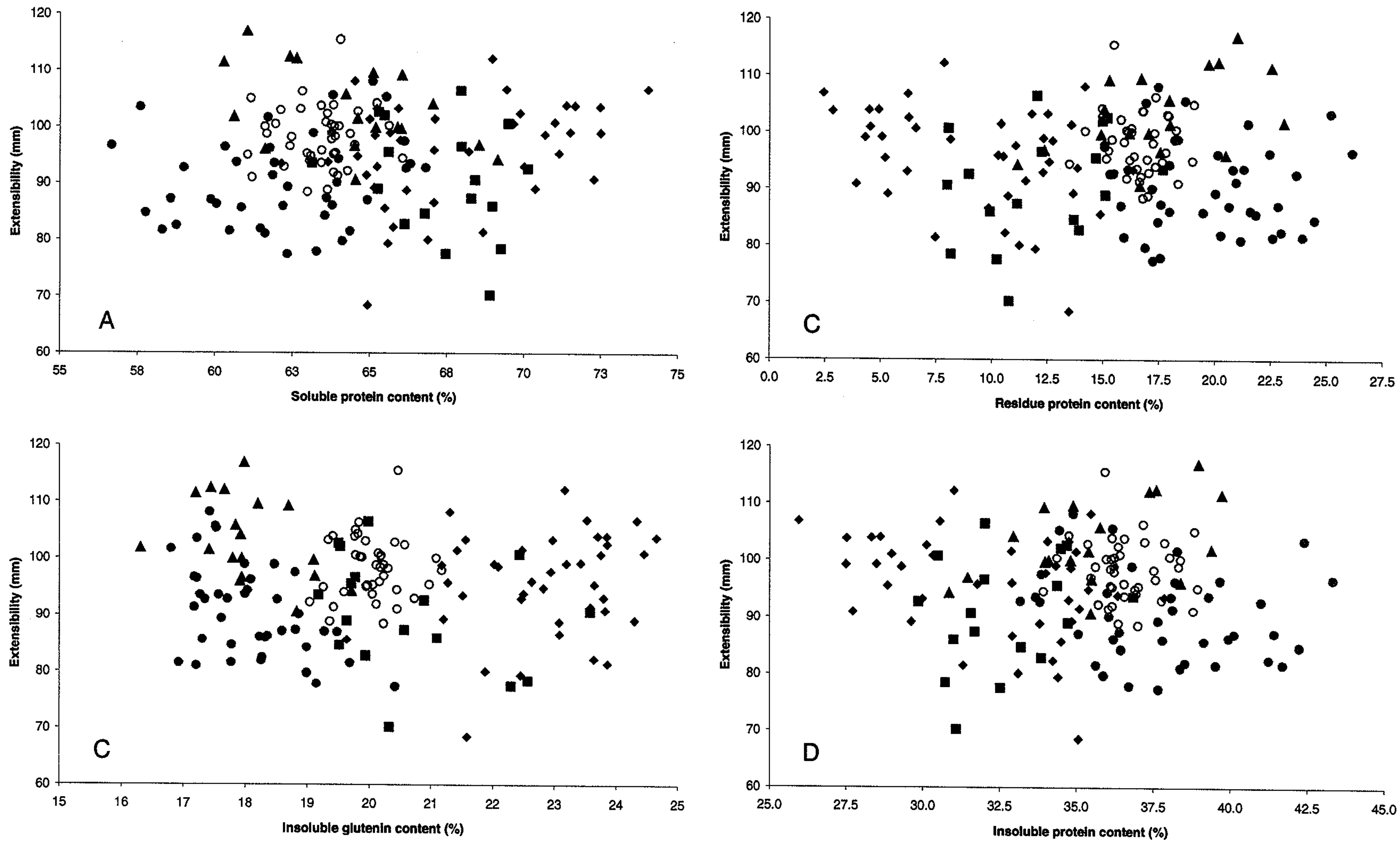


Figure T. 29. Scatterplots of extensibility at dough rupture versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

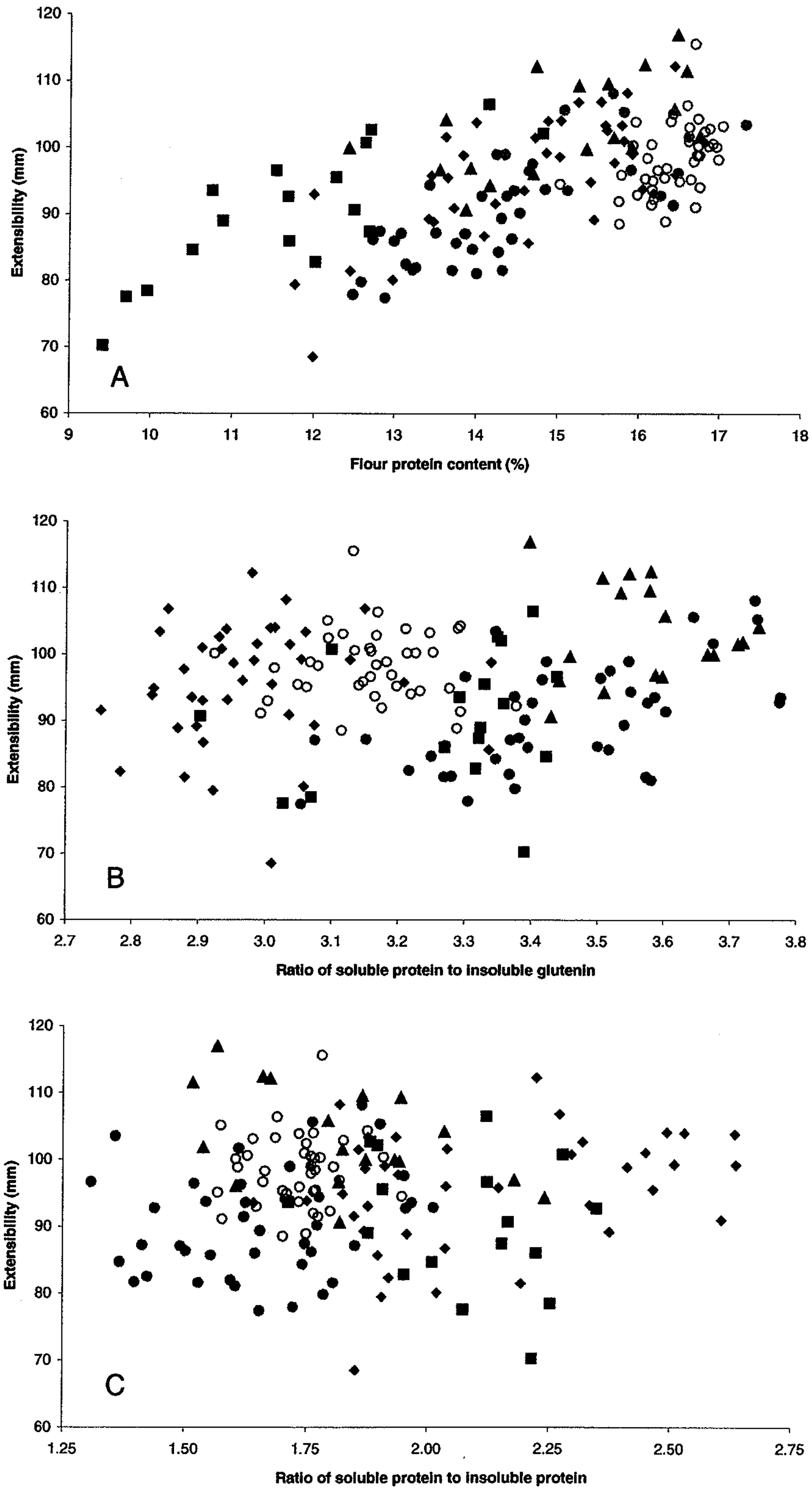


Figure T. 30. Scatterplots of extensibility at dough rupture versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

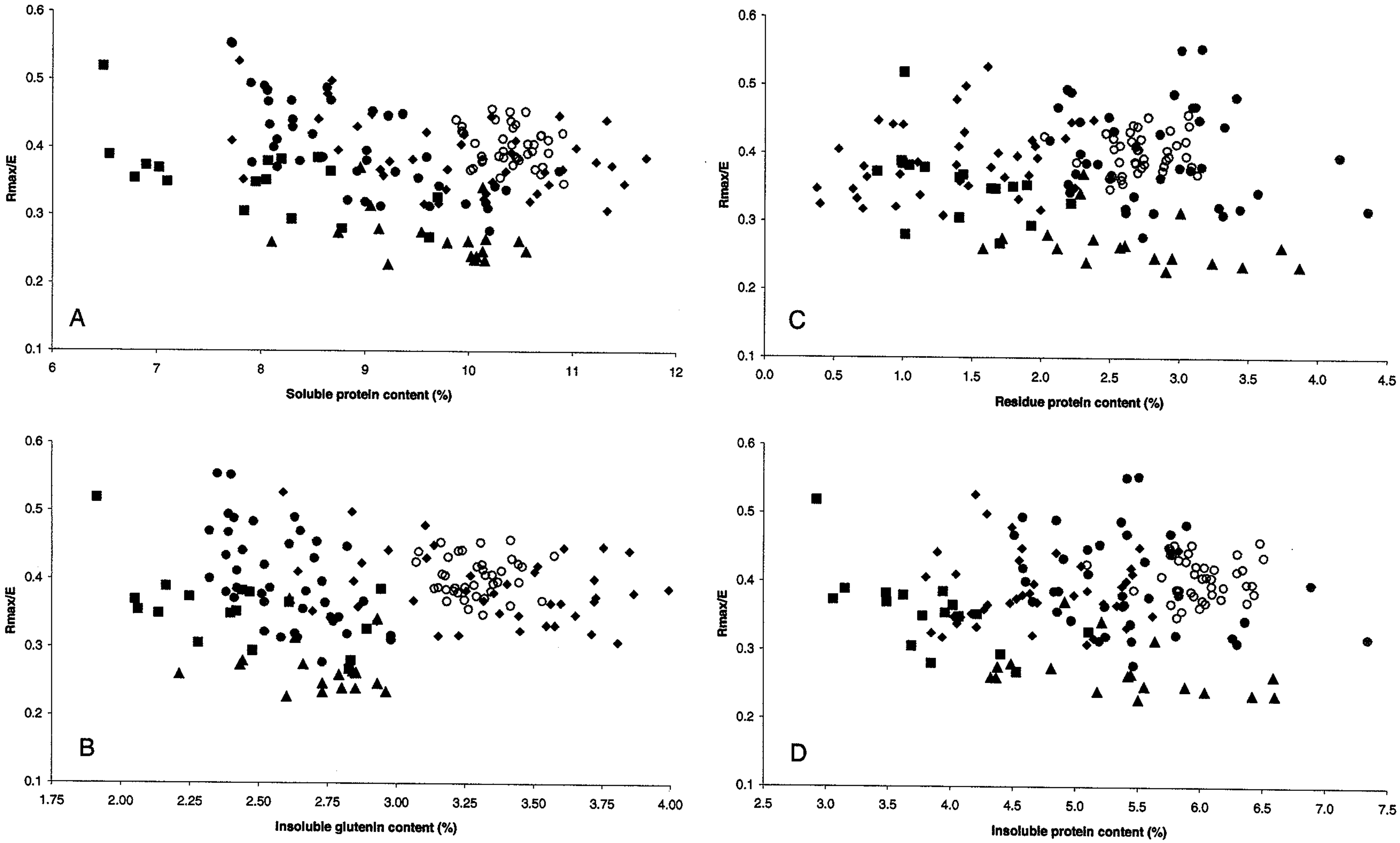


Figure T. 31. Scatterplots of the ratio of dough extensibility to Rmax versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

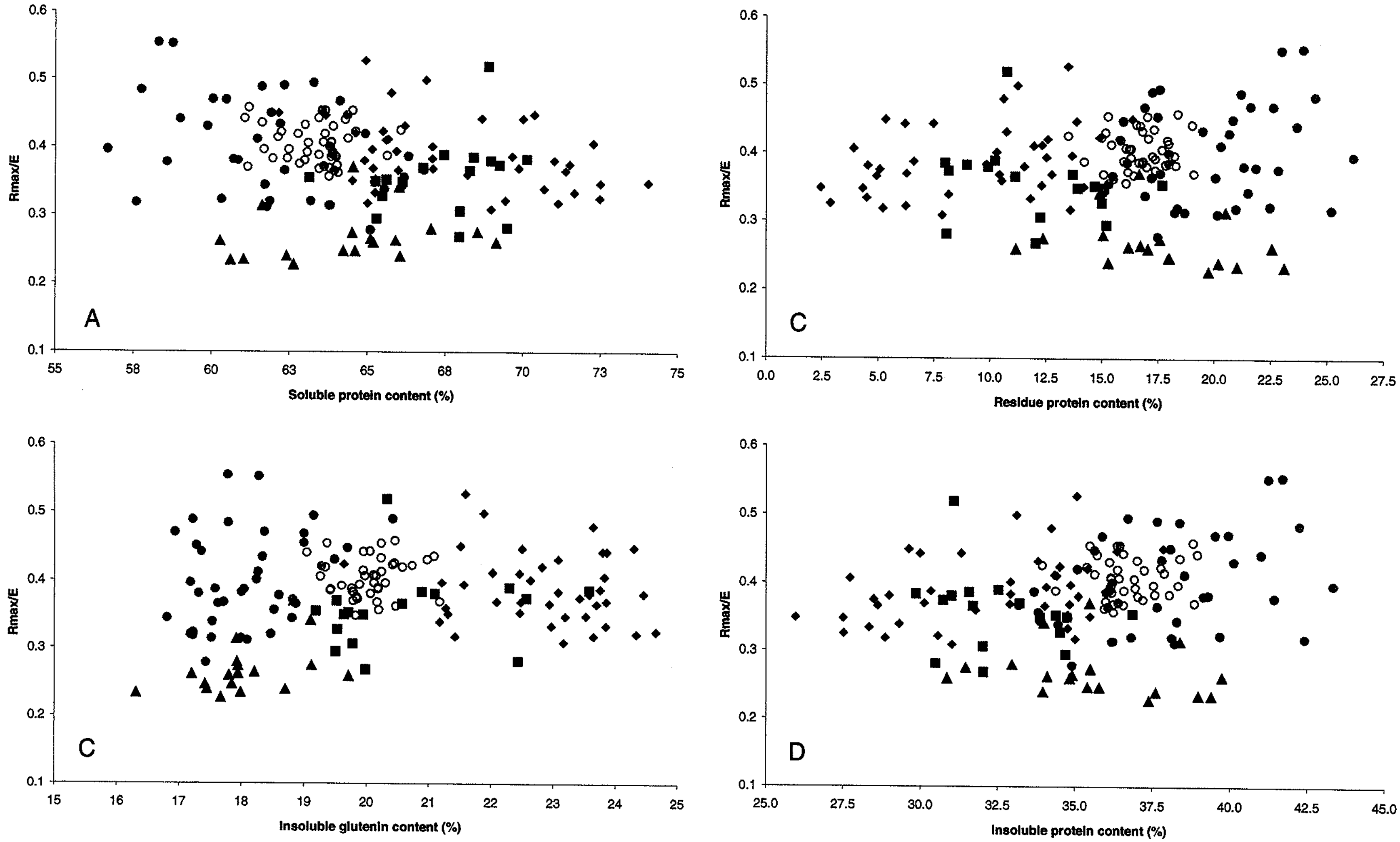


Figure T. 32. Scatterplots of dough extensibility to Rmax versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

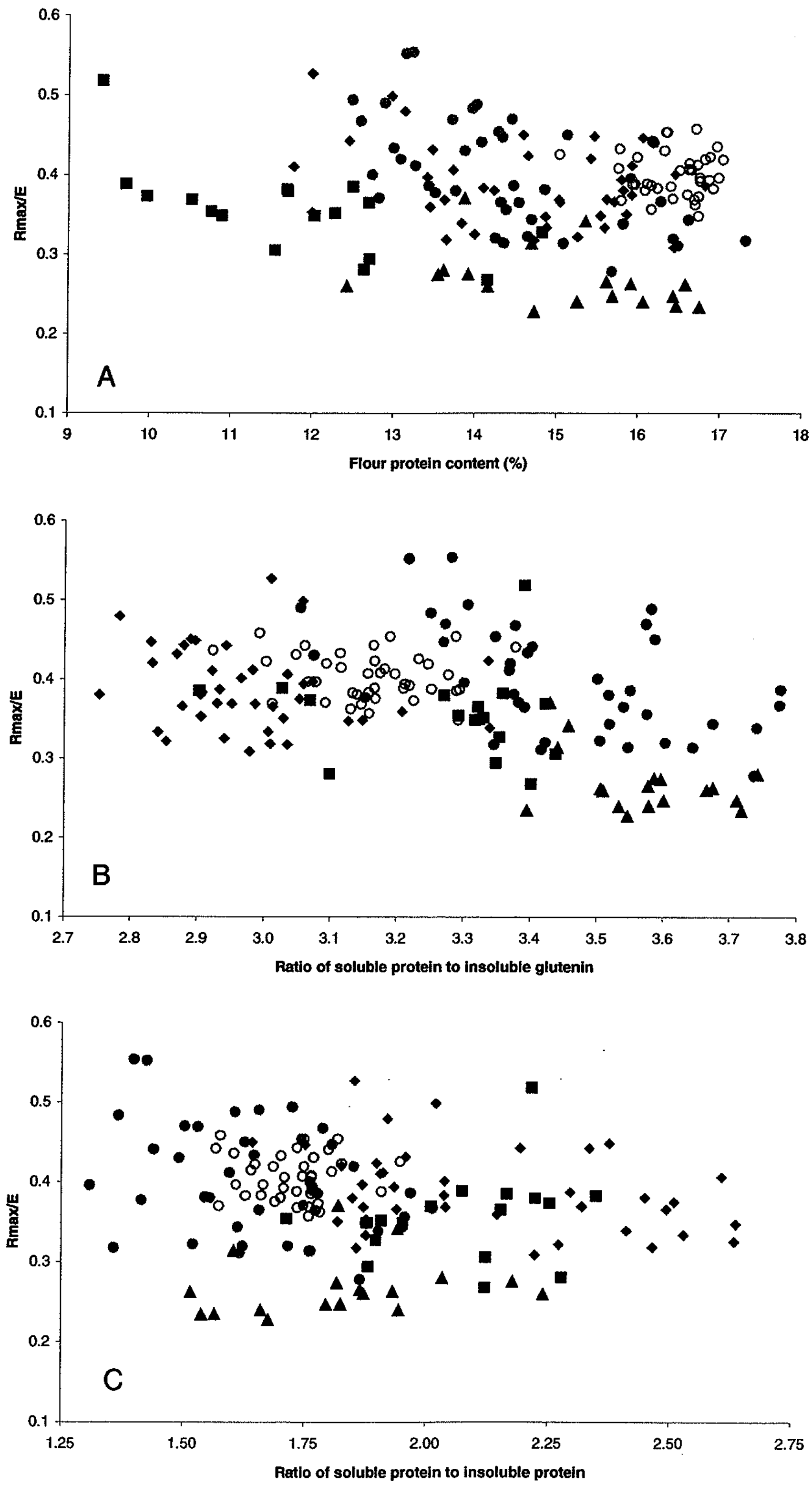


Figure T. 33. Scatterplots of the ratio of dough extensibility to Rmax versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

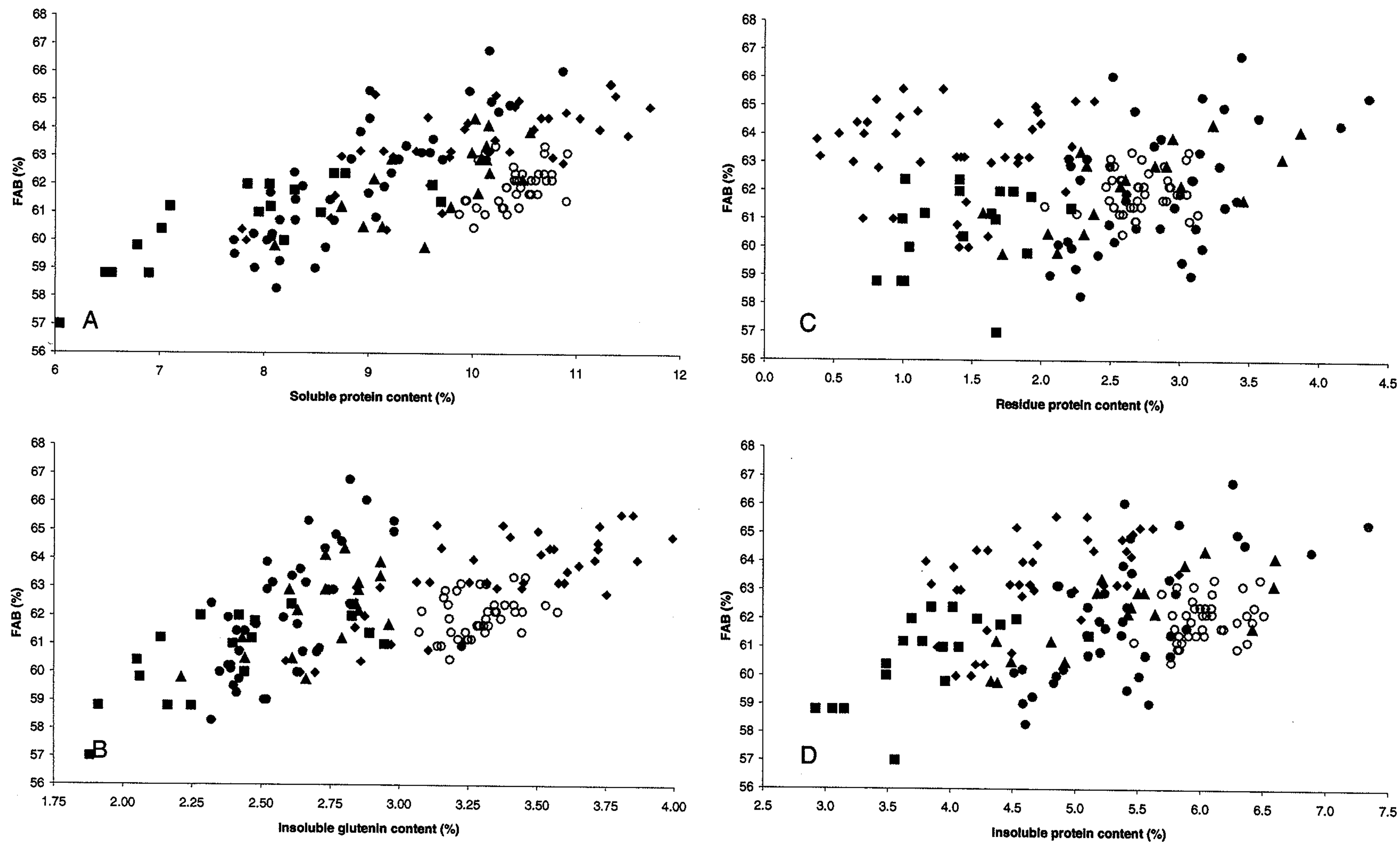


Figure T. 34. Scatterplots of the Farinograph water absorption versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

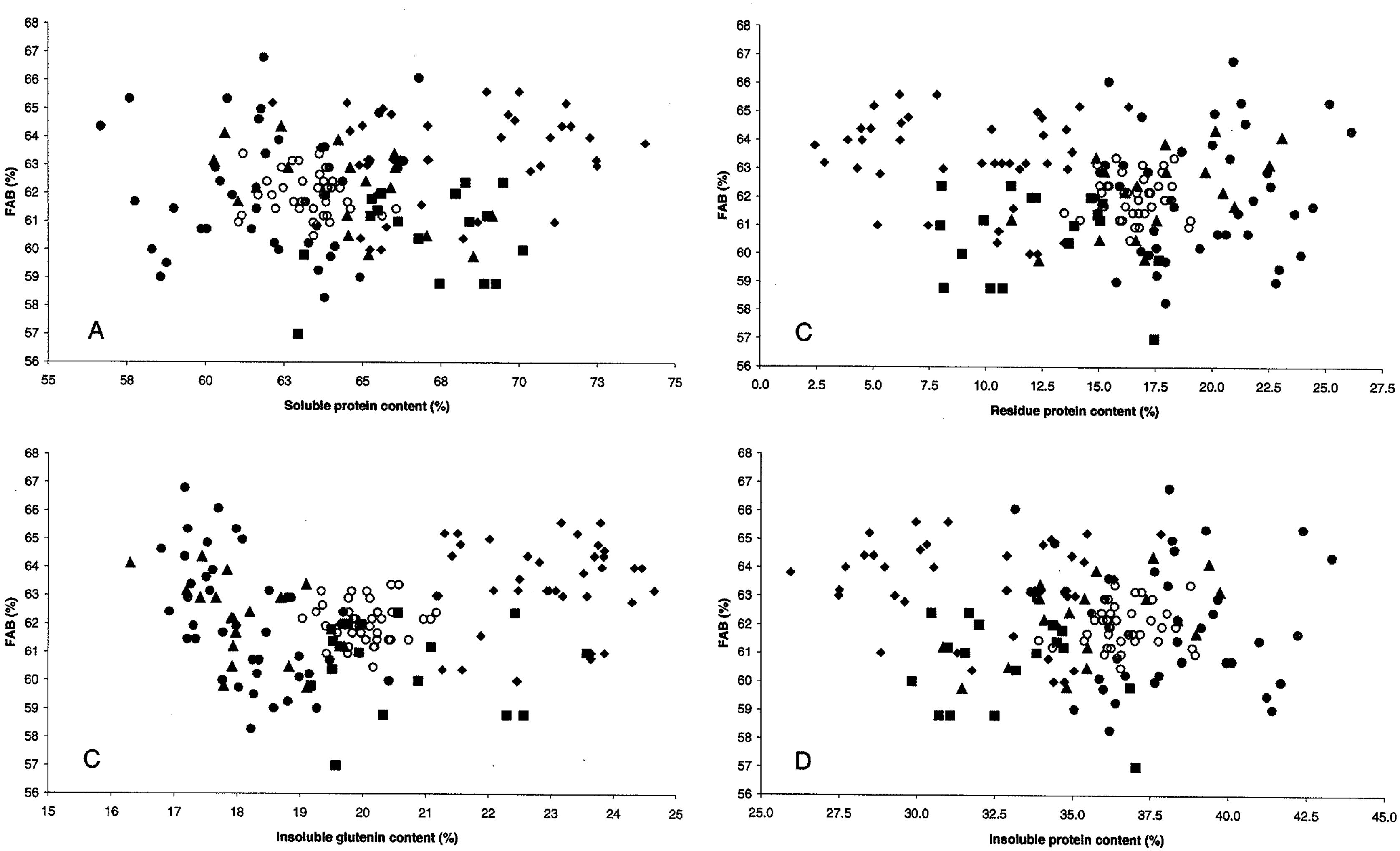


Figure T. 35. Scatterplots of Farinograph water absorption versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

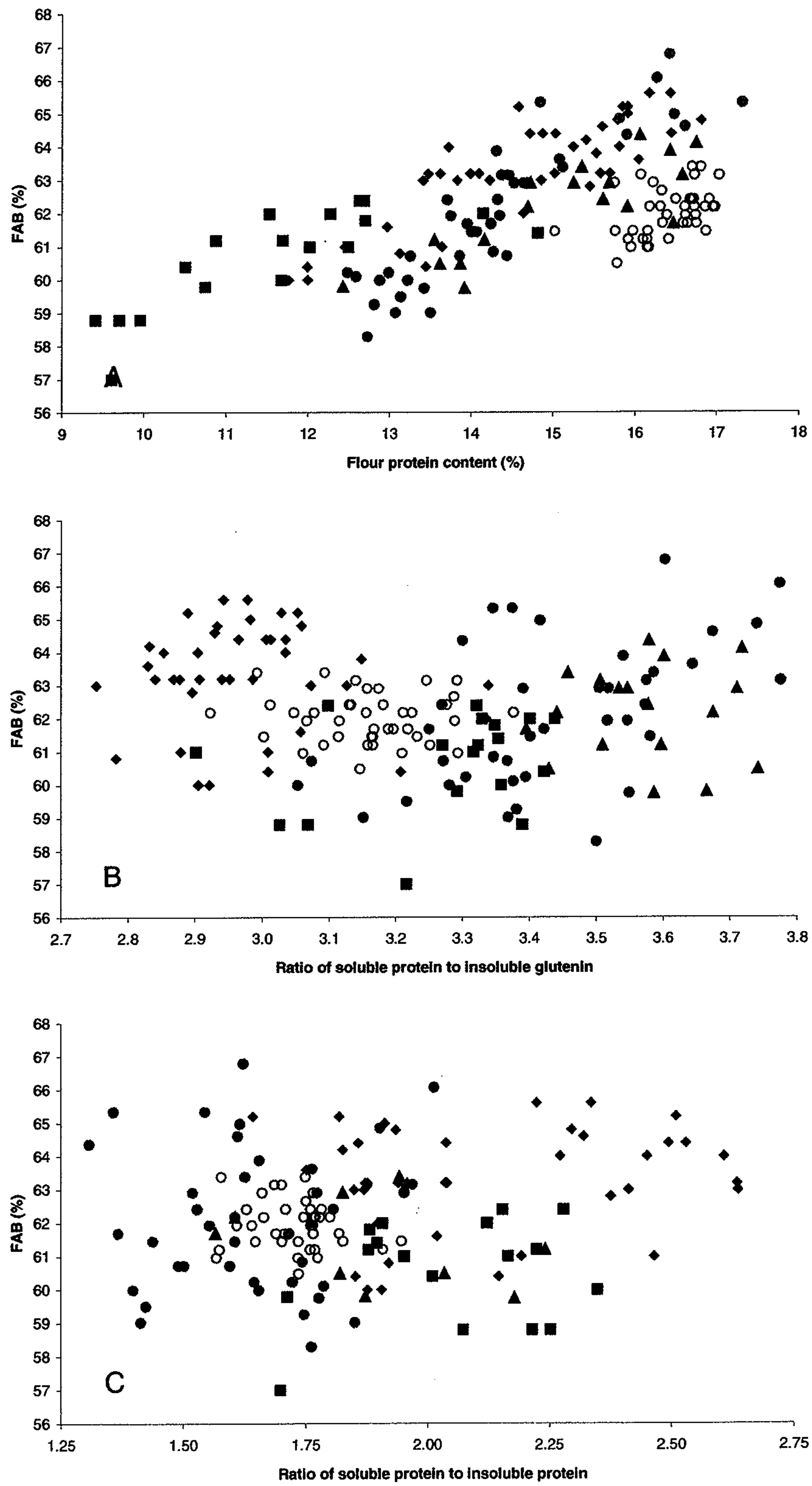


Figure T. 36. Scatterplots of Farinograph water absorption versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

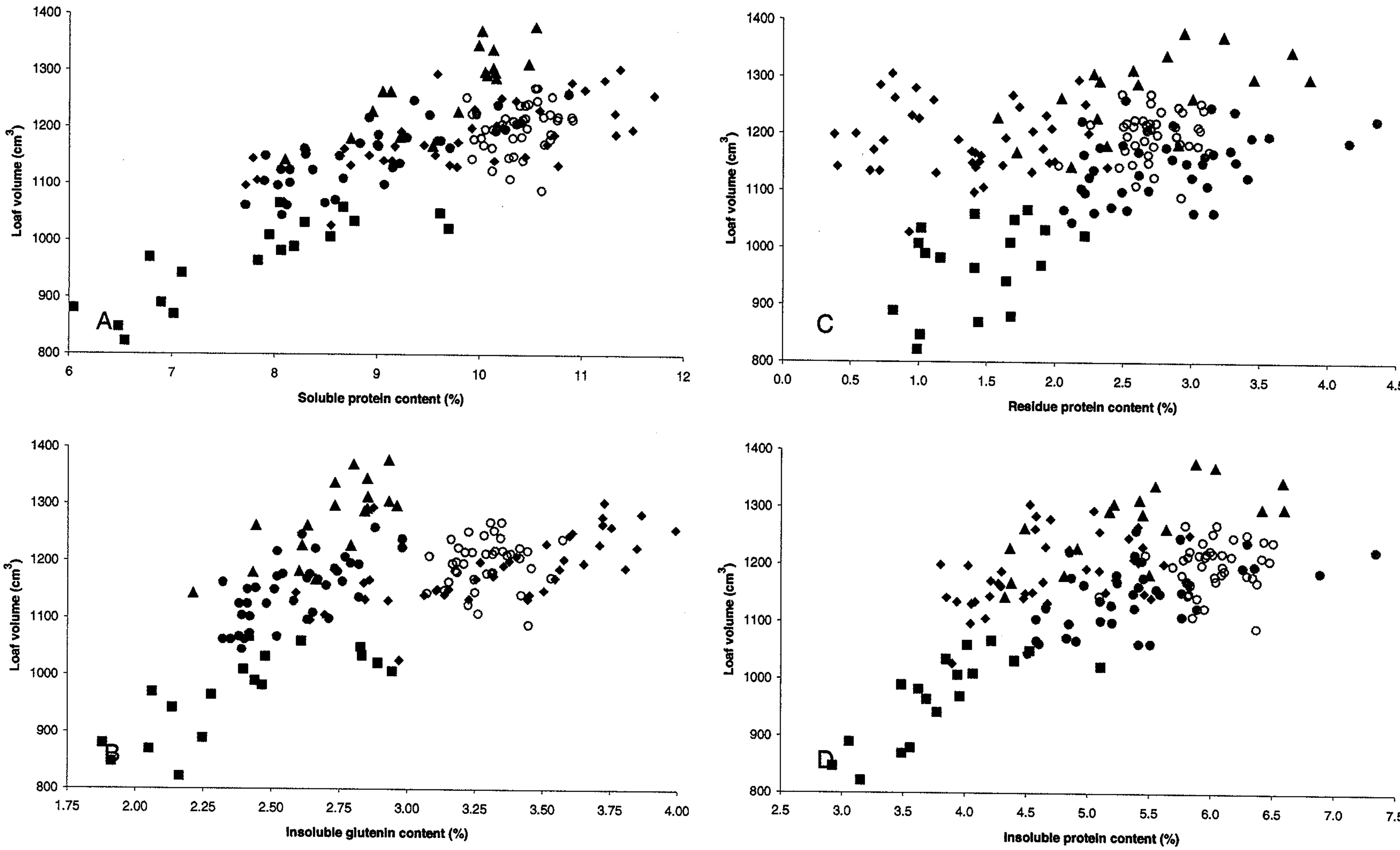


Figure T. 37. Scatterplots of loaf volume versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (●), and Swift Current-01 (▲).

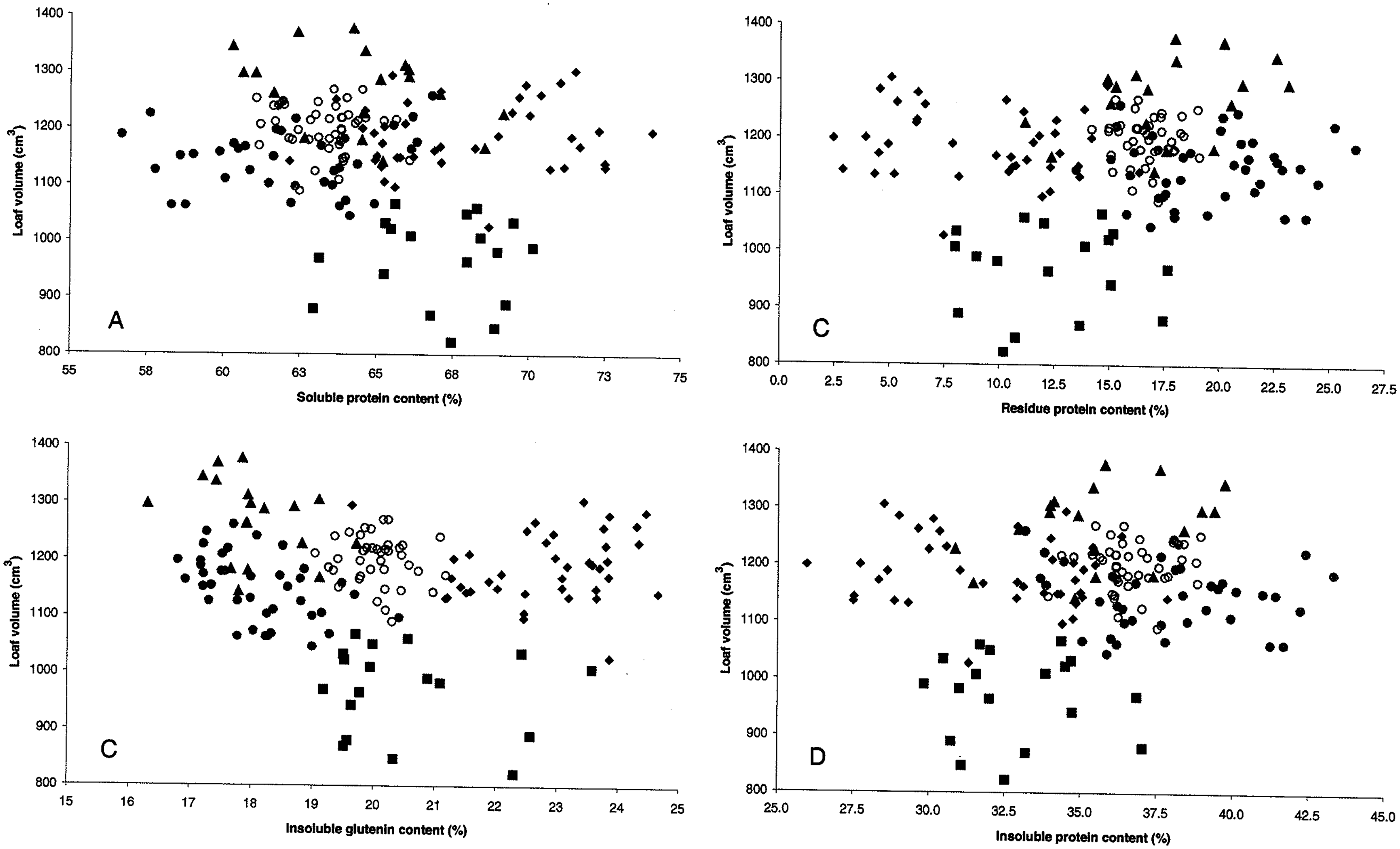


Figure T. 38. Scatterplots of loaf volume versus soluble protein (A), insoluble glutenin (B), residue protein (C), and insoluble protein (D) as a proportion of total flour protein content. Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).

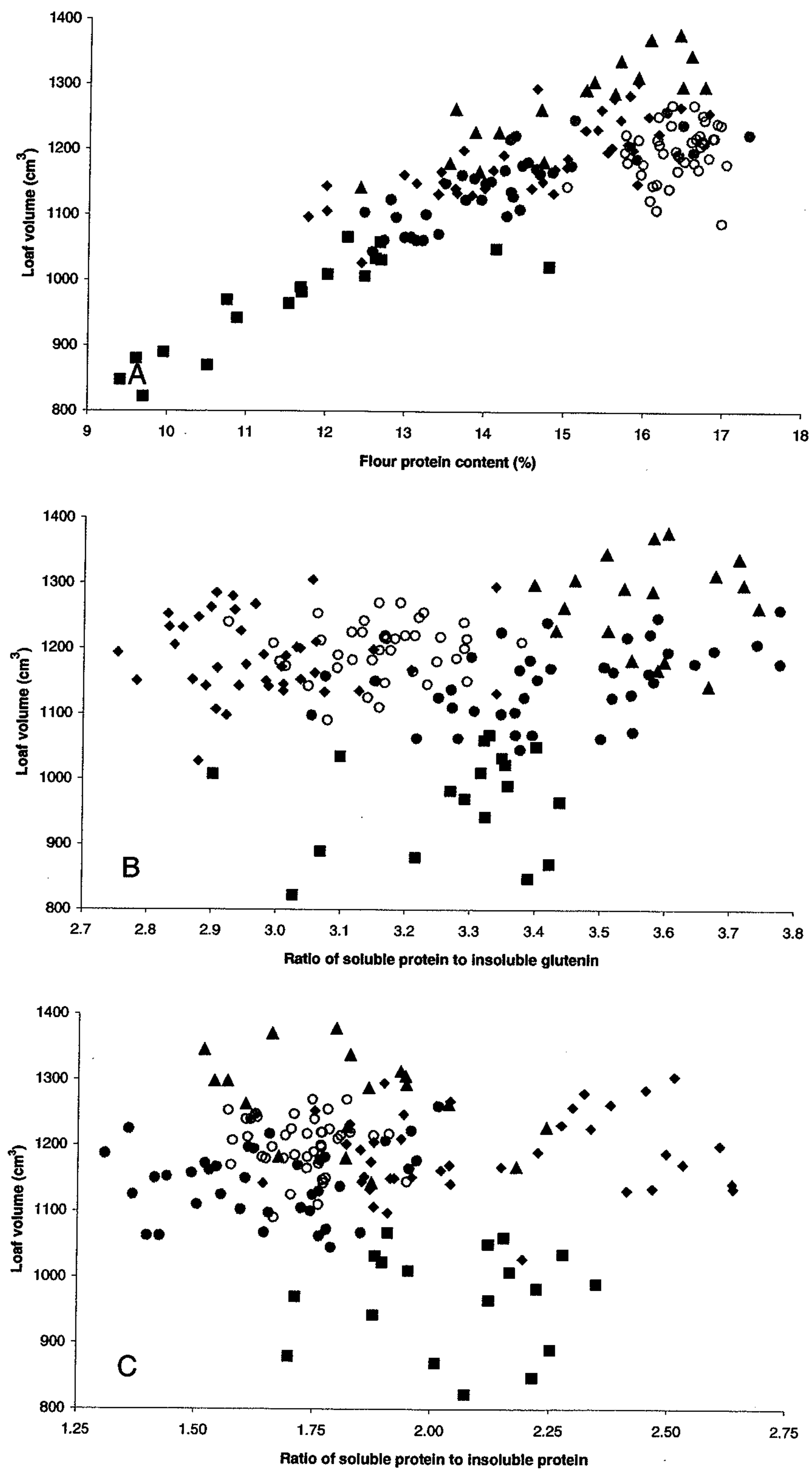


Figure T. 39. Scatterplots of loaf volume versus flour protein content (A), the ratio of soluble protein to insoluble glutenin (B), and the ratio of soluble protein to insoluble protein (C). Data are plotted for Carman-00 (♦), Swift-Current-00 (■), Carman-01 (○), Brandon-01 (•), and Swift Current-01 (▲).