THE INFLUENCE OF FIELD WEATHERING ON SEED QUALITY AND VIGOR OF KATEPWA WHEAT AND HEARTLAND BARLEY

BY

RAY G. WYTINCK

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

April, 1991

National Library of Canada
Bibliothèque nationale du Canada

Canadian Theses Service
Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-76920-3

Canada

THE INFLUENCE OF FIELD WEATHERING ON SEED QUALITY AND VIGOR OF KATEPWA WHEAT AND HEARTLAND BARLEY

BY

RAY WYTINCK

A thesis 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

© 1991

Permission has been granted to the LIBRARY OF THE UNIVERSITY OF MANITOBA to lend or sell copies of this thesis, to the NATIONAL LIBRARY OF CANADA to microfilm this thesis and to lend or sell copies of the film, and UNIVERSITY MICROFILMS to publish an abstract of this thesis.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

ABSTRACT

Ray Wytinck, M.Sc., The University of Manitoba.
The influence of field weathering on seed quality and vigor of Katepwa wheat and Heartland barley.

Major Professor, Dr. M.H. Entz.

Seedlots of the same cultivar, grown in different environments frequently perform at significantly different levels (up to 14% differences in yield), when tested under field conditions. This study was conducted to determine the effects of field weathering on seed quality and vigor of mature wheat (Triticum aestivum L. cv. Katepwa) and barley (Hordeum vulgare L. cv. Heartland) and to determine the specific environmental parameter having the greatest influence on various seed characteristics including vigor. A second experiment (experiment 2) was conducted to determine whether the negative effects of field weathering on seed quality and vigor could be altered by harvest management practices.

Field trials were conducted at Portage la Prairie in 1989 and 1990. Seed quality characteristics such as bulk density and kernel density were significantly reduced for both crops in both years. The actual water vapor pressure in the windrow had the greatest negative effect on these seed characteristics for wheat. As well, kernel hardness was significantly decreased for wheat as the weathering period increased. Water vapor pressure deficit was most influential on this characteristic. Fungal colonization by

Fusarium spp. on seed increased with weathering for both crops. The actual water vapor pressure had the greatest positive effect on Fusarium spp. infection for barley. Seed protein concentration was not affected by field weathering, however both crops displayed lower concentrations of protein in 1990 than in 1989. Alpha-amylase activity, determined by the Falling number test, increased significantly as the weathering period was prolonged. For barley, precipitation accounted for the largest amount of variation in alpha-amylase activity, (i.e., 60%). No environmental parameters were significantly correlated with standard germination in either wheat or barley. Low temperature germination (5oC) was significantly reduced by weathering for barley in both years and for wheat in 1990. Precipitation during the exposure period accounted for the greatest loss in cold germination in wheat.

Experiment 2 demonstrated minimal differences between harvest management systems (i.e., standing vs. windrowed crop) in terms of physical seed properties. Microbial invasion by Fusarium spp. was higher ($P = 0.057$) for windrowed wheat compared with standing wheat in 1989. Higher levels of Fusarium spp. infection were observed on windrowed wheat again in 1990, however, the differences were not significant ($P > 0.05$). Barley seed infected by Fusarium spp. was not different between systems. Protein concentration was not significantly affected by harvest management for either crop. However, alpha-amylase activity

in both wheat and barley was significantly higher for the windrowed treatment compared with the standing treatment. The negative effects of weathering on low temperature germination were reduced for standing crop compared with windrowed crops of wheat and barley in 1989 but not in 1990.

ACKNOWLEDGEMENTS

Conducting a research project such as this provides circumstances which contribute to a students education in many ways. I am indebted to all the people who were involved in this project, and provided assistance.

First, I would like to thank my advisor, Dr. M. Entz, who's enthusiasm and encouragement will always be a source of inspiration for me. Also, I extend sincere thanks to the members of my advisory committee, Drs., W.E. Muir, E.H. Stobbe and W. Woodbury, who provided assistance in many ways during the past two years.

Special thanks to Randy Clear and Susan Patrick of the Mycology Lab at the Canadian Grain Commission, who unhesitantly went above and beyond the call of duty to provide assistance towards this research project. As well, the technical assistance provided by Keith Bamford is gratefully appreciated.

I want to thank my wife Kim, who physically assisted with the research and provided continual support and encouragement, but who also prevented this project from becoming an obstacle or barrier to anything else in life. I am grateful to my family, particularly my parents, who taught me by example that there is no substitute for hard work. And finally, the friendship and experiences shared by fellow graduate students will never be forgotten.

Financial support, provided by the Canadian Seed Growers' Association, the Manitoba Seed Growers' Association and the University of Manitoba is also gratefully acknowledged.

Table of Contents

ABSTRACT iii

ACKNOWLEDGEMENTS vi

TABLE OF CONTENTS viii

LIST OF TABLES xi

LIST OF FIGURES xvi

Chapter page

1.0 INTRODUCTION..... 1

2.0 LITERATURE REVIEW..... 4
2.1 Definition of Seed Vigor..... 4
2.2 Measurement of Seed Vigor..... 5
2.2.1 The Standard Germination Test..... 5
2.2.2 The Cold Germination Test..... 7
2.3 Seed Characteristics Related to Seed Vigor..... 8
2.3.1 Bulk Density..... 8
2.3.1.1 Relationship between Bulk Density and Seed Vigor..... 9
2.3.1.2 Effect of Field Weathering on Bulk Density.....10
2.3.2 Kernel Density.....11
2.3.2.1 Relationship between Seed Density and Seed Vigor.....12
2.3.2.2 Effect of Weathering on Seed Density.....12
2.3.3 Kernel Mass.....13
2.3.3.1 Relationship between Kernel Mass and Seed Vigor.....13
2.3.3.2 Effect of Weathering on Kernel Mass.....16
2.3.4 Kernel Hardness.....17
2.3.4.1 Measurement of Kernel Hardness.17
2.3.4.2 Effect of Weathering on Kernel Hardness.....17
2.3.5 Seed Protein Concentration.....18
2.3.5.1 Relationship between Seed Protein Concentration and Seed Vigor.....18
2.3.5.2 Effect of Weathering on Seed Protein Concentration.....20
2.3.6 Alpha-Amylase Activity.....21
2.3.6.1 Measurement of Alpha-Amylase...22
2.3.6.2 Effect of Weathering on Alpha-Amylase.....23

2.3.6.3 Relationship between Alpha-Amylase Activity and Seed Vigor....24
2.4 Presence of Microorganisms....25
2.4.1 Geographical Distribution of Field Fungi....26
2.4.2 Effect of Weathering on Microbial Colonization....27
2.4.3 Effect of Microorganisms on Seed Vigor..28
2.4.4 Fungal Isolation Techniques....29
2.5 The Effect of Harvest Management System on Seed Quality....30
2.5.1 Effect of Harvest System on Drying Rate.30
2.5.2 Effect of Harvest System on Seed Quality Characteristics....32
3.0 METHODS AND MATERIALS....34
3.1 Field Experiments....34
3.2 Experimental Treatments....35
3.2.1 Experiment 1....35
3.2.1.1 Seed Moisture Content....39
3.2.1.2 Environmental Measurements....40
3.2.2 Experiment 2....44
3.2.2.1 Environmental Measurements....45
3.3 Seed Quality Measurements....46
3.3.1 General....46
3.3.2 Physical Properties....47
3.3.3 Microbial Properties....48
3.3.4 Physiological Properties....49
3.4 Statistical Analysis....51
4.0 RESULTS AND DISCUSSION....52
4.1 Experiment 1....52
4.1.1 Physical Properties....52
4.1.1.1 Bulk Density....52
4.1.1.2 Kernel Density....57
4.1.1.3 Kernel Mass....62
4.1.1.4 Kernel Hardness....64
4.1.1.5 Official Grades....67
4.1.2 Microbial Properties....68
4.1.3 Physiological Properties....81
4.1.3.1 Seed Protein Concentration....81
4.1.3.2 Alpha-Amylase Activity....82
4.1.3.3 Standard Germination....88
4.1.3.4 Cold Germination....93
4.2 Experiment 2....110
4.2.1 Environmental Conditions....110
4.2.2 Physical Properties....116
4.2.2.1 Bulk Density....116
4.2.2.2 Kernel Density....118
4.2.2.3 Kernel Mass....121
4.2.2.4 Kernel Hardness....123
4.2.3 Microbial Properties....125

4.2.4 Physiological Properties.....135
4.2.4.1 Protein Concentration.....135
4.2.4.2 Alpha-Amylase Activity.....136
4.2.4.3 Standard Germination.....137
4.2.4.4 Cold Germination.....139

5.0 SUMMARY AND CONCLUSIONS.....147

LITERATURE CITED.....153

6.0 APPENDIX.....162

List of Tables

Table page

1. The effect of varying quantity and frequency of elevated kernel moisture on bulk density of wheat....11

2. Influence of field weathering on bulk density (kg hL^{-1}) of wheat and barley grown at Portage la Prairie in 1989 and 1990.....54

3. Correlation coefficients between individual environmental parameters and bulk density of wheat and barley grown at Portage la Prairie in 1989 and 1990.....55

4. Regression of several environmental parameters on bulk density of wheat grown at Portage la Prairie in 1989 and 1990.....56

5. Influence of field weathering on kernel density (g mL^{-1}) of wheat and barley grown at Portage la Prairie in 1989 and 1990.....58

6. Correlation coefficients between individual environmental parameters and kernel density of wheat and barley grown at Portage la Prairie in 1989 and 1990.....59

7. Regression analysis of several environmental parameters on kernel density of barley grown at Portage la Prairie in 1989 and 1990.....60

8. Influence of field weathering on kernel mass (mg $kernel^{-1}$) of wheat and barley grown at Portage la Prairie in 1989 and 1990.....62

9. Correlation coefficients between individual environmental parameters and kernel mass of wheat and barley grown at Portage la Prairie in 1989 and 1990.....64

10. Influence of field weathering on kernel hardness (PSI units) of wheat grown at Portage la Prairie in 1989 and 1990.....65

11. Correlation coeffients between individual environmental parameters and kernel hardness of wheat grown at Portage la Prairie in 1989 and 1990.....66

12. Influence of field weathering on official grain grade of wheat and barley grown at Portage la Prairie in 1989 and 1990.....67

13. Correlation coefficients between individual environmental parameters and *Fusarium* spp. infection of wheat and barley grown at Portage la Prairie in 1989 and 1990.....74

14. Regression of several environmental parameters on *Fusarium* spp. infection of barley grown at Portage la Prairie in 1989 and 1990.....76

15. Influence of field weathering on *Fusarium* spp. infection of wheat grown at Portage la Prairie in 1989.....77

16. Influence of field weathering on *Fusarium* spp. infection of barley grown at Portage la Prairie in 1989.....77

17. Influence of field weathering on *Fusarium* spp. infection of wheat grown at Portage la Prairie in 1990.....78

18. Influence of field weathering on *Fusarium* spp. infection of barley grown at Portage la Prairie in 1990.....78

19. Influence of field weathering on seed protein concentration (%) of wheat and barley grown at Portage la Prairie in 1989 and 1990.....82

20. Influence of field weathering on falling number (s) of wheat and barley grown at Portage la Prairie in 1989 and 1990.....83

21. Correlation coefficients between individual environmental parameters and falling number of wheat and barley grown at Portage la Prairie in 1989 and 1990.....84

22. Regression analysis of precipitation on falling number of wheat at Portage la Prairie in 1989 and 1990.....86

23. Regression of several environmental parameters on falling number of barley grown at Portage la Prairie in 1989 and 1990.....87

24. Influence of field weathering on standard germination of wheat grown at Portage la Prairie in 1989.....88

25. Influence of field weathering on standard germination of wheat and barley grown at Portage la Prairie in 1989 and 1990.....89

26. Influence of field weathering on abnormal germination of wheat grown at Portage la Prairie in 1989 and 1990.....92

27. Correlation coefficients between individual environmental parameters and standard germination of wheat and barley grown at Portage la Prairie in 1989 and 1990.....92

28. Correlation coefficients between individual environmental parameters and cold germination of wheat and barley grown at Portage la Prairie in 1989 and 1990.....103

29. Regression of several environmental parameters on cold germination of wheat grown at Portage la Prairie in 1989 and 1990.....105

30. Regression of precipitation on cold germination of barley at 10 and 12 days after planting.....106

31. Correlation coefficients between seed quality characteristics and cold germination of wheat grown at Portage la Prairie in 1989 and 1990.....108

32. Correlation coefficients between seed quality characteristics and cold germination of barley grown at Portage la Prairie in 1989 and 1990.....109

33. Effect of harvest management system on infection level by six different genera of field fungi on wheat grown at Portage la Prairie in 1990.....127

34. Effect of harvest management system on infection level by six different genera of field fungi on barley grown at Portage la Prairie in 1990.....128

35. Effect of harvest management system on *Fusarium* spp. infection on wheat grown at Portage la Prairie in 1990.....131

36. Effect of harvest management system on *Fusarium* spp. infection on barley grown at Portage la Prairie in 1990.....132

37. Effect of harvest management system on seed protein concentration of wheat and barley grown at Portage la Prairie in 1989 and 1990.....135

38. Effect of harvest management system on falling number of wheat and barley grown at Portage la Prairie in 1989.....136

39. Effect of harvest management system on falling number of wheat and barley grown at Portage la Prairie in 1990.....137

40. Effect of harvest management system on standard germination of wheat and barley grown at Portage la Prairie in 1989.....138

41. Effect of harvest management system on standard germination of wheat and barley grown at Portage la Prairie in 1990.....138

42. Effect of harvest management system on abnormal germination of wheat grown at Portage la Prairie in 1989 and 1990.....139

43. Effect of harvest management system on cold germination of wheat and barley grown at Portage la Prairie in 1990.....144

44. Effect of harvest management system on abnormal germination (cold) of wheat grown at Portage la Prairie in 1989 and 1990.....146

A1. Seed moisture content at threshing for wheat and barley grown at Portage la Prairie in 1989 and 1990.....162

A2. Average daily environmental parameter values during weathering period for barley in 1989.....162

A3. Average daily environmental parameter values during weathering period for wheat in 1989.....163

A4. Average daily environmental parameter values during weathering period for barley in 1990.....164

A5. Average daily environmental parameter values during weathering period for wheat in 1990.....165

A6. Cold germination of wheat grown at Portage la Prairie in 1989.....166

A7. Cold germination of barley grown at Portage la Prairie in 1989.....166

A8. Cold germination of wheat grown at Portage la Prairie in 1990.....166

A9. Cold germination (%) of barley grown at Portage la Prairie in 1990.....167

A10 Seed moisture (%) at threshing for wheat and barley grown at Portage la Prairie in 1989 and 1990.....167

A11 Effect of harvest management system on cold germination (%) of wheat grown at Portage la Prairie in 1989.....169

A12 Effect of harvest management system on cold germination (%) of barley grown at Portage la Prairie in 1989.....170

List of Figures

Figure page

1. Relationship between seed vigor and seed viability.....7

2. Triphasic pattern of water uptake by germinating seed.....21

3. Tractor-mounted spray boom used to simulate precipitation.....36

4. Collection channels used to determine water distribution across spray pattern.....38

5. Water distribution across spray pattern.....38

6. Kernel moisture and precipitation during the exposure period (Aug 11 to Aug 13) for wheat in 1989.....41

7. Kernel moisture and precipitation during the exposure period (Aug 2 to Aug 22) for barley in 1989.....41

8. Kernel moisture and precipitation during the exposure period (Aug 16 to Sept 25) for wheat in 1990.....42

9. Kernel moisture and precipitation during the exposure period (Aug 18 to Sept 25) for barley in 1990.....42

10. Influence of field weathering on fungal infection of wheat grown at Portage la Prairie in 1989.....69

11. Influence of field weathering on fungal infection of barley grown at Portage la Prairie in 1989.....69

12. Influence of field weathering on fungal infection of wheat grown at Portage la Prairie in 1990.....70

13. Influence of field weathering on fungal infection of barley grown at Portage la Prairie in 1990.....70

14. Effect of weathering on cold germination of wheat grown at Portage la Prairie in 1989.....94

15. Effect of weathering on cold germination of barley grown at Portage la Prairie in 1989.....94

16. Effect of weathering on cold germination of wheat grown at Portage la Prairie in 1990.....95

17. Effect of weathering on cold germination of barley grown at Portage la Prairie in 1990.....95

18. Quantity and frequency of precipitation during weathering period for wheat in experiment 2, Portage la Prairie, 1989.....111

19. Quantity and frequency of precipitation during weathering period for barley in experiment 2, Portage la Prairie, 1989.....111

20. Actual water vapor pressure and precipitation during weathering period (Aug 16 to Sept 25) for wheat in experiment 2, Portage la Prairie, 1990.....112

21. Water vapor pressure deficit and precipitation during weathering period (Aug 16 to Sept 25) for wheat in experiment 2, Portage la Prairie, 1990.....112

22. Temperature and precipitation during weathering period (Aug 16 to Sept 25) for wheat in experiment 2, Portage la Prairie, 1990.....112

23. Actual water vapor pressure and precipitation during weathering period (Aug 18 to Sept 25) for barley in experiment 2, Portage la Prairie, 1990....113

24. Water vapor pressure deficit and precipitation during weathering period (Aug 18 to Sept 25) for barley in experiment 2, Portage la Prairie, 1990....113

25. Temperature and precipitation during weathering period (Aug 18 to Sept 25) for barley in experiment 2, Portage la Prairie, 1990.....113

26. Effect of harvest management system on bulk density of wheat grown at Portage la Prairie in 1989.....117

27. Effect of harvest management system on bulk density of barley grown at Portage la Prairie in 1989.....117

28. Effect of harvest management system on bulk density of wheat grown at Portage la Prairie in 1990.....117

29. Effect of harvest management system on bulk density of barley grown at Portage la Prairie in 1990.....117

30. Effect of harvest management system on kernel density of wheat grown at Portage la Prairie in 1989.....118

31. Effect of harvest management system on kernel density of barley grown at Portage la Prairie in 1989.....118

32. Effect of harvest management system on kernel density of wheat grown at Portage la Prairie in 1990.....120

33. Effect of harvest management system on kernel density of barley grown at Portage la Prairie in 1990.....120

34. Effect of harvest management system on kernel mass of wheat grown at Portage la Prairie in 1989.....122

35. Effect of harvest management system on kernel mass of barley grown at Portage la Prairie in 1989.....122

36. Effect of harvest management system on kernel mass of wheat grown at Portage la Prairie in 1990.....122

37. Effect of harvest management system on kernel mass of barley grown at Portage la Prairie in 1990.....122

38. Effect of harvest management system on kernel hardness of wheat grown at Portage la Prairie in 1989.....124

39. Effect of harvest management system on kernel hardness of wheat grown at Portage la Prairie in 1990.....124

40. Effect of harvest management system on infection level by six different genera of field fungi on wheat grown at Portage la Prairie in 1989.....126

41. Effect of harvest management system on infection level by six different genera of field fungi on barley grown at Portage la Prairie in 1989.....126

42. Effect of harvest management system on *Fusarium* spp. infection on wheat grown at Portage la Prairie in 1989.....130

43. Effect of harvest management system on *Fusarium* spp. infection on barley grown at Portage la Prairie in 1989.....130

44. Effect of harvest management system on cold germination of wheat grown at Portage la Prairie in 1989.....140

45. Effect of harvest management system on cold germination of barley grown at Portage la Prairie in 1989.....140

46. Effect of harvest management system on cold germination of wheat grown at Portage la Prairie in 1990.....142

47. Effect of harvest management system on cold germination of barley grown at Portage la Prairie in 1990.....142

1.0 INTRODUCTION

Seedlots of wheat and barley of the same cultivar, produced in different environments by different seed producers, frequently exhibit significantly different levels of field performance, (i.e., emergence and yield) (Das Gupta and Austenson, 1973; Sonntag, 1989, Morrison et al., 1991). This differential performance has been attributed to differences in seed vigor (Das Gupta and Austenson, 1973). There is compelling evidence which indicates that a major reason for seed vigor loss is exposure to field weathering during the post-maturity period (i.e., period from physiological maturity to harvest maturity).

Field weathering exposes seed[1] to cycles of wetting and drying and to periods of high atmospheric humidity. Mondragon and Potts (1974) indicated that fluctuations in temperature and relative humidity (RH) in the field determine the degree of seed deterioration in soybean, while Tekrony et al. (1980) found that seed deterioration was most closely related to mean air temperature, maximum daily RH and daily precipitation.

Previous researchers have shown that exposure to field weathering causes an irreversible decrease in kernel density

---

[1] The botanically correct terminology for cereal kernels is caryopsis, as they are one-seeded fruits. However, caryopsis are commonly referred to as seeds and therefore, this term will be used.

(Milner and Shellenberger, 1953; Czarnecki and Evans, 1986), reduced bulk density (Swanson, 1941; Pushman, 1975; Czarnecki and Evans, 1986) and premature enzyme activation, particularly alpha-amylase (Clarke et al., 1984). Furthermore, it has been demonstrated that seedlots of wheat and/or barley consisting of either low kernel density (Spilde, 1989) or low bulk density (Sonntag et al., 1988) displayed a significantly lower level of performance in the field.

Another contributor to seed vigor loss in wheat and barley is the presence of degradative microorganisms within the seed. The two mechanisms by which microorganisms (primarily field and storage fungi) damage seeds are by production of exocellular enzymes and toxins (Halloin, 1986). However, surprisingly little information exists regarding the effects of field weathering on the incidence of seed fungal infection.

Studies have shown that the negative effects of field weathering on certain seed quality parameters were reduced by use of different harvest management practises. For example, Clarke et al. (1984) reported less weathering damage (i.e., alpha-amylase activation), occurred on standing wheat compared to windrowed wheat.

This research project was conducted with the following objectives:

1) to determine if field weathering causes a significant reduction in seed vigor of Katepwa wheat and Heartland barley;

2) to determine the effect of field weathering on other seed quality characteristics;

3) to quantify several environmental parameters during the course of the weathering period and to determine which is most detrimental to seed quality and subsequent vigor; and

4) to determine if a different harvest management system could be used to reduce the effects of weathering on seed quality and vigor.

2.0 LITERATURE REVIEW

2.1 Definition of Seed Vigor

Many definitions of seed vigor have been proposed since Fredrick Nobbe introduced the concept in 1876. Although there are many different technical definitions, these are generally classified as either one of two types: an academic definition, and an operational definition. The academic definition discusses, identifies, and describes seed vigor (i.e., it attempts to relay what seed vigor *is*), while the operational definition focuses on what seed vigor *does*, (i.e., the observable characteristics of seed vigor are described).

To conduct a scientific study in which seed vigor is compared among treatments, one must define those characteristics which are related to seed vigor. Furthermore, the necessity of scientific comparison requires the identification of characteristics which can be measured. For this reason, an operational definition of seed vigor is essential.

The Association of Official Seed Analysts (1983), defined seed vigor as "those seed properties which determine the potential for rapid, uniform emergence and development of normal seedlings under a wide range of field conditions." For the purpose of this study however, the above definition of seed vigor will be modified to: "those seed properties

which determine the potential for rapid, uniform germination, emergence and development of normal seedlings under a wide range of conditions."

2.2 Measurement of Seed Vigor

2.2.1 The Standard Germination Test

Seed germination is defined by the Association of Official Seed Analysts (1983) as "the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under *favorable* conditions."

To determine the germinability of a particular seedlot, standard germination tests are conducted in accordance with the rules set by the Association of Official Seed Analysts (1981). These rules outline specific procedures and conditions with regard to type of substrata, moisture conditions, temperature, and duration of the test. These specifications ensure that the results of standard germination tests are consistent and reproducible, within and among laboratories.

The established conditions of the standard germination test ensure that all the requirements for germination are met, and exceeded. Consequently, germination test results represent the maximum plant producing potential of a seedlot

which was found to correlate quite well with emergence under *ideal* field conditions (Association of Official Seed Analysts, 1983). Unfortunately, *ideal* conditions for seed germination in the field do not always exist, and hence the standard germination test tends to over-predict field emergence (Tekrony and Egli, 1977; Das Gupta and Austenson, 1973; Sonntag et al., 1988; and Morrison et al., 1991). Consequently, many researchers have reached the conclusion that the standard germination test is inadequate for describing the true field potential of a particular seedlot, particularly where plants are subjected to stress at an early development stage. It is now generally accepted that the standard germination test is a determination of seed viability, not seed vigor. The loss of germination capacity is the final practical consequence of deterioration processes in seed. Vigor tests, on the other hand, test seed performance under a wide range of conditions, (i.e., usually much less favorable than the optimum). Therefore, it is theoretically correct to assume that seed having incurred partial but not total deterioration will display a loss in vigor prior to a loss in viability (Figure 1).

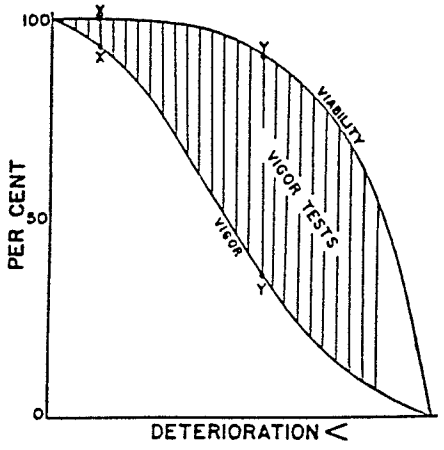


FIGURE 1. RELATIONSHIP BETWEEN SEED VIGOR AND SEED VIABILITY, (Association of Official Seed Analysts, 1983).

2.2.2 The Cold Germination Test

Field conditions at seeding are usually less than optimal. Under suboptimal or stress conditions, high vigor seeds can have a greater potential for emergence and stand establishment than low vigor seeds. One important stress which is often imposed on prairie wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.) crops is low soil temperature at seeding (Das Gupta and Austenson, 1973). Some vigor tests are, therefore, conducted under stress conditions, similar to the stresses which seeds may encounter in a field situation. One such test is the cold germination test.

The cold germination test for wheat and barley is normally conducted at temperatures of 4 to 6°C. It should be

noted that the cold germination test does not rely on the activity of microorganisms to stress the germinating seeds, but rather on the low temperatures which reduce the normal metabolic rates of the seed (McDonald and Copeland, 1985). Cold germination tests have been used extensively to determine the vigor of cotton (Gossypium hirsutum L.) (Christiansen, 1963), corn (Zea mays L.) (Martin et al., 1988), wheat (Sonntag et al., 1988; Das Gupta and Austenson, 1973; Morrison et al., 1991) and barley (Sonntag et al., 1988). These low temperatures reduce the germination rate of seeds (Read and Beaton, 1963; Ashraf and Abu-Shakra, 1978; Lafond and Baker, 1986a), thus allowing differences in seed vigor to be more clearly expressed.

Results of cold germination tests have been positively correlated with field performance and final yield in wheat (Sonntag, 1989; and Morrison et al. 1991) and barley Sonntag, 1989). Based on these findings, and given the fact that the cold germination test is reproducible between laboratories, it appears to be an appropriate vigor test for use on cereal seed crops such as wheat and barley.

2.3 Seed Characteristics Related To Seed Vigor.

2.3.1 Bulk Density

Bulk density is the mass of grain divided by the volume occupied by the grain and intergranular space (Muir and

Sinha, 1988). Thus, bulk density is dependent upon kernel density and the packing characteristics of the grain (Pushman, 1975).

2.3.1.1 Relationship between Bulk Density and Seed Vigor

Bulk density of parental seed for barley, wheat and oat (Avena sativa L.) crops has been positively correlated with seedling dry mass (Frey and Wiggans, 1956), grain yield (Austenson and Walton, 1970; Sonntag et al., 1988; Spilde, 1989), and kernel mass (McNeal and Berg, 1960). Frey and Wiggins (1956), compared seedling dry mass of oat plants grown from parental seed ranging in bulk density from 21.2 to 48.7 kg hL^{-1}). In general, they found a 25-50% reduction in seedling mass from seeds of low parental weight during the period 14 to 21 days after planting. The mass of plants grown from high bulk density and low bulk density seed did not converge until 50 to 70 days after planting.

In a comparison of several dozen pedigreed seedlots of wheat and barley, Sonntag et al. (1988) found bulk density to be the most important seed quality characteristic determining yield in wheat, and also provided a good indication of yield in barley. He concluded that practices designed to minimize losses in bulk density may lead to seed with higher yield potential. McNeal and Berg (1960) evaluated spring wheat seed from different sources, in which four samples with extremes in bulk density and protein

content were selected for yield trials. Although they did not find any significant differences in grain yield between seedlots, they did observe that individual kernel mass at harvest was lowest for the low bulk density seedlot.

2.3.1.2 Effect of Field Weathering on Bulk Density

Occasional periods of rain or a combination of rain and high humidity during the harvest period can negatively affect seed quality parameters. During these periods of field weathering the kernel moisture content increases, resulting in a subsequent loss in bulk density (Swanson, 1941; Czarnecki and Evans, 1986; Bauer and Black, 1983). Swanson (1941) postulated that the extent of weather-induced bulk density loss was dependent upon specific weather conditions, such as quantity and frequency of precipitation, and also the duration of kernel wetness. Quantity of precipitation had a much greater influence on bulk density reduction than did frequency of precipitation (Table 1). Swanson (1943) later demonstrated in field experiments, that the greatest decline in bulk density occurred after the first day of kernel wetting. Presumably this was because maximum levels of seed moisture promoted extensive kernel swelling, followed by incomplete contraction upon dehydration. Further cycles of wetting/drying had little effect on subsequent bulk density as the internal adjustments were already made.

TABLE 1. THE EFFECT OF VARYING QUANTITY AND FREQUENCY OF ELEVATED KERNEL MOISTURE ON BULK DENSITY OF WHEAT

Initial Dry Kernel Moisture (%)	Wet/Dry Cycles	Raised kern. Moist. (%)[1]	Bulk Dens. (kg hL^{-1})
11 (check)	0	-	74.7
11	1	14	70.9
11	2	14,17	69.3
11	3	14,17,20	68.4
11	4	14,17,20,23	67.6
11	5	14,17,20,23,26	66.3
11	1	26	67.3
11	2	26,23	66.9
11	3	26,23,20	66.9
11	4	26,23,20,17	66.9
11	5	26,23,20,17,14	67.9

Swanson, (1941)

[1] Kernel moisture content dried to 11% between each wet/dry cycle.

Czarnecki and Evans (1986), found that the largest reduction (approximately 5%) in bulk density for wheat occurred after one cycle of weathering (i.e., one cycle of kernel wetting and drying). However, it must be noted that rainfall during this period for each year of their two year field experiment was substantial (32 and 55mm, respectively). They also found that individual kernel density and grain packing efficiency were affected about equally following a 5% reduction in bulk density.

2.3.2 Kernel Density

Kernel density is the mass of grain divided by the volume occupied by the kernels (i.e., excluding the volume of intergranular space) (Muir and Sinha, 1988). The overall density of the grain is a function of the relative

proportion of the main components of the seed kernel (i.e., starch, protein and water). The addition of moisture to the seed of wheat has been found to cause a linear reduction in kernel density (Sharpe, 1927; Tkachuk and Kuzina, 1979). Thus, to accurately compare results of kernel density, seed moisture content must be standardized.

2.3.2.1 Relationship between Seed Density and Seed Vigor

It has been demonstrated that seed density has a positive effect on the overall germination in cotton (Krieg and Bartee, 1975), and grain sorghum (Sorghum bicolor L.) (Maranville and Clegg, 1977). Hoy and Gamble (1987) indicated that plants grown from high density soybean seed have a greater capacity for yield compensation than plants grown from low density seed. Working with wheat and barley, Sonntag et al. (1988) found significant correlations between seed density and grain yield for barley but not wheat.

2.3.2.2 Effect of Weathering on Seed Density

Bushuk and Hlynka (1960) reported that wheat subjected to a sorption-desorption cycle within the moisture range 0-26%, had a decrease in density of 0.014 g mL^{-1}. Similarly, Czarnecki (1980) demonstrated that wheat, exposed to field weathering during delayed harvest resulted in a 2.7 and 2.1%

reduction in density for the first and second years, respectively, of a two year study.

Utilizing X-ray techniques, Milner and Shellenberger (1953) discovered that weathered wheat developed internal fissures oriented at right angles to the longitudinal axis of the kernel. This resulted in the formation of internal air spaces within the kernel. These air spaces within the kernel were cited as the main reason for the irreversible loss in kernel density of weathered seed. Milner and Shellenberger (1953) also found that the extent of fissuring increased greatly with elevated drying temperatures and high initial kernel moisture content.

2.3.3 Kernel Mass

One method used to determine average seed size is the thousand kernel mass measurement. Since mass is a measurement of the quantity of matter present, a high thousand kernel mass would correspond to large sized seed.

2.3.3.1 Relationship between Kernel Mass and Seed Vigor

Many studies have been conducted with the objective of determining the relationship between seed size and seed vigor. Results of these studies indicate positive relationships between these two parameters for soybean (Glycine max L.) (Hoy and Gamble, 1985), grain sorghum

(Maranville and Clegg, 1977), wheat (Evans and Bhatt, 1977; Lafond and Baker, 1986b; Peterson et al., 1989; Spilde, 1989) and barley (Kaufman and McFadden, 1963; Spilde, 1989).

Lafond and Baker (1986a) demonstrated that over a wide range of temperatures (5°C to 30°C), small sized wheat seeds consistently germinated more rapidly than large sized seed (seeds were considered large if they fell through a 3.9 mm sieve but remained on top of a sieve with hole diameters of 3.6 mm; medium if they fell through a 3.6 mm sieve but remained on top of a sieve with hole diameters of 3.2 mm; and small if they fell through a 3.2 mm sieve but remained on top of a sieve with hole diameters of 2.8 mm). However, final germination percentage was not affected by seed size. One explanation for this finding is that small seeds may have a greater rate of water uptake. Surprisingly, when this hypothesis was tested (Lafond and Baker, 1986a), it was found that water uptake rate was not significantly affected by seed size. Hence, it is likely that the smaller seed germinated more rapidly simply due to a lower total moisture requirement.

In another study, Lafond and Baker (1986b) reported that seed size of wheat significantly affected seedling emergence, seedling dry weight, and plant leaf development in nine cultivars of wheat. Again, seedlings grown from small seed (25.9 to 32.9 mg kernel^{-1}) were found to emerge more rapidly than large seed (35.8 to 43.6 mg kernel^{-1}). However, despite the delay in emergence, seedlings grown

from large seed consistently displayed greater seedling shoot dry mass, and more rapid leaf development. Peterson et al. (1989) indicated that seed size had no significant effect on time of emergence for winter wheat, but was significantly positively correlated to final tiller number.

With barley, Kaufman and McFadden (1963) observed greater performance and yield from crops grown from large size seed (37 to 44 mg kernel^{-1}) than from small sized seed (22 to 26 mg kernel^{-1}). As well, large barley seeds (45.6 to 56.5 mg kernel^{-1}) were found to produce seedlings of greater dry mass two weeks after germination than small barley seeds (29.5 to 39.5 mg kernel^{-1}) (Boyd et al. 1971).

Bremner et al. (1963) demonstrated that the size of the wheat embryo and endosperm were both linearly related to total seed size. Interestingly though, embryo size was found to have negligible effects on subsequent seedling growth, whereas endosperm size had a positive effect. This discovery has been substantiated by Chin and Aitkens (1976), who demonstrated that a loss or reduction in endosperm reserves due to seed damage significantly reduced seedling growth. Hence, the quantity of nutrients stored in the endosperm is reflected directly in terms of seed size, but more importantly, is expressed in terms of seed vigor.

2.3.3.2 Effect of Weathering on Kernel Mass

Exposure of mature cereal crop to periods of heavy precipitation will result in elevated seed moisture levels. The actual rate of moisture imbibition is dependent upon the moisture gradient between the seed and surrounding environment (Versavel and Muir, 1988a). Solutes such as organic and inorganic ions, sugars, amino acids and even proteins, may leak from seeds which have undergone rapid water imbibition (Simon and Raja Harum, 1972). If weather conditions are severe enough to cause solute leakage, one would expect a subsequent reduction in kernel mass.

Czarnecki and Evans (1986) found that post-maturity weathering caused a significant reduction in 1000 kernel mass of wheat in one year of a two year study. Examination of weather records indicated that the reduction in 1000 kernel mass in this study may have been due to very rapid water imbibition, however, the actual kernel moisture contents were not determined. Whitcomb and Johnson (1928) found that field weathering did not affect kernel mass of Marquis, a hard red spring wheat, or Kanred, an awned hard red winter wheat. During the course of this study, unthreshed shocks of wheat were left in the field until spring, with samples collected on a monthly basis.

2.3.4 Kernel Hardness

Terms such as hardness and vitreosity have long been used to describe wheat quality, especially by breeders and millers. However, kernel hardness may also be an important factor in seed vigor. For example, Czarnecki and Evans (1986) pointed out that softer kernels may be more susceptible to mechanical damage during harvesting and handling operations.

2.3.4.1 Measurement of Kernel Hardness

A variety of tests have been used to determine kernel hardness of wheat. These include the pearling test, (Swanson, 1941), the grinding time test (De la Roche and Fowler, 1975), and the particle size index test (Baker and Dyck, 1975). The particle size index test uses near-infrared (NIR) spectroscopy to determine hardness of wheat. Williams and Sobering (1986) reported that the NIR method for measuring wheat was readily transferable among instruments and laboratories. Furthermore, the test is very rapid and simple to perform.

2.3.4.2 Effect of Weathering on Kernel Hardness

Natural weathering, or wetting and drying in the laboratory is known to cause a reduction in kernel hardness in wheat (Swanson, 1941; Milner and Shellenberger, 1953).

More recently, Czarnecki and Evans (1986), found that windrowed wheat crop exposed to weathering consistently displayed lower kernel hardness than unweathered wheat, regardless of cultivar. One explanation for reduction in hardness in weathered seed may be related to the formation of internal fissures (Milner and Shellenberger, 1953). The formation of fissures would sever intermolecular bonding, resulting in a weaker seed structure. Hence, the kernel would be more susceptible to mechanical damage. In fact, Entz et al. (1991), demonstrated that wheat threshed at high moisture content, ie., 21% (high moisture content is associated with softer kernels), resulted in a reduction in seed vigor (determined by cold germination).

2.3.5 Seed Protein Concentration

2.3.5.1 Relationship between Seed Protein Concentration and Seed Vigor.

Several investigators have found that the protein concentration of a given seedlot of wheat and/or barley is positively and significantly correlated with seedling vigor (measured as the rate of seedling dry matter accumulation 18-21 days after planting), (McDaniel, 1969; Ries and Everson, 1973; Evans and Bhatt, 1977).

Other researchers have shown that high-protein wheat and oat seed resulted in higher grain yields than low-

protein seed (Schweizer and Ries, 1969; Ries et al. 1976). This was disputed by Welch (1977), who found in glasshouse and field experiments that seed protein content did not consistently affect grain yield of cereal crops. However, Welch did note that under very low soil fertility conditions, some differences between yield of high and low-protein seed occurred. Similar to the previous researchers, Welch (1977) also noted that high-protein seed produced more vigorous seedlings than low-protein seed. The degree of this response depended on soil nutrient level and seedling age.

Lowe and Ries (1972) have provided two possible explanations why seedlings grown from high protein seed demonstrate more vigorous growth during the first three weeks after planting compared to seedlings grown from low-protein seed. First, the small differences in endosperm protein content (4.0 to 5.7 mg protein $seed^{-1}$) may provide different levels of respiratory substrate and amino acids for protein synthesis. Secondly, higher levels of amino acids during hydrolysis for high protein seed may result in greater enzyme induction, in turn, supplying the seedling with more energy in the form of glucose. Thus, it appears that early seed vigor of high protein seed can be explained on a physiological basis.

The relationship between seed protein content and final grain yield may also be dependent on fertility and environmental conditions. Bulisani and Warner (1980) demonstrated that as additional nitrogen was placed with the

seed at planting the effect of seed protein content on plant performance (ie., dry matter accumulation) decreased.

2.3.5.2 Effect of Weathering on Seed Protein Concentration

Swanson (1943) studied the effects of weathering on the physical and other properties of hard red spring wheat. He found that weathering did not affect the protein concentration of the grain. Likewise, Pool et al. (1958) indicated that delayed harvest, resulting in extensive field weathering, did not reduce the protein content of soft spring wheat seed. The protein content in these experiments was determined by the Kjeldahl method, where total nitrogen content was multiplied by a factor of 5.7 to indicate crude protein levels. Perhaps this test is not sensitive enough to identify reduced levels of intracellular protein.

Reduction in protein due to weathering could, however, be expected under certain conditions. For example, when dry seeds imbibe water rapidly, the seed leaks solutes such as organic and inorganic ions, sugars, amino acids, and proteins. This leakage has been unambiguously ascribed to loss of intracellular constituents (Crowe et al., 1989).

2.3.6 Alpha-amylase Activity

As seeds imbibe water, drastic metabolic changes occur. A triphasic pattern of water uptake has been demonstrated during the germination of most seeds (Figure 2). Enzyme activation begins during phases I and II of imbibition. The process of enzyme activation serves to break down stored tissues, promote the transfer of stored nutrients from the cotyledons or endosperm to the growing points, and trigger chemical reactions that use breakdown products for the synthesis of new materials.

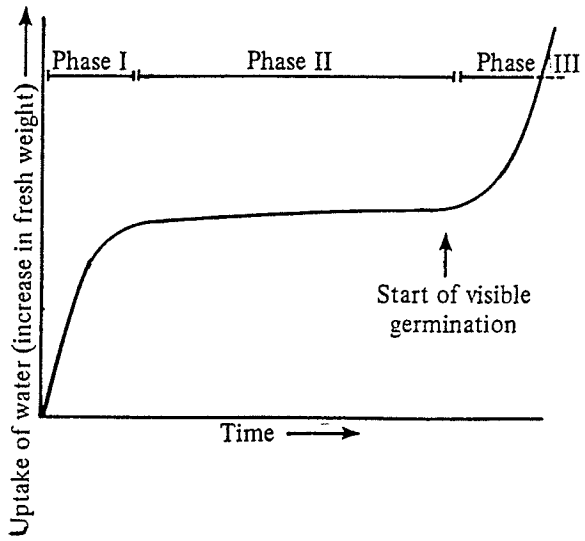


FIGURE 2. TRIPHASIC PATTERN OF WATER UPTAKE BY GERMINATING SEED, (McDonald and Copeland, 1985).

In monocotyledonous plants such as wheat and barley, gibberellins are released from the scutellum and move through the endosperm of the aleurone layer. This then activates the synthesis of hydrolytic enzymes such as alpha-amylase, ribonuclease, endo-beta-glucanase, and phosphatase. These enzymes consequently cause a degradation of the

endosperm and endosperm cell walls. This process begins near the scutellum, with subsequent hydrolysis occurring to the sides and upwards through the endosperm (McDonald and Copeland, 1985).

2.3.6.1 Measurement of Alpha-Amylase

The falling number test is a quantitative measurement which examines wheat for evidence of alpha-amylase activity (Moss et al., 1972). This test is based primarily on the change in viscosity of a heated suspension of ground wheat due to enzymatic degradation of starch by alpha-amylase.

Mathewson and Pomeranz (1978) found very high correlations ($r = 0.953$ to 0.998) between the results of a colorimetric alpha-amylase assay and falling number values for a variety of wheats from various locations. It has been concluded by Moss et al. (1972) and Mathewson and Pomeranz (1978) that the falling number test is much more rapid than the colorimetric alpha-amylase assay, and also more reliable than a visual assessment of the state of wheat. In addition, the Falling Number test is applicable to both meal and flour of wheat, rye (Secale cereale L.), barley, other grains and malted cereals (American Association of Cereal Chemists, 1983).

2.3.6.2 Effect of Weathering on Alpha-Amylase

Since enzyme activation is dependent upon water imbibition, and field weathering is associated with periods of precipitation causing elevated kernel moisture content, it is not surprising that weathering increases alpha-amylase activity (Moss et al., 1972; Clarke et al., 1984; Czarnecki and Evans, 1986). Czarnecki (1980) indicated that although there was a significant cultivar by falling number interaction, there was also a significant harvest date by falling number interaction for wheat. These results demonstrate that different cultivars of wheat have a range of susceptibilities to the effect of delayed harvest on falling number. However, substantial weathering of all cultivars resulted in significantly reduced falling number. Similarly, it has been demonstrated that Australian white wheats undergo an increase in alpha-amylase activity if exposed to pre-harvest rain (Moss et al., 1972). Since the objective of steeping in malt production is to induce enzyme formation within the barley kernel, one would expect that barley seed subjected to weathering would also display an increase in enzyme activity, particularly alpha-amylase.

2.3.6.3 Relationship between Alpha-Amylase Activity and Seed Vigor

The germination rate of wheat and annual rye-grass was found to double after one hydration-dehydration cycle (Lush et al., 1981). The seeds were hydrated to 145% (wheat), and 155% (ryegrass) of original seed dry weight. This increased germination rate was attributed to a reduction in the lag phase occurring from the initiation of water imbibition until radicle emergence. This period has been described by McDonald and Copeland (1985) as the enzyme activation period. Thus, it seems likely that the hydration-dehydration cycle stimulated enzyme activation. Consequently, the germination processes were activated upon hydration, and resumed from that point upon the second hydration. Therefore, this work indicates that stimulation of enzyme activity may increase germination rate.

However reports by Crowe et al. (1989), indicate that very rapid water imbibition by dry seeds can also result in significant solute leakage. Excessive solute leakage from imbibing seeds can reduce seedling performance. Thus, if seed priming (hydration-dehydration) is not executed properly (i.e., low imbibition rates), a reduction in seedling vigor may occur. Furthermore, Morrison et al. (1991) indicated that superior performance associated with non-weathered seed may be due to higher food reserves within the caryopsis. As weathering proceeds, enzymes degrade the

nutritional starch which may then be more susceptible to oxidation or leaching.

2.4 Presence of Microorganisms

An important factor which may reduce the physiological performance of seeds is the presence of harmful microorganisms. Studies to determine the role of microorganisms in seed deterioration have centered on a number of fungal genera that are facultative parasites (Halloin, 1986). Many different genera of fungi have been observed on cereal seed, and these various groups are considered as either field fungi or storage fungi (Christensen and Kaufmann, 1969). Field fungi are those that contaminate or invade seeds in the field, often during or after ripening. These primarily include genera such as *Fusarium, Alternaria, Helminthosporium* and *Cladosporium* (Halloin, 1986).

Field fungi become prevalent when seed moisture content is maintained above 16% for extended periods of time (Tuite and Christensen, 1955). Therefore, weather conditions which are conducive to seed quality loss also promote the existence of detrimental field fungi on and within seed.

2.4.1 Geographical Distribution of Field Fungi

In a Canada-wide survey consisting of 6204 samples of wheat, barley and oat seed collected directly after harvest, Machacek et al. (1951) found that the genus *Alternaria*, a saprophytic fungi, was isolated most frequently. These results were recently confirmed by Clear (1987) working on wheat seed with various levels of mildew infection. In total, Machacek and coworkers identified 43 different fungal genera and 102 different species. Of the fungi with pathogenic capabilities, *Helminthosporium* was found to be the most prevalent. Various levels of *Fusarium* spp. were also observed. In fact, these two genera were the only ones to exceed a 1% infection level.

In general, seed obtained from eastern Canada had a higher level of infection than seed from western Canada (Machacek et al., 1951). Seed from Alberta and Saskatchewan displayed the lowest levels of infection, while seed from the Maritime provinces were infected at the highest levels. The explanation given for this trend is that the level of infection is a function of the amount of inoculum in the seed environment. The wetter environment in eastern Canada would enhance inoculum levels. Seedlots from Manitoba displayed relatively high levels of seed infection by *Alternaria*, H. sativum and *Nigrospora*, while H. teres, H. avenae, *Fusarium* spp. and *Cladosporium* displayed relatively low levels of seed infection.

2.4.2 Effect of Weathering on Microbial Colonization.

Clear (1987) determined that the level of *Alternaria* infection was equal for unweathered wheat and severely weathered, mildewed wheat. These findings demonstrate that field weathering during the post-maturity period had no influential effect on *Alternaria* growth.

Helminthosporium sativum is a pathogenic fungus known to cause cereal diseases such as crown and root rot of wheat, as well as head blight, smudge, and black point of seed (Martens et al., 1984). *Helminthosporium* was found to have the greatest level of spore germination when temperatures were between 15 and 18°C, and soil conditions were moist (Mead, 1942). Therefore, it appears possible that environmental weathering during the post-maturity period may increase the level of seeds contaminated with *Helminthosporium*.

Research has shown that moist conditions during the maturity period favour infection of spikes by *Fusarium* (Duthie et al., 1986; Sutton, 1982). However, environmental conditions necessary for disease development vary depending on the particular *Fusarium* species (Martin and Johnston, 1982).

Two major concerns with seed infected by *Fusarium* spp. is the capacity of these fungi to cause plant disease and produce mycotoxins. For example, species such as F.

graminearum, F. culmorum, and to a lesser extent F. avenaceum, cause seedling blight, head blight, and root and crown rot in wheat (Duthie et al., 1986) and barley, and may reduce yield (Martin and Johnston, 1982). Furthermore, seed-transmitted inoculum has specifically been demonstrated as causing seedling blight and infections of tiller bases in mature plants (Duthie et al., 1986). Mycotoxins such as zearalenone and deoxynivalenol have been associated largely with epidemics of head blight caused by F. graminearum (Sutton, 1982). However, other mycotoxigenic species such as F. sporotrichioides have also been detected in affected grain (Trenholm et al., 1981). Species such as F. poae and to a lesser extent F. avenaceum, are not considered strong pathogens. However, it has been demonstrated that these species are primary colonizers of cereal spikes, (i.e., infect spikes five to seven days prior to spike emergence), making the spikes more susceptible to later infections by more pathogenic species such as F. culmorum and F. graminearum (Sturz and Johnston, 1983).

2.4.3 Effect of Microorganisms on Seed Vigor.

Clear (1987) indicated that seed viability was not affected by *Alternaria* infection. However, when mature kernels of barley infected with Helminthosporium sativum were planted in soil, the resulting seedlings showed evidence of blighting, malformation, stunting and lesioning

(Mead, 1942). The greatest seedling injury was found to occur under conditions of high temperature and excessive moisture.

It has also been demonstrated that planting *Fusarium* infected seed may result in weak seedlings, giving rise to a poor stand (Martin and Johnston, 1982). The reduced performance was found to be expressed more widely in barley than in wheat, while oats appeared to have the most tolerance to seed-borne fusaria.

2.4.4 Fungal Isolation Techniques

Fungi occur on seeds as spores and mycelium. When monitoring seed for the presence of harmful microflora, it is prudent to try to eliminate interference from those fungi which are present merely as contaminants. For this reason, seeds are often surface sterilized before being examined. Flannigan (1969) used a sodium hypochlorite solution (NaOCl) to surface sterilize barley grains. The method was safe, easy, effective and without lingering effect of the chemical.

When isolating field fungi, a broad spectrum medium is preferred over selective media. This is because no specific organism is being targeted. Burgess and Liddell (1983) have used potato dextrose agar (PDA) for identifying *Fusarium* spp.

2.5 The Effect of Harvest Management System on Seed Quality

In western Canada, wheat and barley crops are normally windrowed when the kernel moisture content is between 30 to 40%. The practise of windrowing was introduced to hasten crop drying, to avoid storage problems caused by immature weed seeds in the grain, and to reduce shattering losses due to natural and mechanical causes (Dodds, 1967). Windrowing also overcomes the problems of delayed maturity of low spots in fields (Clarke, 1984).

2.5.1 Effect of Harvest System on Drying Rate

Dodds and Dew (1958) reported that barley windrowed at a kernel water concentration (KWC) of 40% reached a safe combining KWC five to seven days sooner than standing crops in the Swift Current, Sask. area. Feather et al. (1968) reported that barley windrowed at KWC between 31% and 38% dried two days earlier than standing barley at Davis, California. Working with wheat, Dodds (1957) stated that windrowing of wheat could begin seven to nine days sooner than direct combining could be started, and that the windrowed crop could generally be combined about four days after windrowing. Thus, windrowing hastened the drying process by three to five days compared to the standing crop. Published reports indicate that windrowed wheat reached safe combining KWC (14.5%) two days earlier than standing wheat

in a small plot trial using simulated windrows (Clarke, 1982). The main reason for more rapid drying in windrowed crops is related to the abrupt termination of transpiration processes which may still be occurring in unmature plants (Clarke, 1984). For example, not all cereal plants in a field mature at exactly the same time. Windrowing halts the translocation processes and allows drying to proceed. However, during this time, the immature plants within standing crop are still transpiring, and thereby avoiding dry down.

Conversely, if periods of precipitation occur during the seed maturation period, windrowed cereal crops often dry more slowly than standing crops (Bauer and Black, 1983; Clarke, 1984; Clarke, 1989). Dodds and Pelton (1967) reported that the rate of moisture loss was influenced by vapor pressure deficit, hours of sunshine, evaporation, and wind velocity. Therefore, seed located in a windrow could be expected to be exposed to higher vapor pressure, lower evaporation rate and reduced air circulation compared with seed located in a standing crop. This may result in greater seed deterioration for windrowed compared with standing crops.

2.5.2 Effect of Harvest Management System on Seed Quality Characteristics

Bauer and Black (1983) conducted a field study to evaluate the effects of field weathering on grain yield and quality of ripe, standing and windrowed hard red spring wheat. No differences in total grain yield were observed, however, the grain protein content was significantly lower for the windrowed crop in one of three years. Bulk density of the grain was found to be higher for the straight combine method in two out of three years.

Differences in bulk density between harvesting systems were associated with differences in water evaporation rates. Water evaporation rate from spikes of the standing crop was considered to be greater than from spikes within windrows because of better air circulation. Consequently, seed of the swathed crop imbibed greater quantities of water, and was subjected to a greater degree of swelling and, hence, incurred greater bulk density loss.

Clarke et al. (1984) determined the effects of weathering on alpha-amylase activity for 18 wheat cultivars harvested either by straight combine or by the windrow-combine method. Results indicated that the falling number values were substantially higher for the straight combined crop compared to the windrow-combined crop, indicating less alpha-amylase activity in the straight combine system. The greatest differences in falling number were observed between

the two systems for cultivars known to be especially susceptible to weathering. Again, the reason for the difference in falling number between the two treatments was attributed to greater drying rates for the standing crop after periods of precipitation. These results indicate that the adverse effects of field weathering on specific seed quality characteristics can be reduced by allowing crop to remain standing during periods of inclement weather.

3.0 METHODS AND MATERIALS

3.1 Field Experiments

Katepwa wheat (Triticum aestivum L.), is a commercial cultivar of hard red spring wheat which is grown extensively across the Canadian prairies, while Heartland barley (Hordeum vulgare L.) is a 6-rowed feed cultivar recommended for all cropping zones in Manitoba (Anon., 1989a).

Field experiments were conducted to investigate the effects of field weathering on seed quality and vigor of the above mentioned cultivars. Experiments were conducted at the University of Manitoba field research station at Portage la Prairie, MB. in 1989 and 1990. The soil type in both years was a Neuhorst clay loam composed of clay (31%), silt (44%) and sand (25%) with a pH of 7.7.

The experimental area was seeded each year using a commercial zero-till drill (Amazone, model 300), with a 17.8 cm row spacing and a seeding depth of 4 to 5 cm. Wheat crops were sown on May 12 in both years at a rate of 95 kg ha^{-1}, while barley was sown on May 10 in 1989 and on June 1 in 1990 at a rate of 115 kg ha^{-1} each year. Fertilizer N (Ammonium nitrate) was broadcast on the soil prior to seeding. According to Manitoba Soil Test Laboratory recommendations, 100 kg of actual N ha^{-1} was applied in 1989, while 80 kg of actual N ha^{-1} was applied in 1990. P_2O_5 was seed placed at rates of 35 and 20 kg ha^{-1} in 1989

and 1990, respectively. Weeds were controlled chemically according to Provincial recommendations (Anon., 1989b)

3.2 Experimental Treatments

3.2.1 Experiment 1

The crops were windrowed as soon as possible after the kernel moisture content reached approximately 35%. Commercial self-propelled windrowers with 5.54 m headers were used to cut the crop (Versatile, model 400 -both wheat and barley crops in 1990, and the barley in 1989; Co-op Implements, model 550 -wheat crop 1989). The plot sizes were 5.54 m (the width of the windrower), by 10 m in 1989, and 5.54 m by 7 m long in 1990. The experiment was arranged as a randomized complete block design with four replications. The windrows were then left, exposed to weathering in the field for various lengths of time. The four experimental treatments included each year were: unweathered, slight, moderate and severely weathered.

During periods of little or no natural precipitation, water was sprayed onto the windrows in an attempt to simulate natural precipitation. Water was delivered using a tractor-mounted spray boom consisting of two nozzles (Flood-Jet, model 3/4K-SS120) (Figure 3). The nozzles were spaced 1 m apart and adjusted such that the two spray patterns overlapped completely at approximately 45 cm above ground



FIGURE 3. TRACTOR-MOUNTED SPRAY BOOM USED TO SIMULATE PRECIPITATION.

level. Total water output was 59.43 L min^{-1} at approximately 200 kPa. The amount of water applied was based on the 30 year average rainfall during the month of August at Portage la Prairie. All rain simulations were performed after 6:00 pm to reduce evaporative water loss.

The water distribution across the spray pattern was determined by quantifying water output for each 15.2 cm interval across the pattern (Figure 4). The apparatus was positioned such that the top of the channel dividers were 45 cm above ground (equivalent to the height of the top of a windrow). Water from each channel was collected for a 30 second interval and quantified. This procedure was repeated four times. The results were pooled and the averages are plotted in Figure 5.

Due to the fact that the total width of the spray pattern was 2.0 m at a height of 45 cm, the two end channels did not intercept a full track-width of water. However, the 12 center channels, intercepting 182.9 cm of the spray pattern, received full track-widths of water. Windrow width seldom exceeded 100 cm, and hence the spray apparatus adequately covered the entire windrow. The variation in water output within the center 182.9 cm was less than 3.4%.

Seed from the different weathering treatments was threshed using a small plot combine (Hege, Model 125B, Hans-Urich Hege, D-7112 Waldenberg, West Germany). In 1989, all treatments of wheat and barley were threshed in the field. Little attention was given to the seed moisture content at



FIGURE 4. COLLECTION CHANNELS USED TO DETERMINE WATER DISTRIBUTION ACROSS SPRAY PATTERN.

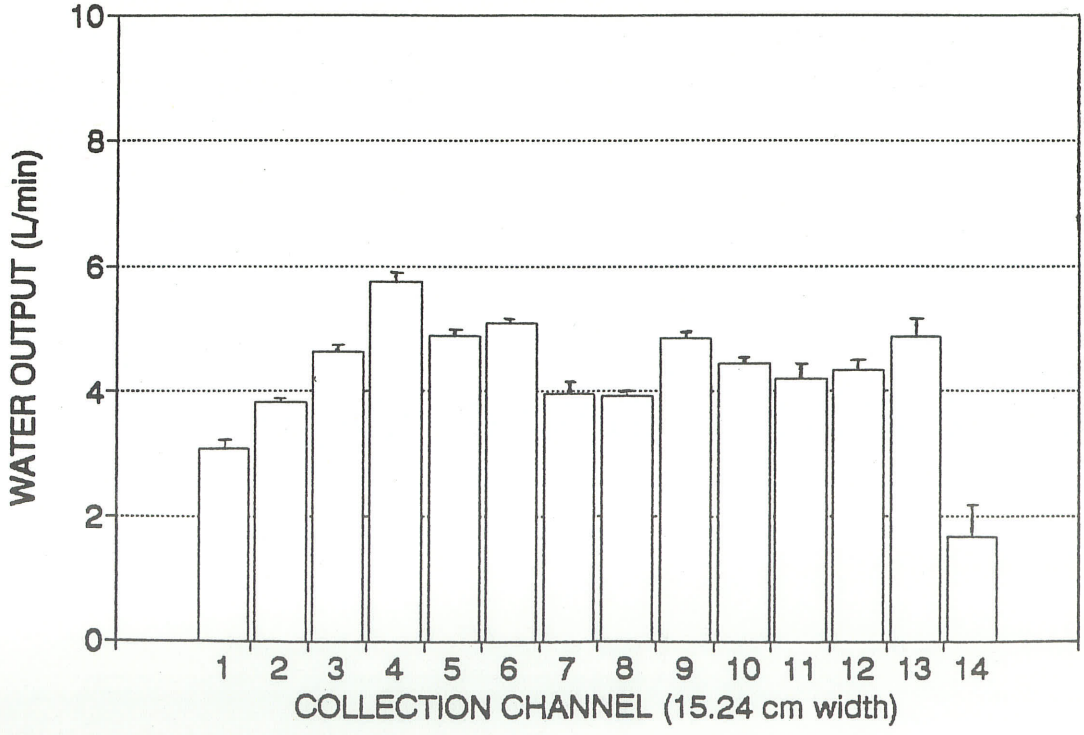


FIGURE 5. WATER DISTRIBUTION ACROSS SPRAY PATTERN. BARS REPRESENT STANDARD ERROR.

threshing. In fact, it was reasoned that threshing seed at relatively high moisture levels would reduce the amount of cracked kernels. Seed was then air dried in cloth bags after threshing. This practise was changed in 1990. Directly after windrowing the unweathered treatment was gathered and placed in burlap bags. These bags were placed indoors to allow the seed moisture content to equilibrate with ambient atmospheric moisture levels. As well, all other treatments were harvested after the seed moisture content levels were fairly uniform between treatments and replicates (Appendix Table A1).

3.2.1.1 Seed Moisture Content

Milner and Shellenberger (1953) demonstrated that cycles of seed wetting and drying can be very detrimental to the physical composition of the seed. Therefore, the seed moisture content was determined on a daily basis for both crops. Samples were collected at approximately 10:00 am (after dew had evaporated). Shocks of crop were removed from four specific locations within the windrow, top, right side, left side, and underneath, providing approximately 200 g of seed. Samples were collected from either treatment 3 or 4 in 1989, while a separate set of plots within each replicate were allocated for moisture content sampling in 1990. Moisture content was determined by the oven-dry

method (Bauer and Black, 1989), and moisture contents were expressed on a wet mass basis calculated as follows:

$$\text{Seed Moisture Content} = \frac{(\text{wet seed mass} - \text{dry seed mass})}{(\text{wet seed mass})} * 100 \quad (1)$$

The fluctuation in seed moisture over the duration of the exposure period, along with precipitation occurrence, and harvest dates are plotted in Figures 6 to 9.

3.2.1.2 Environmental Measurements

In the present study, a number of environmental parameters were monitored to determine which factor had the greatest effect on seed quality.

One relative humidity/temperature sensor (Thermistor and Relative Humidity Probe, Model 207, Campbell Scientific Inc. Edmonton Alta.), was used for each experiment. The sensor was placed just below the surface of the windrow (i.e., location of majority of spikes), in the first replicate of treatment 4. The environmental parameters were recorded every 2 min, and averaged over a 2 h interval for the entire duration of the weathering period. The information was recorded and stored in a data-logger, (Measurement and Control Module, Model CR-10, Campbell Scientific Inc. Edmonton, Alta.), which was connected to the sensors.

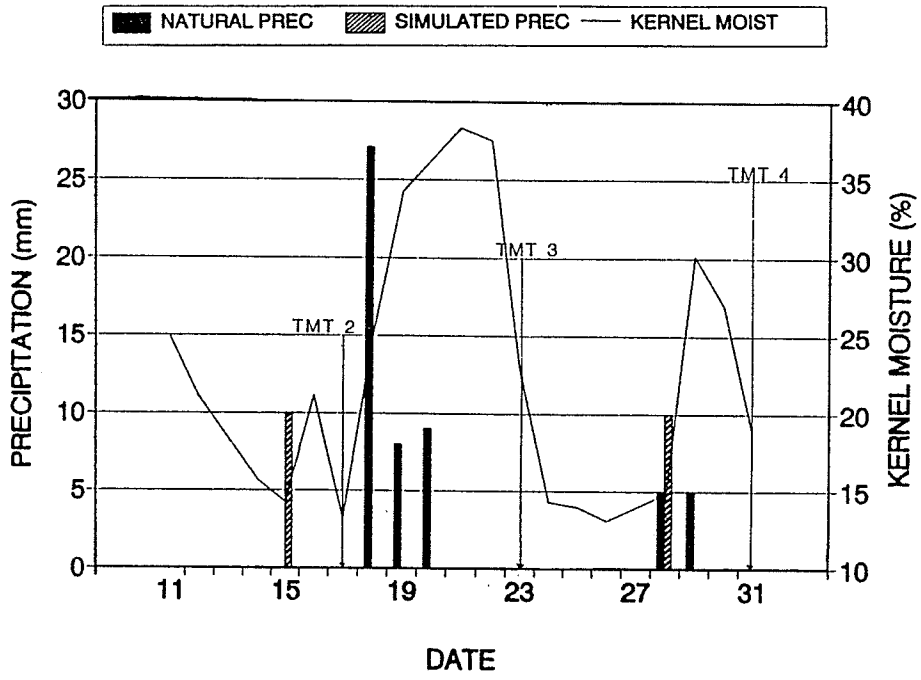


FIGURE 6. KERNEL MOISTURE AND PRECIPITATION DURING THE EXPOSURE PERIOD (AUG 11 TO AUG 31) FOR WHEAT IN 1989. TMT 2 = SLIGHTLY WEATHERED TREATMENT, TMT 3 = MODERATELY WEATHERED TREATMENT, TMT 4 = SEVERELY WEATHERED TREATMENT.

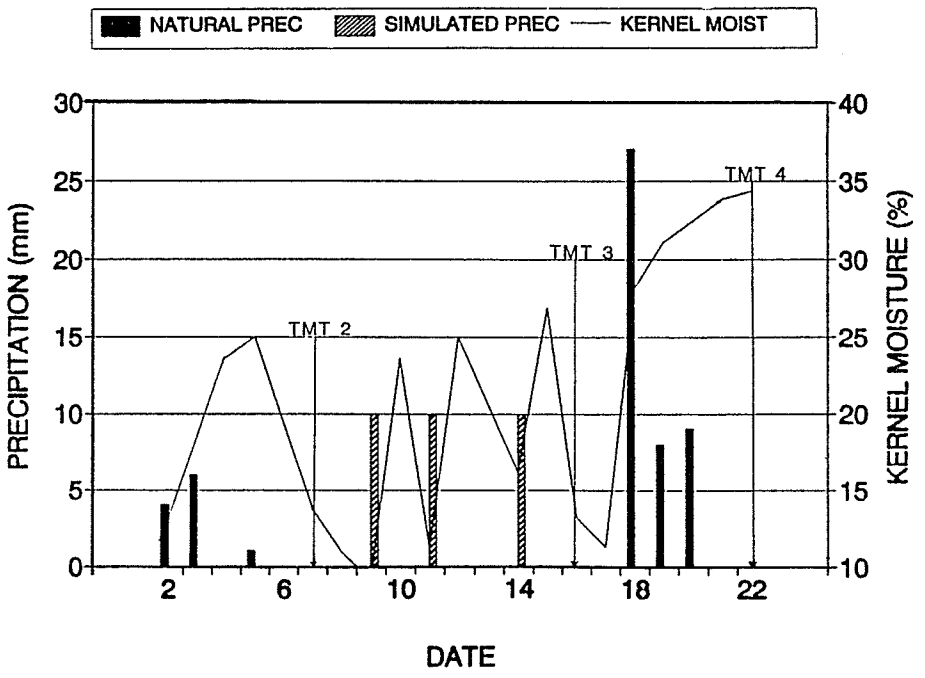


FIGURE 7. KERNEL MOISTURE AND PRECIPITATION DURING THE EXPOSURE PERIOD (AUG 2 TO AUG 22) FOR BARLEY IN 1989. TMT 2 = SLIGHTLY WEATHERED TREATMENT, TMT 3 = MODERATELY WEATHERED TREATMENT, TMT 4 = SEVERELY WEATHERED TREATMENT.

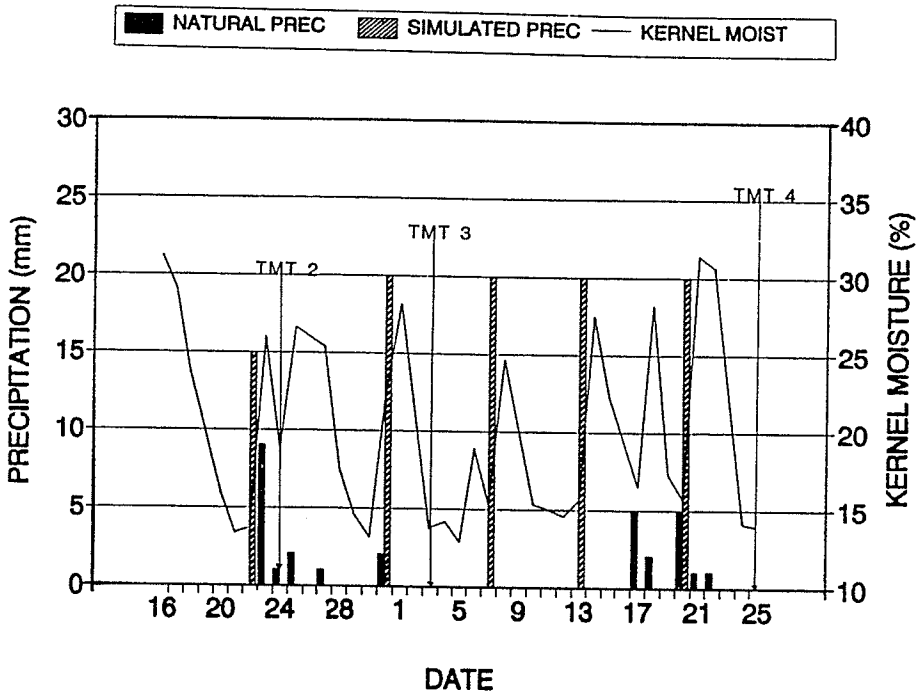


FIGURE 8. KERNEL MOISTURE AND PRECIPITATION DURING THE EXPOSURE PERIOD (AUG 16 TO SEPT 25) FOR WHEAT IN 1990. TMT 2 = SLIGHTLY WEATHERED TREATMENT, TMT 3 = MODERATELY WEATHERED TREATMENT, TMT 4 = SEVERELY WEATHERED TREATMENT.

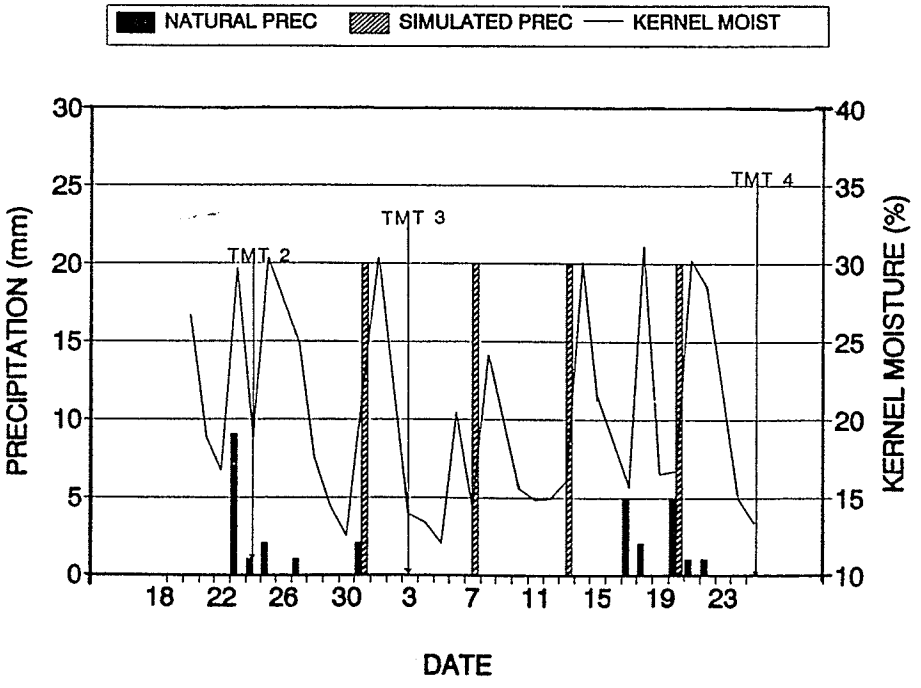


FIGURE 9. KERNEL MOISTURE AND PRECIPITATION DURING THE EXPOSURE PERIOD (AUG 18 TO SEPT 25) FOR BARLEY IN 1990. TMT 2 = SLIGHTLY WEATHERED TREATMENT, TMT 3 = MODERATLY WEATHERED TREATMENT, TMT 4 = SEVERELY WEATHERED TREATMENT.

Using the temperature data, saturation vapor pressure (Esat), in kPa, was determined using the following formula:

$$Esat = 10^{\exp\left[\frac{(7.49848 * T)}{(T + 237.3)}\right]} - 0.21408 \qquad (2)$$

(where T = temperature °C)

To determine the actual water vapor pressure (Eact), again in kPa's, the saturation vapor pressure was multiplied by the relative humidity (RH);

$$Eact = (Esat * RH/100) \qquad (3)$$

The difference between the actual water vapor pressure and saturation vapor pressure was determined to monitor the water vapor pressure deficit (Edef);

$$Edef = (Eact - Esat) \qquad (4)$$

Over the course of the weathering period the actual water vapor pressure and water vapor pressure deficit were determined for each two-hour recording. These values were then used to determine the average daily values. The daily averages were cumulated to obtain a total value for each weathered treatment. Similar procedures were performed using temperature data.

Average daily solar radiation (MJ/m^2) and precipitation (mm) were recorded approximately 0.5 km from the experimental site, (Minimum Data Set Recording System, Model

LI-1200S, Li-Cor Inc., Lincoln, NE.). Similar to the actual water vapor pressure and water vapor pressure deficit, these values were cumulated for each experimental treatment. Daily values for all environmental measurements are included in Appendix Tables (A2-A5). The final parameter monitored during the exposure period was time (h), when kernel moisture content exceeded 20%. This was determined by extrapolating the graphed data (Figures 6 to 9).

3.2.2 Experiment 2

Two experimental treatments were tested each year: 1) mature crop exposed to field weathering in a windrow, (windrowing was performed at physiological maturity, with windrowers as outlined in Experiment 1), and 2) mature crop exposed to field weathering in a standing position. In 1989, one harvest was performed (after a weathering period of 20 days). In 1990, three harvest dates were performed after 11, 24 and 38 days of weathering for barley, and after 13, 26 and 40 days of weathering for wheat. In 1989, the experimental design was a randomized complete block, while in 1990, a split-plot design was utilized, with standing versus windrowed as the main plot and time of harvest as the subplot. The plot sizes were 5.54 X 10 m in 1989, and 5.54 X 7 m in 1990, with the subplots being 5.54 X 2.33 m.

A small plot combine (Hege, model 125B, Hans-Urich Hege, D-7112 Waldenberg, West Germany) was used to thresh

the crops. Seed moisture content at threshing was determined (equation 1) for all treatments (Appendix Table A10).

3.2.2.1 Environmental Measurements

The only environmental variable monitored during the exposure period in 1989 was precipitation. However, in 1990, in addition to precipitation, temperature and relative humidity were also monitored within the two microclimates. Relative humidity/temperature sensors (Thermistor and Relative Humidity probe, model 207, Campbell Scientific Inc. Edmonton, Alta.) were placed in one main plot per experiment: 1) in the center of the windrow, just below the surface, and 2) at spike level in the standing crop. Probes in both locations were shielded from direct sunlight, however, air was able to circulate freely around the sensors. Environmental recordings were logged at a two-minute interval, and averaged for each two-hour period, (Measurement and Control Module, model CR-10, Campbell Scientific Inc. Edmonton, Alta.). The temperature data was used to calculate Esat, (equation 2). The Eact was determined using equation 3, while Edef was determined using equation 4.

3.3 Seed Quality Measurements

3.3.1 General

Physical, microbial and physiological seed properties were measured on all treatments from experiment one and experiment two. Physical measurements included bulk density, kernel density, 1000 kernel mass and kernel hardness (wheat only).

The percentage of seed infected by each of six different genera of field-fungi was determined as a means of monitoring the microbial characteristics. The physiological seed properties determined were protein content and alpha-amylase activity. The physiological performance, or seed vigor, was assessed by conducting standard and cold germination tests.

Directly after threshing in 1989, seed was placed in cloth sacks and fan dried for approximately one week. The seed was dry prior to threshing in 1990. After threshing the seed was sieve cleaned, removing foreign material such as weed seeds and chaff. The physical properties; bulk density and kernel density were determined on all seedlots after kernel moisture equilibrated with the ambient conditions. The seed was then stored at room temperature for approximately two months before any physiological measurements were determined, allowing for a period of after-ripening.

3.3.2 Physical Properties

Bulk density was determined by use of a Cox funnel with a top diameter of 225 mm, and a bottom diameter of 38 mm. The total depth of the funnel was 160 mm. The bottom of the cone was situated 45 mm above the top of a volumetric 500 ml cup. The flat slide gate on the bottom of the cone was opened, allowing grain to flow freely into the volumetric cup. The excess grain was struck off with a rod and the mass of the grain in the cup was measured. The mass value was multiplied by 200 in order to convert to kg hL^{-1}.

Kernel mass was determined on a representative sample of 250 kernels from each plot. Only unbroken kernels were counted and weighed.

The volume of approximately 20 g of seed was determined by use of an air compression pycnometer (Model 930, Beckman Instruments Inc., Cal.). Densities were expressed as g mL^{-1}, and were calculated by dividing kernel mass by kernel volume. All physical measurement values were adjusted to a standard kernel moisture content of 14.0%.

The Particle Size Index (PSI) as outlined by Williams and Sobering (1986), was measured on wheat to determine the effect of weathering on kernel hardness.

As a final step, all treatments were submitted to the Canadian Grain Commission for official grading, in terms of grain quality. The rationale for this was to determine the relationship between grain grade and seed quality.

3.3.3 Microbial Properties

Cladosporium, Epicoccum, Septoria, Nigrospora, Drechslera and *Fusarium* were the six different genera of fungi monitored in this study. Seed samples of approximately 1 kg from each treatment were collected directly after threshing, and placed in brown paper bags and stored at -20°C. Upon removal from cold storage, seeds were immediately surface sterilized in 0.3% sodium hypochlorite for 1 min with constant agitation (Flannigan, 1969), and then dried under a laminar flow hood. Ten randomly selected sterilized seeds were plated on potato dextrose agar (Difco Laboratories Inc.) in sterile, disposable polystyrene petri plates (90 mm X 15 mm). A total of 400 seeds were examined for each treatment (i.e., 100 seeds per replicate).

The plates were incubated under a light source consisting of one 40 watt 'cool white' fluorescent tube per 30 plates. The photoperiod was continuous for 12 hour intervals, and the total incubation period was five days (Clear, 1987).

Fungal identifications were made at the Mycology Laboratory of the Canadian Grain Commission. Genera-level identifications were made under a dissecting microscope (Nikon, model SMZ-10). Species identification of all the Fusarium isolates encountered was done by transferring small portions of mycelium onto slides, followed by examination under a compound microscope with differential

interference contrast 'NT" (Nikon Optishot). As well, samples of severely weathered seed from experiment one were submitted to the Toxicology Lab at the Canadian Grain Commission for mycotoxin determination.

3.3.4 Physiological Properties

Approximately 100 g of seed from each plot was milled using a Udy cyclone sample mill with a 1.0 mm screen and was used for protein analysis. Level of seed protein was determined using Near-Infrared Reflectance (American Association of Cereal Chemists, method 39-10, 1983).

The Hagberg Falling Number Test as described by the Association of American Cereal Chemists (Method 56-81B, 1983), was employed to verify the presence of alpha-amylase. This method is based on the unique ability of alpha-amylase to liquify a starch gel. Falling number is defined as time (seconds) required to stir and allow the stirring plunger to fall a specific distance through a hot aqueous flour gel undergoing liquefaction. Thus, relatively low falling number values correspond to relatively high levels of alpha-amylase activity. Three tests were conducted per plot. Each test required 7 g of flour, based on a 14% moisture content.

Seed viability was determined by using the standard germination test. Two sets of 50 unsprouted seeds were evaluated per plot. Seeds were placed crease down on a double layer of moist filter paper (Whatman, Qualitative #1,

90 mm), wetted with 6 mLs of distilled water and incubated for 7 days at 20°C in a Controlled Environments, model I-24 germination cabinet.

After the seven day incubation period, seeds of wheat were grouped into one of three categories; normal germinated (visible presence of both coleoptile and radicle), abnormal germinated (presence of either, coleoptile, or radicle, but not both) and ungerminated (no visible signs of germination). Due to the presence of the hull in barley, abnormal growth was very difficult to detect. Hence, barley seeds were only classified as germinated, or ungerminated.

Seed vigor was determined by the cold germination test. Procedures for the cold germination test were similar to the standard germination test, with the following exceptions. First, 200 unsprouted seeds per plot were tested each year. The test was split into two replications, conducted approximately 30 days apart. Secondly, the incubation temperature was reduced to a constant level of 5°C, and thirdly germination was determined at approximately the same time every second day. Seeds were again classified as either normal germinated, abnormal germinated or ungerminated for the wheat, and either normal germinated or ungerminated for the barley. The incubation period was maintained for a total of 18 days, after which germination naturally ceased.

3.4 Statistical Analysis

All data sets for experiment one were analyzed as randomized complete block design (RCBD) experiments, using analysis of variance (ANOVA) procedures on the Statistical Analysis Systems (SAS) software package (SAS Institute, 1985). Means were compared using Fisher's Least Significant Difference (LSD) test at the P=0.05 level, after ANOVA indicated significant ($P < 0.05$) differences.

Correlation analysis were used to determine the relationships between environmental parameters and specific seed characteristics. Forward selection stepwise regression analysis was used to identify environmental variables with the largest influence on seed quality and vigor. This step was used only if there was more than one environmental variable significantly correlated with seed quality for both years combined. Furthermore, all environmental variables included in the forward selection stepwise regression were significantly ($P < 0.05$) related to the dependent variable.

For experiment two, data sets were also analyzed as randomized complete block experiments in 1989. However, in 1990, data sets were analyzed as split-plot designs, again using analysis of variance procedures. Means (treatments in 1989, and treatments and harvest dates in 1990), were compared using Fisher's Least Significance Difference (LSD) test at the P=0.05 level, after analysis of variance indicated significant ($P < 0.05$) differences.

4.0 RESULTS AND DISCUSSION

4.1 Experiment 1

4.1.1 Physical Properties

4.1.1.1 Bulk Density

The official bulk densities for Katepwa wheat and Heartland barley are 77.0 kg hL^{-1} and 62.0 kg hL^{-1}, respectively (Anon., 1988a). For both crops average bulk density values were higher in 1989 than in 1990 (Table 2). The greatest difference between years occurred for barley, where the bulk density level for the unweathered treatment was 5.0 kg hL^{-1} lower in 1990 than in 1989. One of the reasons for lower bulk density in 1990, may be related to the relative maturity of the crop at the time of windrowing. Since the average seed moisture at this time in 1990 was 39.7%, it is conceivable that the translocation processes were prematurely halted thus, resulting in smaller, less-dense seed of low bulk density.

In each year of the study, seed bulk densities decreased significantly with increased field weathering (Table 2). The total reduction in bulk density for wheat was 9.5% and 8.0% in 1989 and 1990, respectively. Similarly, the barley incurred bulk density losses of 10.26% in 1989 and 6.43% in 1990.

In 1989, the greatest losses in bulk density occurred between the slight and moderately weathered wheat (5.3%) and between the moderate and severely weathered barley (5.4%). These losses followed the period when kernel moisture content (KMC) reached maximum levels. The three day natural rain of 44 mm which occurred from August 18-21 in 1989, resulted in seed moisture levels of 38.2% for the wheat and 34.3% for the barley (Figures 6 and 7). Consequently, in 1989, over half of the overall reductions in bulk densities were observed for wheat (54.8%) and barley (52.7%) were related to this period of high KMC. A similar but less obvious trend was observed in 1990. In this year, 48.6% and 66.6% of the total loss in bulk density for wheat and barley respectively, occurred between the slight and moderately weathered seed. Once again, this large decline in bulk density was related to extreme seed moisture levels during weathering. A combination of simulated and natural precipitation prior to the harvest of the moderately weathered treatment raised the KMC to near maximum levels of 28.1% and 30.2% respectively, for the wheat and barley. Therefore, KMC appeared to be important in determining bulk density loss. This conclusion is supported by Swanson (1941), who demonstrated in a series of laboratory experiments that the degree of seed wetting had a much greater effect on bulk density reduction than frequency of wetting. Czarnecki and Evans (1986) also found the largest

loss in bulk density occurred during the periods of significant precipitation.

TABLE 2. INFLUENCE OF FIELD WEATHERING ON BULK DENSITY (kg hL^{-1}) OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	WHEAT		BARLEY	
	1989	1990	1989	1990
UNWEATHERED	82.0a*	80.9a	62.8a	57.8a
SLIGHT	79.2b	78.0b	61.8a	56.6a
MODERATE	74.9c	74.8c	59.8b	54.1b
SEVERE	74.2c	74.4c	56.4c	54.9b
LSD (0.05)	1.8	1.1	1.1	1.3
C.V.	1.4	0.9	1.1	1.5

* numbers in a column followed by different letters are significantly different at $P < 0.05$.

Correlation analysis was conducted to determine the relationships between the measured environmental parameters and bulk density (Table 3). In 1989, precipitation was the only environmental parameter that significantly affected bulk density of wheat. Precipitation was also significantly negatively correlated with bulk density for barley, however, temperature and the actual water vapor pressure were significantly correlated as well. No significant relationships between bulk density and the environmental parameters studied, were observed in 1990 for either wheat or barley. One reason for the weaker relationships, (i.e., lower correlation coefficients) in 1990 compared with 1989 may have been the longer weathering period. The weathering period was almost twice as long in 1990 compared with 1989. A second possible reason was the relatively smaller reduction in bulk density with weathering in 1990, especially with barley (Table 2). Consequently, values for

the various weather parameters continued to increase (Appendix Tables A2-A5), while there was little further reduction in bulk density after the third harvesting period.

TABLE 3. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND BULK DENSITY OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

BULK DENSITY	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
WHEAT 1989	4	-0.95	-0.97*	-0.95	-0.95	0.94	-0.94
WHEAT 1990	4	-0.91	-0.85	-0.91	-0.91	0.93	-0.87
COMBINED	8	-0.84**	-0.86**	-0.81*	-0.86**	0.79*	-0.86**
BARLEY 1989	4	-0.97*	-0.99**	-0.94	-0.98*	0.91	-0.99*
BARLEY 1990	4	-0.77	-0.63	-0.75	-0.77	0.78	-0.77
COMBINED	8	-0.68	-0.57	-0.63	-0.66	0.66	-0.26

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME MC EXCEEDED 20%.

*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVELY.

Combining the data for the two years resulted in significant effects by each environmental parameter on bulk density for wheat (Table 3). No significant relationships were observed for the combined data on barley. The most probable explanation for the non-significant correlations for the combined barley data may be due to the large differences in bulk density which occurred between years.

Forward selection stepwise regression was used to determine the environmental parameters having the greatest effect on bulk density of wheat for the two years (Table 4). Results indicated that the actual water vapor pressure during the weathering period was the environmental parameter having the greatest influence on bulk density of wheat.

TABLE 4. REGRESSION OF SEVERAL ENVIRONMENTAL PARAMETERS ON BULK DENSITY OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

EQUATION NO.	(n)	REGRESSION EQUATION	R^2
1	8	Y = 80.23 - Eact[1](0.15)	0.75
2	8	Y = 80.38 - Eact(0.49) + SOLAR(0.03)	0.84
3	8	Y = 81.16 - Eact(0.84) + SOLAR(0.15) + Edef(1.54)	0.93
4	8	Y = 81.39 - Eact(0.62) + SOLAR(0.23) + Edef(2.95) - PRECIP(0.16)	0.98

[1] Eact=ACTUAL WATER VAPOR PRESSURE; SOLAR=SOLAR RADIATION; Edef=WATER VAPOR PRESSURE DEFICIT; PRECIP=PRECIPITATION.

Previous research has primarily focused on the effects of precipitation on bulk density, (Swanson, 1941; Milner and Shellenberger, 1953; Pushman, 1975; and Czarnecki and Evans, 1986). This is likely attributable to the fact that rain is considered to be the major contributor to increased kernel moisture (Dodds and Pelton, 1967; Pool et al., 1958). One of the advantages of Eact is that it takes into account a wider range of conditions such as temperature and relative humidity. This may be an important factor in why Eact was more closely correlated with bulk density than precipitation in this study.

Robertson (1956) demonstrated that seed moisture content was strongly correlated with water vapor pressure in the atmosphere. Under saturated conditions the uptake of moisture was relatively slow (approximately 1-2% per day), although the rate of water uptake depends upon the temperature and prior seed moisture levels (Dillman, 1930; Pixton and Warburton, 1968). During periods of precipitation it could be assumed that the atmospheric

moisture levels would be nearly saturated. However, because atmospheric vapor pressure was more highly correlated with seed bulk density than precipitation (Table 3), it could be suggested that periods of high relative humidity, in the absence of precipitation, also increased KMC and consequently reduced seed bulk density levels. In the present study, dew formation during the harvest season may have been a major reason why bulk density was strongly affected by Eact.

4.1.1.2 Kernel Density

Similar to results for bulk density, kernel density for both wheat and barley significantly decreased as field weathering increased (Table 5). The overall decrease in kernel density was 7.2% for barley and 5.7% for wheat in 1989, compared with 1.5% for barley and 3.7% for wheat in 1990.

As was the case for bulk density, kernel densities were lower in 1990 compared to 1989. Bracken and Bailey (1928) attributed annual differences in initial densities to dissimilar levels of protein content (lower protein was related to lower densities). As will be demonstrated (section 4.1.3.1), protein levels were substantially lower for both crops in 1990 compared with 1989.

TABLE 5. INFLUENCE OF FIELD WEATHERING ON KERNEL DENSITY (g mL^{-1}) OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE, IN 1989 AND 1990.

WEATHERING LEVEL	WHEAT		BARLEY	
	1989	1990	1989	1990
UNWEATHERED	1.40a+	1.36a	1.39a	1.34a
SLIGHT	1.38ab	1.31c	1.34b	1.33a
MODERATE	1.35bc	1.33b	1.31c	1.33a
SEVERE	1.32c	1.31c	1.29c	1.32b
LSD (0.05)	0.04	0.01	0.02	0.02
C.V.	1.81	0.67	0.92	0.53

+ NUMBERS IN A COLUMN FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT $P < 0.05$.

Correlation coefficients for both wheat and barley indicated that kernel density was negatively correlated with temperature, precipitation, solar radiation and actual water vapor pressure and positively correlated with water vapor pressure deficit (Table 6).

In 1989, all environmental variables measured were significantly correlated with kernel density for wheat. In barley, all weather parameters measured, except precipitation and time KMC was greater than 20%, were significantly correlated with kernel density. In 1990, no significant correlations were observed for wheat. This may be due to the smaller change in kernel density with weathering in 1990 compared to 1989 (3.7% in 1990, vs. 5.7% in 1989). As well, the effect of weathering did not result in a gradual decline in kernel density. For example, kernel density of moderately weathered seed was greater than that for slightly weathered seed. The combined data for wheat indicated significant correlations for all weather parameters.

TABLE 6. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS KERNEL DENSITY OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

KERNEL DENSITY	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
WHEAT 1989	4	-0.99**	-0.99*	-0.99*	-0.99**	0.96*	-0.98*
WHEAT 1990	4	-0.72	-0.70	-0.73	-0.72	0.74	-0.74
COMBINED	8	-0.76*	-0.74*	-0.75*	-0.76*	0.75	-0.70
BARLEY 1989	4	-0.97*	-0.89	-0.97*	-0.96*	0.96*	-0.94
BARLEY 1990	4	-0.97*	-0.98*	-0.98*	-0.97*	0.97*	-0.95*
COMBINED	8	-0.62	-0.66	-0.65	-0.64	0.62	-0.62

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME KMC EXCEEDED 20%.

*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVLES, RESPECTIVLEY.

Forward selection stepwise regression indicated that actual water vapor pressure was the environmental variable that had the greatest effect on kernel density. The predictive equation is as follows;

$$\text{KERNEL DENSITY} = 1.37 - 0.001(\text{Eact}) \qquad R^2=0.58 \qquad (5)$$

No other environmental variable studied, met the 0.05 significance level for entry into the model.

Although kernel density was significantly correlated with temperature, solar radiation, actual water vapor pressure and water vapor pressure deficit in each of the two years no significant correlations were observed for the combined barley data. One reason why the combined barley data was not significantly correlated to any of the measured environmental parameters is that there was an overall lower kernel density observed in 1990 than in 1989. Another explanation is that the above mentioned environmental

parameters were 10 times more influential on kernel density in 1989 compared to 1990 (i.e., slopes were 10 times greater in 1989) (Table 7).

TABLE 7. REGRESSION ANALYSIS OF SEVERAL ENVIRONMENTAL PARAMETERS ON KERNEL DENSITY OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

KERNEL DENSITY	(n)	REGRESSION EQUATION	R^2
1989	4	Y = 1.38 - 0.0002(TEMP[1])	0.93
1990	4	Y = 1.33 - 0.00002(TEMP)	0.95
1989	4	Y = 1.38 - 0.0003(SOLAR)	0.95
1990	4	Y = 1.33 - 0.00003(SOLAR)	0.96
1989	4	Y = 1.38 - 0.003(Eact)	0.92
1990	4	Y = 1.33 - 0.0003(Eact)	0.95
1989	4	Y = 1.38 - 0.004(Edef)	0.93
1990	4	Y = 1.33 - 0.0004(Edef)	0.95

[1] TEMP=TEMPERATURE; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT.

Packing efficiency is a term used to describe the random packing characteristics of the individual seeds. The packing efficiency is inversely related to porosity, which is the percent fraction of bulk-volume of seed occupied by intergranular space (Czarnecki, 1980). Porosities can be calculated using bulk and kernel densities.

Czarnecki (1980) indicated that the total reduction in bulk density of wheat was caused by an approximately equal reduction in kernel density and packing efficiency. Similar findings by Whitcomb and Johnson (1930), indicated that reduction in kernel density accounted for 43% of a 6.49 kg hL^{-1} reduction in bulk density in overwintered wheat. Results of the present study appear to agree with the work of previous researchers. For example, in 1989 the bulk

density (kg hL^{-1}) of wheat decreased by 9.6%. This corresponded with a 5.7% reduction in kernel density (kg hL^{-1}). Therefore, the total loss in wheat kernel density accounted for 59.4% of the overall loss in bulk density for wheat that year. In 1990, the reduction in kernel density accounted for 45.4% of the total reduction observed in bulk density.

The contribution of kernel density to bulk density loss was more variable for barley than for wheat. For example, in 1989, kernel density reduction in barley accounted for 70.1% of the total reduction in bulk density, while in 1990, kernel density accounted for only 29.7% of the bulk density reduction in barley.

Scott (1951) stated that changes in seed-coat surface friction play a greater role in altering bulk density than do changes in kernel density. This appeared to be the reason for the unproportional changes in bulk and kernel density between seed exposed to weathering for various periods of time. For example, the first cycle of wetting and drying may have a large influence on seed-coat surface friction, thereby affecting bulk density, but leaving kernel density relatively unchanged. Further cycles of wetting and drying may eventually cause microfissure formation within the kernel, which would lead to reduced kernel density.

Milner and Shellenberger (1953) demonstrated that the reduction in kernel density in weathered wheat was caused by air spaces which prevent the complete reversal of the

swelling process which occurs on wetting. As a result of expansive and contractive forces, the seed coat separates from the endosperm forming air spaces beneath it. As well, microfissures were detected radiographically within the endosperm area of the seed. The formation and extent of fissuring was also found to be dependent upon elevated moisture level and rate of drying. Therefore, these findings tend to support the premise that 'light' weathering would be expected to reduce bulk density due to surface effects, but 'heavier' weathering could be expected to affect kernel density.

4.1.1.3 Kernel Mass

Field weathering did not affect kernel mass to the same extend as bulk or kernel density. While there was a significant reduction in kernel mass with weathering for barley in both years, wheat was affected only in 1990 (Table 8).

TABLE 8. INFLUENCE OF FIELD WEATHERING ON KERNEL MASS (mg KERNEL^{-1}) OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	WHEAT		BARLEY	
	1989	1990	1989	1990
UNWEATHERED	33.56a+	32.59a	37.58a	31.89a
SLIGHT	30.23a	30.96b	36.13a	31.50a
MODERATE	30.26a	29.99b	37.05a	27.70b
SEVERE	33.54a	31.02b	32.51b	28.44b
LSD (0.05)	4.13	1.19	2.26	2.51
C.V.	8.08	2.39	3.51	5.24

+ NUMBERS IN A COLUMN FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENET AT P < 0.05.

Other researchers also found unclear trends in the relationship between kernel mass and weathering. Whitcomb and Johnson (1928) reported that severe weathering caused a significant reduction in kernel mass for wheat in only one out of two years. Similar findings were published by Czarnecki and Evans (1986). Likewise, Pool et al. (1958) indicated that delayed harvest caused a reduction in kernel mass for only one year out of three. However, Johnson (1959) observed a 1.4% reduction in thousand kernel mass in wheat over a 20-day weathering period. The dry matter loss was attributed to possible leaching or oxidation.

The only significant correlations between the various environmental parameters studied and kernel mass for barley in 1989 were: precipitation and time seed moisture exceeded 20% (Table 9). One possible explanation for these observations may be that increased kernel moisture facilitated solute leakage. Significant correlations between these environmental parameters and kernel mass occurred for only one crop and in one year. Thus, indicating that specific environmental conditions may be required (Crowe et al., 1989).

TABLE 9. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND KERNEL MASS OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

KERNEL MASS	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
WHEAT 1989	4	0.06	0.08	0.02	0.10	0.08	0.15
WHEAT 1990	4	-0.56	-0.44	-0.55	-0.55	0.59	-0.48
COMBINED	8	-0.29	-0.19	-0.31	-0.25	0.37	-0.17
BARLEY 1989	4	-0.90	-0.98*	-0.85	-0.91	0.81	-0.96*
BARLEY 1990	4	-0.80	-0.69	-0.79	-0.80	0.80	-0.82
COMBINED	8	-0.61	-0.49	-0.57	-0.60	0.60	-0.12

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME KMC EXCEEDED 20%.
*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVLEY.

4.1.1.4 Kernel Hardness

Field weathering significantly affected the kernel hardness in wheat (Table 10). Although the seed was slightly harder in 1989 (i.e., lower PSI units), the net loss in hardness was greater in 1990 than in 1989 (i.e., 16.12% versus 11.47%).

The negative effects of field weathering on kernel hardness of wheat have been well documented (Bracken and Bailey, 1928; Whitcomb and Johnson, 1930; Johnson 1959). Milner and Shellenberger (1953) indicated that reduced kernel hardness due to exposure to weathering is caused by internal fissures. One possible hazard of softer kernels is that they may be more susceptible to mechanical damage during harvesting and handling operations (Czarnecki and Evans, 1986).

TABLE 10. INFLUENCE OF FIELD WEATHERING ON KERNEL HARDNESS (PSI UNITS) OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	1989	1990
UNWEATHERED	53.18a+	57.38a
SLIGHT	53.83a	60.98b
MODERATE	59.88b	65.18c
SEVERE	59.28b	66.63c
LSD (0.05)	2.07	2.80
C.V.	2.28	2.80

+ NUMBERS IN A COLUMN FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT P < 0.05.

Results of correlation analysis indicated that precipitation had a significant negative influence on kernel hardness in 1989, while water vapor pressure deficit (Edef) was significantly positively correlated with kernel hardness in 1990 (Table 11). In 1989, the three-day period of natural precipitation received between the harvest of the slight and moderately weathered treatments (Figure 6) resulted in 99.2% of the total loss in kernel hardness. A more uniform reduction in kernel hardness was observed in 1990. For example, one wet/dry cycle (Figure 7) resulted in 38.9% of the overall loss in kernel hardness. Two additional wet/dry cycles incurred by the moderately weathered treatment caused an additional 45.4% of the overall loss in kernel hardness. While the most severely weathered seed received three separate rain simulations in addition to several small showers (Figure 7). These additional periods of precipitation, had little further effect on kernel hardness, (i.e., 15.71% overall reduction). Hence, the combination of natural and simulated precipitation which caused a fairly uniform distribution of

wet/dry cycles in 1990 appeared to have an equal effect on kernel hardness.

TABLE 11. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND KERNEL HARDNESS OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

KERNEL HARDNESS	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
1989	4	0.86	0.95*	0.85	0.87	-0.81	0.94
1990	4	0.95	0.89	0.94	0.94	-0.96*	0.91
COMBINED	8	0.84**	0.79*	0.84**	0.82*	-0.86**	0.80*

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME KMC EXCEEDED 20%.
*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVELY.

Combining data for the two years resulted in significant correlations for all environmental parameters with kernel hardness. Thus, forward selection stepwise regression was used to identify the weather variable demonstrating the greatest influence on kernel hardness. The water vapor pressure deficit (Edef) was the only environmental variable to meet the 0.05 significance level for entry into the model. Consequently, the actual water vapor pressure deficit within the windrow accounted for 73% of the variation observed in kernel hardness for wheat during the two years. The resulting predictive equation is as follows:

$$\text{Kernel Hardness} = 55.21 - \text{Edef}(0.37) \qquad R^2 = 0.73 \qquad (6)$$

Thus, similar to results for bulk and kernel density, measurement of relative humidity also improved the predictability of kernel hardness. Therefore, it appears with cereal crops at least, that the influence of this

weather variable on seed physical properties has, for the most part, been overlooked (Swanson, 1941; Milner and Shellenberger, 1953; Pushman, 1975; and Czarnecki and Evans, 1986).

4.1.1.5 Official Grades

Official grain grades were determined on all seedlots exposed to weathering for various periods of time. Grades were assessed by federal grain inspectors at the Canadian Grain Commission (Table 12).

TABLE 12. INFLUENCE OF FIELD WEATHERING ON OFFICIAL GRAIN GRADE OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	1989				1990			
	WHEAT	(COMMENT)	BARLEY	(COMMENT)	WHEAT	(COMMENT)	BARLEY	(COMMENT)
UNWEATHERED	1 CW	-	1 CW	-	2 CW	STARCHY	1 CW	-
SLIGHT	2 CW	SMUDGE	1 CW	MILDEW	3 CW	STARCHY	1 CW	-
MODERATE	3 CW	4.5% SPROUTED	1 CW	STAINED	3 CW	MILDEW	1 CW	STAINED
SEVERE	CW FEED	14.0% SPROUTED	1 CW	6% SPROUTED	3 CW	STARCHY	1 CW	STAINED

In 1989, a wide range in quality was observed for the wheat, ranging from 1 CW to CW FEED. However, in 1990, the unweathered seed was graded 2 CW primarily because of starchy kernels. All barley seedlots in both years were graded 1 CW. Heartland barley is a feed variety and therefore, the grading quality standards are fairly low.

Sprouted kernels were observed in 1989 (i.e., moderate and severely weathered wheat, and severely weathered barley), which resulted from the large quantities of natural precipitation that year (Figures 6 & 7).

4.1.2 Microbial Properties

Fusarium spp. were the only group of the six different fungal genera monitored, which significantly increased as weathering period increased in 1989. Both wheat and barley crops that year displayed similar trends in terms of *Fusarium* spp. infection (Figures 10 & 11). Although the overall level of *Fusarium* spp. infection for both crops was much lower in 1990 as compared to 1989, there were still significantly greater levels of infection on weathered barley seed compared to unweathered seed (Figures 12 and 13). There were no significant differences in *Fusarium* spp. infection between treatments for wheat in 1990, even though mean levels of *Fusarium* spp. infection were greater on weathered wheat seed than on unweathered seed (Figure 12). Duthie et al. (1986) stated that information on the incidence of *Fusarium* spp. infection on cereal seed is important because of the capacity of these fungi to cause plant disease and produce mycotoxins.

Lower levels of *Fusarium* spp. infection in 1990 compared to 1989 may be related to the pattern of precipitation (i.e., frequency and quantity, Figures 6 to 9) during the exposure period for the two years. In 1989, both the wheat and barley crops were exposed to periods of weathering in which large quantities of precipitation occurred (Figures 6 & 7). As a result, the KMC of each crop was elevated for extended periods of time. The higher KMC

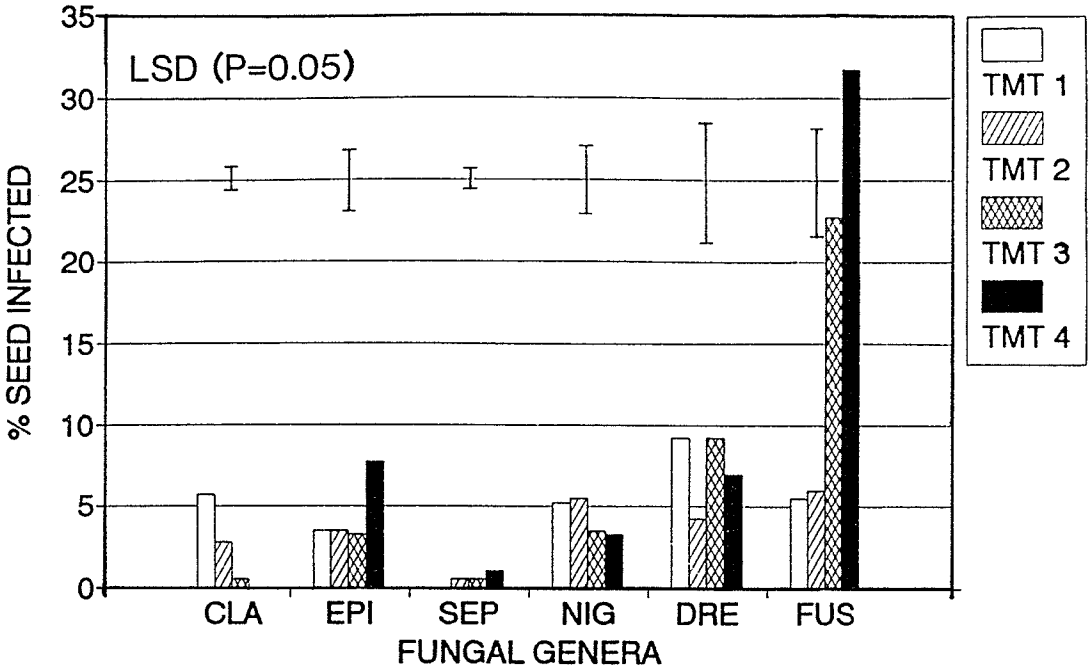


FIGURE 10. INFLUENCE OF FIELD WEATHERING ON FUNGAL INFECTION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

[1] CLA=*CLADOSPORIUM*, EPI=*EPICOCCUM*, SEP=*SEPTORIA*, NIG=*NIGROSPORA*, DRE=*DRECHSLERA*, FUS=*FUSARIUM*.

[2] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

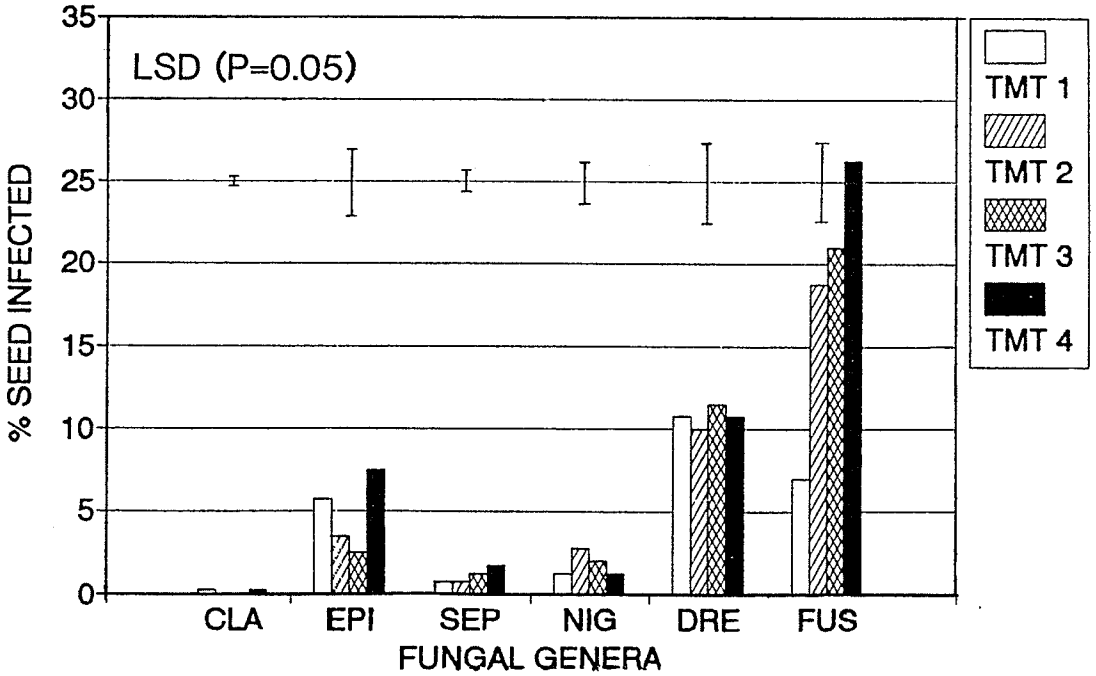


FIGURE 11. INFLUENCE OF FIELD WEATHERING ON FUNGAL INFECTION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

[1] CLA=*CLADOSPORIUM*, EPI=*EPICOCCUM*, SEP=*SEPTORIA*, NIG=*NIGROSPORA*, DRE=*DRECHSLERA*, FUS=*FUSARIUM*.

[2] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

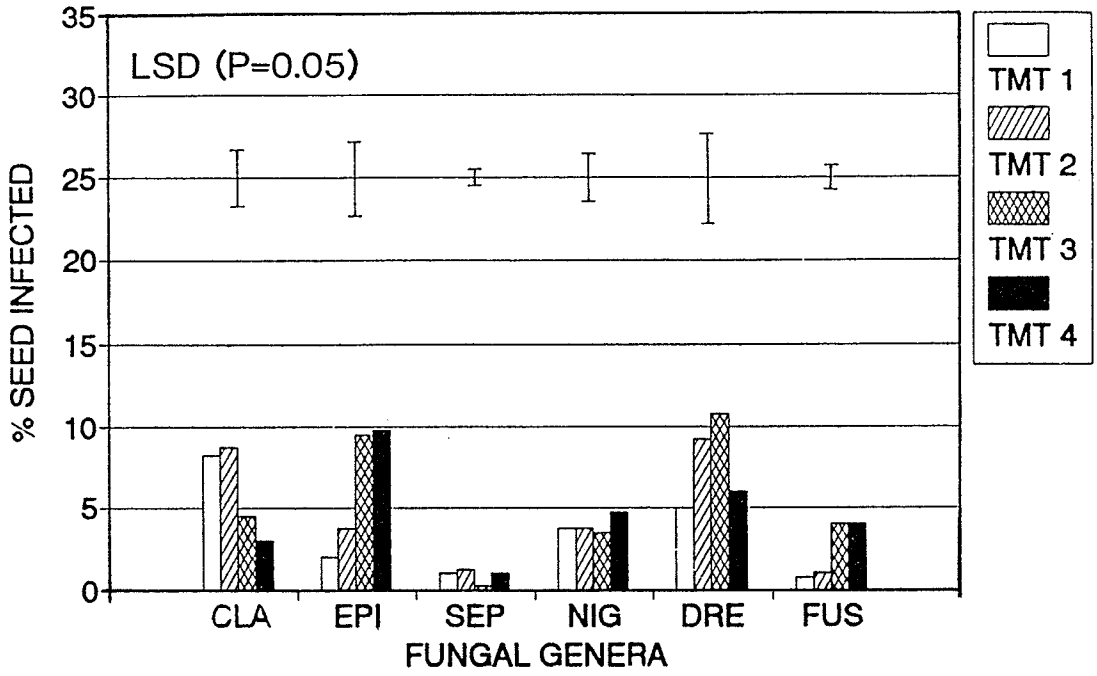


FIGURE 12. INFLUENCE OF FIELD WEATHERING ON FUNGAL INFECTION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990.

[1] CLA=*CLADOSPORIUM*, EPI=*EPICOCCUM*, SEP=*SEPTORIA*, NIG=*NIGROSPORA*, DRE=*DRECHSLERA*, FUS=*FUSARIUM*.

[2] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

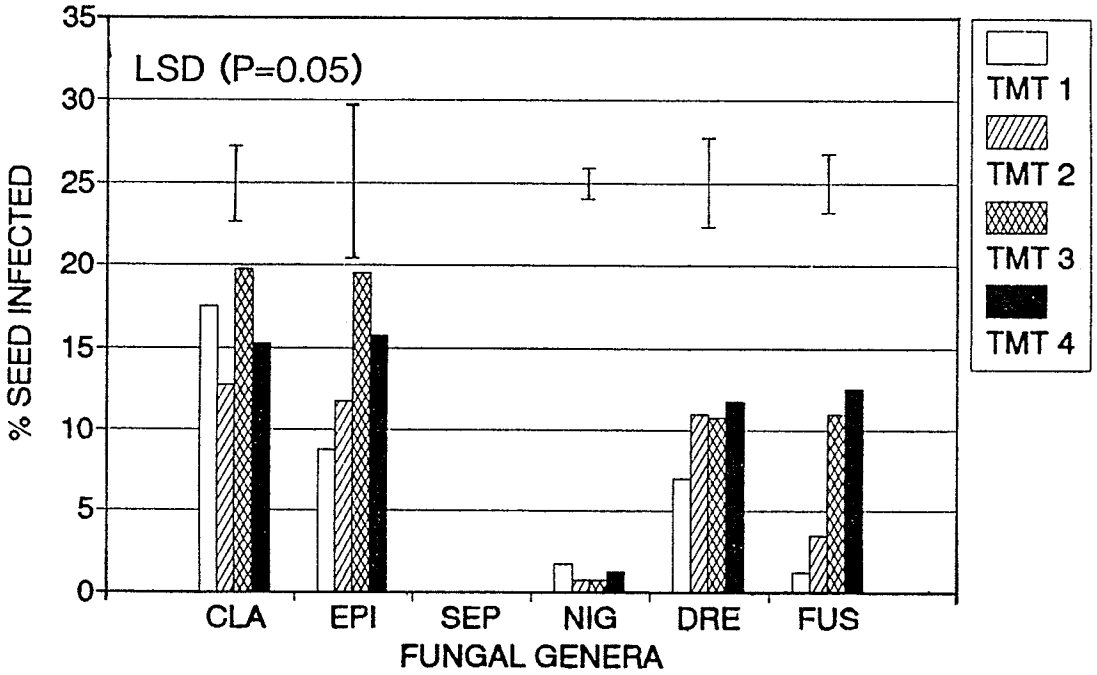


FIGURE 13. INFLUENCE OF FIELD WEATHERING ON FUNGAL INFECTION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

[1] CLA=*CLADOSPORIUM*, EPI=*EPICOCCUM*, SEP=*SEPTORIA*, NIG=*NIGROSPORA*, DRE=*DRECHSLERA*, FUS=*FUSARIUM*.

[2] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

provided an ideal environment for microbial invasion, particularly that of *Fusarium* spp. In 1990, although periods of precipitation were more frequent, the amount of precipitation for each occurrence was much lower. The reduced amount of precipitation in 1990 meant that kernel moisture remained elevated for very short periods of time (Figures 12 and 13). Hence, the environment in 1990 may not have been as favourable for *Fusarium* spp. invasion as in 1989.

Reduced periods of elevated kernel moisture in 1990 may have also been the reason for lower levels of *Fusarium* spp. infection in wheat compared with barley. For example, short periods of high moisture in 1990 may have prevented the *Fusarium* spp. from penetrating beyond the glumes of the wheat and the lemma and palea of the barley. Since this protective barrier is removed at threshing for wheat, but not for barley, infection was noticeably higher in barley. Machecek et al. (1951) also found higher levels of *Fusarium* spp. infection in barley compared to wheat when exposed to similar environmental conditions. Therefore, the morphological features of wheat spikes (i.e., glumes) may provide the seed with extra protection against fungal invasion during periods of inclement weather prior to harvest.

Other fungi which were significantly affected by field weathering included *Cladosporium* spp. and *Epicoccum* spp. In

both years of this study *Cladosporium* spp. infection in wheat significantly decreased as the exposure period increased (Figures 10 and 12). Lower levels of *Cladosporium* spp. infection on weathered seed may be due to greater competition by more aggressive fungi such as *Fusarium* spp., which increased with the level of weathering. In addition, the weathered wheat of 1990 resulted in significantly higher levels of *Epicoccum* spp. infection.

Machacek et al. (1951) monitored the levels of seed microflora on cereal samples obtained from across Canada. They found that oats and barley had higher levels of *Cladosporium* spp. infection than other cereal crops (i.e., 2.5 and 1.5%, respectively). Low levels of *Septoria* spp., *Nigrospora* spp. and *Epicoccum* spp. infections were detected in all seed tested (levels below 1%), with the exception of *Nigrospora* spp. on seed from Manitoba in 1940 and 1941. High levels of infection on this seed was attributed to excessively wet weather which delayed threshing of the windrowed crop. Results of the present study, however, did not show significant differences in *Nigrospora* spp. infection between weathered or unweathered seed (Figures 10 to 13). However, similar to results by Machacek and coworkers, very low levels of *Septoria* spp. were detected in this study for both wheat and barley crops (i.e., < 2.0%). Machecek et al. (1951) also reported that *Drechslera* spp. were detected at levels of up to 5.6% in barley and 2.5% in wheat. It was noted that the heaviest *Drechslera* spp.

infections originated in the Maritime Provinces, Quebec, and Manitoba. High levels of *Drechslera* spp. infection in these areas was attributed to damp weather conditions, particularly during crop maturation. Results of the present study indicated that the mean level of *Drechslera* spp. infection in 1990 was greater for weathered than unweathered barley, although the differences were not significant (Figure 13).

Another survey of fungal infection in field-grown wheat was conducted by Clear (1987). He found species from a total of 56 different fungal genera present on hard red prairie spring wheat from across the Canadian prairies. The most frequently isolated were species of; *Alternaria, Cladosporium, Epicoccum, Drechslera, Nigrospora, Fusarium* and *Septoria.* The level of infection of any particular group of fungi was strongly influenced by the location or origin of the sample. With the exception of *Alternaria* spp., the genera of fungi identified in his study were the same as those identified in the current study. *Alternaria* spp. were not monitored in this study since they are present on virtually all wheat and barley seed (Clear, pers. comm.).

The relationships between *Fusarium* spp. infection and the measured environmental parameters are shown in Table 13. *Fusarium* spp. level in wheat was significantly positively correlated with cumulated temperature, total precipitation and cumulated actual water vapor pressure in 1989. The lack of significant correlations in 1990 were attributed to

different weather conditions during the exposure period. For example, the frequent wet/dry cycles in 1990 were not particularly conducive to *Fusarium* spp. colonization. However, the extended weathering period (i.e., 40 days in 1990) resulted in substantially greater weather parameter values. Hence, correlations between the weather variables and *Fusarium* spp. infection were much weaker than in the previous year. The combined 1989 and 1990 data for wheat was not significantly related to the environmental parameters studied primarily due to vast differences in level of *Fusarium* spp. infection between the two years.

TABLE 13. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND *FUSARIUM* SPP. INFECTION OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

FUSARIUM INFECTION	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
WHEAT 1989	4	0.95*	0.99**	0.93	0.97*	-0.88	0.99**
WHEAT 1990	4	0.88	0.81	0.87	0.88	-0.88	0.89
COMBINED	8	0.20	0.34	0.13	0.27	-0.07	0.34
BARLEY 1989	4	0.92	0.86	0.92	0.92	-0.89	0.94
BARLEY 1990	4	0.93	0.85	0.92	0.93	-0.93	0.94
COMBINED	8	0.94**	0.91**	0.93**	0.95**	-0.93**	0.52

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME SEED MOISTURE EXCEEDED 20%.

*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVLEY.

The barley did not display any significant correlations for individual years. However, when the data were combined, highly significant correlations were observed for each independent variable with the exception of MC20. This occurrence may be due to the larger sample number for the combined data (i.e., 8 observations for the combined data vs. 4 for individual years). Perhaps one explanation for

the lack of significant correlations between MC20 and *Fusarium* spp. infection is that 20% moisture content is not the optimum for *Fusarium* spp. growth (Tuite and Christensen, 1955).

Forward selection stepwise regression was conducted on the combined barley data to determine the environmental parameter which had the greatest influence on *Fusarium* spp. infection (Table 14). Similar to the results for seed physical properties, actual water vapor pressure (Eact) was the environmental parameter which had the single, greatest influence on the level of *Fusarium* spp. infection in barley over the two years. The relationship between atmospheric moisture and *Fusarium* spp. infection in this study, agrees with reports that moist conditions during the latter part of the growing season favour infection of cereal spikes by *Fusarium* spp. (Martin and Johnston, 1982; Sutton 1982). The second weather variable to enter the regression equations was solar radiation. This variable is predicted to have a negative effect on *Fusarium* spp. infection (Table 14). This finding appears logical since solar radiation is associated with dry weather, (i.e., condition not conducive to *Fusarium* spp. growth). The entry of MC20 into the regression equation (Table 14) again demonstrates the importance of kernel moisture on *Fusarium* spp. infection.

TABLE 14. REGRESSION OF SEVERAL ENVIRONMENTAL VARIABLES ON *FUSARIUM* SPP. INFECTION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

EQUATION NO.	REGRESSION EQUATION	R^2
1	Y = 3.91 + Eact[1](0.45)	0.90
2	Y = 4.31 + Eact(1.43) - SOLAR(0.09)	0.92
3	Y = 3.61 + Eact(3.21) - SOLAR(0.27) + MC20(0.03)	0.95

[1] Eact=ACTUAL WATER VAPOR PRESSURE, SOLAR=SOLAR RADIATION, MC20=TIME MC IS GREATER THAN 20%.

Since *Fusarium* spp. were the only fungal genera to consistently respond to extended periods of field weathering, the individual species of this fungus were identified (Tables 15 to 18). Seven different species were identified for both wheat and barley in 1989. In 1990, these same species were found on barley, however, F. culmorum (W.G. Smith) and F. graminearum Schwabe were not present on the wheat. The two most abundant *Fusarium* spp. identified in this study were F. sporotrichioides Sherb. and F. poae (Peck), while other species such as F. culmorum, F. acuminatum Ell. and Everh., F. equiseti (Cda.), F. avenaceum (Fr.) Sacc. and F. graminearum occurred at relatively low levels. These findings compare favorably with Clear, (1987) who also found that F. sporotrichioides and F. poae were the two most common fusaria on wheat harvested in Manitoba.

F. graminearum, F. culmorum, and to a lesser extent F. avenaceum, have been cited as pathogenic species causing seedling blight, head blight and root and crown rot in wheat (Duthie et al., 1986). However, Sturz and Johnston (1983) observed that F. poae, and to a lesser extent F. avenaceum, are primary colonizers of the ears of cereals, thus

TABLE 15. INFLUENCE OF FIELD WEATHERING ON *FUSARIUM* SPP. INFECTION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

SPECIES	TMT 1[1]	TMT 2	TMT 3	TMT4	LSD(0.05)	C.V.
F. SPORO-TRICHIOIDES	1.25a[2]	0.75a	6.00b	11.50c	4.26	54.59
F. POAE	3.00a	4.50a	7.75b	9.50b	2.99	30.27
F. AVENACEUM	1.00a	0.75a	2.50ab	3.75b	2.32	72.65
F. EQUISETI	0.25a	0.00a	3.00b	3.00b	2.48	99.06
F. CULMORUM	0.00a	0.00a	1.00b	1.00b	0.65	81.65
F. ACUMINATUM	0.00a	0.00a	1.75b	1.25b	0.53	44.44
F. GRAMINEARUM	0.00a	0.00a	0.25a	1.25b	0.60	99.38
TOTAL	5.50a	6.00a	22.25b	31.25c	6.03	23.12

[1] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

[2] VALUES IN THE SAME ROW, FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANLTY DIFFERENT AT P=0.05.

TABLE 16. INFLUENCE OF FIELD WEATHERING ON *FUSARIUM* SPP. INFECTION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

SPECIES	TMT 1[1]	TMT 2	TMT 3	TMT 4	LSD(0.05)	C.V.
F. SPORO-TRICHIOIDES	4.25a[2]	13.50b	15.25b	18.25b	6.30	30.73
F. POAE	0.75a	1.75a	0.75a	2.00a	2.07	98.57
F. AVENACEUM	0.75a	0.25a	0.50a	1.00a	1.22	122.20
F. EQUISETI	1.25a	2.25a	3.25a	2.50a	2.30	62.10
F. CULMORUM	0.00a	0.00a	0.25a	0.00a	0.40	400.00
F. ACUMINATUM	0.00a	0.50ab	0.25ab	1.25b	1.19	149.07
F. GRAMINEARUM	0.00a	0.50ab	0.25a	1.25b	0.84	105.41
TOTAL	7.00a	18.75b	21.00b	26.25c	4.65	15.93

[1] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

[2] VALUES IN THE SAME ROW, FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT P=0.05.

TABLE 17. INFLUENCE OF FIELD WEATHERING ON *FUSARIUM* SPP. INFECTION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990.

SPECIES	TMT 1[1]	TMT 2	TMT 3	TMT 4	LSD(0.05)	C.V.
F. SPORO-TRICHIOIDES	0.00a[2]	0.25a	0.75ab	2.00b	1.69	140.55
F. POAE	0.50a	0.75a	1.50a	1.50a	1.31	77.25
F. AVENACEUM	0.25a	0.00a	0.50a	0.00a	0.93	311.11
F. EQUISETI	0.00a	0.00a	0.75a	0.50a	1.07	214.99
F. CULMORUM	-	-	-	-	-	-
F. ACUMINATUM	0.00a	0.00a	0.50a	0.00a	0.80	400.00
F. GRAMINEARUM	-	-	-	-	-	-
TOTAL	0.75a	1.00a	4.00a	4.00a	3.60	92.31

[1] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

[2] VALUES IN THE SAME ROW, FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANLTY DIFFERENT AT P=0.05.

TABLE 18. INFLUENCE OF FIELD WEATHERING ON *FUSARIUM* SPP. INFECTION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

SPECIES	TMT 1[1]	TMT 2	TMT 3	TMT 4	LSD(0.05)	C.V.
F. SPORO-TRICHIOIDES	0.75a[2]	1.75ab	6.50bc	8.00c	4.90	72.10
F. POAE	0.50a	0.00a	1.75b	2.00b	0.93	54.90
F. AVENACEUM	0.00a	0.25a	0.50a	0.50a	0.85	170.75
F. EQUISETI	0.00a	0.75a	1.50a	1.25a	1.66	118.95
F. CULMORUM	0.00a	0.00a	0.25a	0.00a	0.40	400.00
F. ACUMINATUM	0.00a	0.50a	0.50a	0.75a	1.07	153.57
F. GRAMINEARUM	0.00a	0.25a	0.00a	0.00a	0.40	400.00
TOTAL	1.25a	3.50a	11.00b	12.50b	3.54	31.33

[1] TMT 1=UNWEATHERED SEED, TMT 2=SLIGHTLY WEATHERED SEED, TMT 3=MODERATELY WEATHERED SEED, TMT 4=SEVERELY WEATHERED SEED.

[2] VALUES IN THE SAME ROW, FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT P=0.05.

predisposing these crops to later infections by other fusaria. Significantly greater levels of F. poae infection were observed on the weathered seed of wheat in 1989 and barley in 1990.

Toxins such as zearalenone and deoxynivalenol (DON) have been associated with F. graminearum and F. sporotrichioides (Duthie et al., 1986). The results of this study clearly demonstrate the dominant presence of F. sporotrichioides, particularly in weathered seed (Tables 15 to 18). Infection by F. graminearum was also found to increase significantly for both crops as exposure period increased in 1989.

In the present study, severely weathered seed was tested for mycotoxin contamination. In 1989, DON was found on samples of wheat and barley at levels of 0.11 and 0.05 ppm, respectively. In both cases, F. sporotrichioides was the dominant species of *Fusarium* present, with levels of 12.0 for wheat and 20.0% for barley. Also F. graminearum was present on both crops at levels of 1.0%. These findings appear to support the current literature (Duthie et al., 1986) which implicates F. sporotrichioides and F. graminearum as mycotoxin producers.

Greater levels of DON were detected on both wheat and barley seed in 1990 than in 1989. Three of the four replicates of severely weathered wheat were found to have DON contamination, while all four replicates of barley were contaminated. The mean level of this mycotoxin was found to

be 1.43 ppm for the wheat, and 0.20 ppm for barley. Although F. sporotrichioides was the dominant species of *Fusarium* present in both cases, the average level of seed infection by this species was much lower in 1990 than in 1989. F. graminearum was not detected in 1990 on either wheat or barley. These results tend to dispute those of the previous year. However, it remains a possibility that the level of mycotoxin produced by a particular species may be related to growing conditions. Since the general environmental conditions were conducive to rapid fungal growth in 1989, perhaps mycotoxin concentration was diluted. These results also suggest that F. sporotrichioides may have been the most important species causing mycotoxin contamination in the present study.

The implications of *Fusarium* spp. contamination on weathered seed are two fold. Firstly, if the seed is planted there is the possibility of yield loss due to increased seedling blight (Duthie, 1986; Martin and Johnston, 1982). Secondly, if the seed is marketed as human or animal food, there is the potential problem of mycotoxin contamination.

4.1.3 Physiological Properties

4.1.3.1 Seed Protein Concentration

Exposure of mature wheat and barley crops to field weathering had no significant effect on seed protein concentration, as measured by the NIR method, in any of the trials in this study (Table 19). Similar observations have been made by Swanson (1943), and Pool et al., (1958).

However, results of this study show much lower protein levels for the wheat in 1990 compared to 1989 (Table 19). Typical protein concentrations for wheat grown in Manitoba average around 13.2 to 13.5%, however as soil nitrogen becomes limiting, a loss in seed protein is observed followed by a loss in seed yield (Anon., 1986). In fact, Bulisani and Warner (1980) demonstrated that nitrogen fertilization could increase the seed protein concentration of winter wheat from 8.9 to 15.0%. Thus, the low protein levels of the 1990 wheat crop may be related to lower levels of soil nitrogen. Braken and Bailey (1928) observed that wheat of lower protein concentration also displayed lower kernel density. Similar observations were made in the present study (Table 5).

Since the current seed certification process in Canada does not take into consideration seed protein concentration, it could be assumed that commercial seed has a wide range of

protein concentrations. Furthermore, low protein seed may be more susceptible to environmentally induced vigor loss.

TABLE 19. INFLUENCE OF FIELD WEATHERING ON SEED PROTEIN CONCENTRATION (%) OF WHEAT AND BARLEY GROWN AT PORTAGE LA PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	WHEAT		BARLEY	
	1989	1990	1989	1990
UNWEATHERED	14.35a+	9.60a	9.37a	8.01a
SLIGHT	14.35a	9.45a	9.03a	8.07a
MODERATE	13.85a	9.65a	9.03a	7.98a
SEVERE	14.03a	9.73a	8.75a	8.03a
LSD (0.05)	0.64	0.28	0.99	0.33
C.V.	2.84	1.80	6.84	2.59

+ NUMBERS IN A COLUMN FOLLOWED BY DIFFERENT LETTERS ARE SIGNIFICANTLY DIFFERENT AT $P < 0.05$.

4.1.3.2 Alpha-Amylase Activity

In the present study, seed of wheat and barley exposed to field weathering had significantly higher levels of alpha-amylase activity (i.e., significantly lower falling number) than unweathered seed (Table 20). However, a much greater level of enzyme activity was observed for both wheat and barley in 1989 compared to 1990. The higher enzyme activity of 1989 supports the observation of greater levels of sprouting in 1989 compared with 1990 (Table 12). In 1989, no differences in alpha-amylase activity were observed between unweathered and slightly weathered seed of wheat or barley. However, alpha-amylase activity was significantly increased for moderate and severely weathered seed of both wheat and barley. These results confirm those of Clarke et al. (1984), who showed that prolonged wet periods with

little or no drying were particularly conducive to alpha-amylase activation.

TABLE 20. INFLUENCE OF FIELD WEATHERING ON FALLING NUMBER (s) OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	WHEAT		BARLEY	
	1989	1990	1989	1990
UNWEATHERED	334.75a*	408.83a	365.25a	337.84b
SLIGHT	357.75a	399.83a	369.75a	367.67a
MODERATE	167.00b	399.75a	276.25b	363.58a
SEVERE	88.25c	309.17b	62.50c	225.17c
LSD (0.05)	54.89	47.38	19.10	16.22
C.V.	14.48	7.81	4.45	3.13

* NUMBERS IN A COLUMN FOLLOWED BY DIFFERENT LETTERS ARE SIGNIGICANTLY DIFFERENT AT P < 0.05.

In 1990, only severely weathered wheat demonstrated a significant increase in alpha-amylase activity. In barley, the unweathered seed actually demonstrated higher enzyme activity than did seed which was slight or moderately weathered. This observation does not follow the expected trend. However, it has been demonstrated that alpha-amylase is present during kernel development and germination (Kruger, 1972). Therefore, the unweathered seed may have been harvested before the developmental alpha-amylase was completely denatured. However, the seed which underwent severe field weathering (Figure 9), did display a significant reduction in falling number, indicating a significant increase in alpha-amylase activity.

Correlation analysis was performed to evaluate the relationship between prevailing environmental conditions and alpha-amylase activity. Results for wheat in 1989 indicate that although there was a significant correlation

between precipitation and falling number, there was a slightly stronger correlation between hours of seed moisture above 20% (MC20), and falling number (Table 21). The significant correlation between MC20 and falling number again confirms the importance of prolonged wet periods for increased alpha-amylase activity (Clarke et al., 1984).

TABLE 21. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND FALLING NUMBER OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

FALLING NUMBER	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
WHEAT 1989	4	-0.91	-0.98*	-0.89	-0.93	0.83	-0.99**
WHEAT 1990	4	-0.90	-0.95*	-0.91	-0.90	0.88	-0.91
COMBINED	8	-0.30	-0.46	-0.23	-0.37	0.17	-0.45
BARLEY 1989	4	-0.90	-0.98*	-0.86	-0.91	0.82	-0.94
BARLEY 1990	4	-0.80	-0.90	-0.81	-0.80	0.79	-0.81
COMBINED	8	-0.59	-0.79*	-0.62	-0.63	0.56	-0.33

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME KMC EXCEEDED 20%.

*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVLEY.

In 1990, precipitation was the only environmental parameter which was significantly correlated with falling number in wheat. Since seed moisture levels were elevated for only very short periods in 1990, due to light showers or rain simulations, extended periods of uninterrupted high kernel moisture did not occur (Figure 9). Thus, the correlation between MC20 and falling number was not as strong as in the previous year.

Although precipitation was significantly correlated with falling number in each year for wheat, the combined falling number data (1989 and 1990) was not significantly correlated with any of the environmental parameters

measured. One explanation for this may be that the falling number values were different between years (i.e., initial falling number for wheat was 334.75 s in 1989 and 408.83 s in 1990) (Table 20). McCaig and DePauw (1983) demonstrated that growing conditions may affect starch characteristics and contribute to differences in falling numbers among grains grown in different locations.

However, the more probable reason for lack of correlation of combined data with weather parameters was the difference in weather conditions during the exposure periods between the two years. The large differences in alpha-amylase response to weathering in 1989 and 1990 are evident in Table 22, where the regression of alpha-amylase on precipitation is shown. Large differences in the slopes of the lines not only point out why the combined data was not significantly related to precipitation, but also point out that the effect of precipitation on wheat was more powerful in 1989 than in 1990. The reason for the stronger effect in 1989 appears to be related to the effect of precipitation on kernel moisture content. For example, large natural rains in 1989 raised kernel moisture levels for extended periods (Figure 6), which would be expected to have a large influence on alpha-amylase activity (Clarke et al., 1984). However, in 1990, kernel moisture was not elevated for prolonged periods (Figure 8).

TABLE 22. REGRESSION ANALYSIS OF PRECIPITATION ON FALLING NUMBER OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

DEPENDENT VARIABLE	REGRESSION EQUATION	R^2
1989 FALLING NUMBER $n = 4$	$Y = 362.43 - 3.64(PRECIP^1)$	0.96
1990 FALLING NUMBER $n = 4$	$Y = 420.92 - 0.83(PRECIP)$	0.90

[1] PRECIP=PRECIPITATION

For barley, precipitation was the only environmental parameter significantly correlated with falling number in 1989 (Table 21). Examination of the weathering period for barley in 1990 (Figure 9) reveals a pattern similar to that of the 1990 wheat (i.e., much of the precipitation was a result of simulated precipitation or light showers and, therefore, extended periods of high kernel moisture did not occur). Thus, correlations between falling number and MC20 were not significant for barley in 1990.

No significant correlations between the environmental parameters and falling number of barley were observed in 1990. These non-significant correlations appeared to be due to the significantly lower falling number observed for unweathered seed compared to slight and moderately weathered seed (Table 21). However, the combined data of the two years did indicate that precipitation was significantly correlated with falling number. Thus, forward selection stepwise regression was used to identify which environmental

parameter had the greatest impact on alpha-amylase activity (Table 23).

TABLE 23. REGRESSION OF SEVERAL ENVIRONMENTAL PARAMETERS ON FALLING NUMBER OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

EQUATION NO.	n	REGRESSION EQUATION	R^2
1	8	Y=372.46 - 2.10(PRECIP[1])	0.63
2	8	Y=335.51 - 6.73(PRECIP) + 0.84(TEMP)	0.93
3	8	Y=356.11 - 4.29(PRECIP) + 3.44(TEMP) - 38.33(Eact)	0.97
4	8	Y=357.58 - 4.70(PRECIP) + 4.05(TEMP) - 39.08(Eact) + 9.07(Edef)	0.98
5	8	Y=349.70 - 6.05(PRECIP) + 5.80(TEMP) -57.82(Eact) + 48.91(Edef) + 2.53 (SOLAR)	0.99

[1] PRECIP=PRECIPITATION, TEMP=TEMPERATURE, Eact=ACTUAL WATER VAPOR PRESSURE, Edef=WATER VAPOR PRESSURE DEFICIT, SOLAR=SOLAR RADIATION.

Results of this analysis show that precipitation was the environmental parameter demonstrating the greatest influence on alpha-amylase of weathered barley seed. Alone, it accounted for 63% of variability in alpha-amylase activity over the two years. Although the actual water vapor pressure (Eact) has been demonstrated to affect seed moisture content of wheat (Dodds and Pelton, 1969), and barley (Robertson, 1956), the influence of this parameter was insufficient to promote enzyme activation in this study. In fact, Eact was the third variable to enter the regression equations, and improved the predictability of falling number of barley by only 4%. The fourth and fifth parameters entered into the regression equations were water vapor pressure deficit (Edef) and solar radiation (SOLAR), respectively. Each parameter increased predictability by 1%. Therefore, most of the variation in alpha-amylase

activity for barley can be explained by simple and inexpensive weather measurements (i.e., temperature and precipitation).

4.1.3.3 Standard Germination

Standard germination tests were performed on representative samples of each seedlot to determine the level of seed viability. Currently, standard germination is the only indication of performance potential provided for pedigreed seed in Canada (Anon., 1988b). In the present study, only unsprouted seed was tested. Under commercial conditions it is assumed that sprouted seed would be removed by mechanical cleaning.

Seed germination in 1989 using the standard germination test in wheat indicated that unweathered seed was significantly lower than the remaining weathered seedlots (Table 24).

TABLE 24. INFLUENCE OF FIELD WEATHERING ON STANDARD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

WEATHERING LEVEL	GERMINATION (%)
UNWEATHERED	86.0a+
SLIGHT	97.3b
MODERATE	97.5b
SEVERE	98.0b
LSD (0.05)	5.5
C.V.	3.7

+ MEANS IN A COLUMN, FOLLOWED BY A DIFFERENT LETTER ARE SIGNIFICANTLY DIFFERENT AT P < 0.05.

Entz et al. (1991) demonstrated that seed with a high KMC at threshing had a significant reduction in cold

germination compared with seed threshed at low KMC. In this study, the unweathered wheat seed had the greatest KMC at harvest, compared to the other treatments (Appendix, Table A1). Analysis of covariance showed that KMC at threshing had a significant effect on the standard germination level. Thus, estimated values for wheat germination were determined based on a uniform KMC at threshing (Table 25). Analysis of covariance procedures on the other data sets indicated that KMC at threshing had no significant effects on standard germination for wheat in 1990 or for barley in 1989 or 1990. Therefore, values shown for these trials represent observed data (Table 25).

TABLE 25. INFLUENCE OF FIELD WEATHERING ON STANDARD GERMINATION OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	WHEAT		BARLEY	
	1989(est)	1990	1989	1990
UNWEATHERED	90.3c*	91.0b	97.3a	88.1a
SLIGHT	92.8c	92.8ab	94.5a	83.0ab
MODERATE	99.0a	93.5a	95.4a	77.5bc
SEVERE	96.7b	94.0a	85.4b	76.3c
LSD (0.05)	-	2.5	4.3	6.7
C.V.	-	1.7	2.9	5.1

* MEANS IN A COLUMN, FOLLOWED BY A DIFFERENT LETTER ARE SIGNIFICANTLY DIFFERENT AT P < 0.05.

Results of standard germination for wheat indicated that weathered seed had a significantly higher germination percentage than the unweathered seed in both years. These observations are supported by Lush et al. (1981) who found that the germination rate in wheat approximately doubled after one hydration-dehydration cycle where the seed was moistened 45%. This accelerated rate of germination was

attributed to a much shorter lag phase (i.e., the time from planting to the germination of the first seed). Another reason for higher germination of weathered wheat may be that the mechanical resistance to germination imposed by the seed coat of wheat is reduced for weathered compared with unweathered seed. As the seed is exposed to greater levels of weathering, the physical condition of the seed coat deteriorates (i.e., bleached, extended, rougher, etc.). Therefore, it is very probable that the strength of this barrier is reduced, eliminating a major barrier for germination to proceed. Thus, it is postulated that weathered wheat seed may have a weaker seed coat, and in turn, enhance the level of standard germination.

Standard germination of the barley was quite different than the wheat. In both years of the study, weathering significantly decreased germination percentage (Table 25), despite significantly greater alpha-amylase (Table 20). Unlike wheat, barley seed is encapsulated within a tight structure commonly referred to as the hull. The presence of this structure appears to pose strong mechanical resistance to germination. For example, the radicle emerges from the hull at the basal end of the seed. However, the coleoptile must elongate over the dorsal region of the seed, beneath the hull, and then emerges at the apical end of the seed. Consequently, the strong resistance imposed by the hull ensures that germination is a very stressful event for barley seed. Therefore, this may be one explanation for

lower standard germination observed for weathered barley seed compared to unweathered seed.

Another reason for lower germination of weathered barley compared to unweather barley may have been due to the higher levels of *Fusarium* spp. contamination on the weathered seed (Figures 11 & 13). Haikara (1983) artificially inoculated barley with Fusaria in the field for two successive years. The most marked change in barley quality infected with *Fusarium* spp. was a decrease in germination. Hence, it is possible that the higher levels of *Fusarium* spp. infection observed on the weathered barley seed in the present study may have contributed to a reduction in germination in a similar manner.

The level of abnormal seed germination (presence of either coleoptile or radicle, but not both), was fairly constant for all treatments of wheat regardless of weathering level (Table 26). The high coefficient of variation values indicate that there was a high degree of variation between replications. Thus, factors other than exposure to field weathering, such as internal damage during threshing, may have greater influence on abnormal germination of wheat seeds (Entz et al., 1991).

TABLE 26. INFLUENCE OF FIELD WEATHERING ON ABNORMAL GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

WEATHERING LEVEL	ABNORMALLY GERMINATED SEED (%) 1989	1990
UNWEATHERED	3.5a+	5.3a
SLIGHT	2.6a	4.5a
MODERATE	2.9a	3.5a
SEVERE	3.0a	4.0a
LSD (0.05)	1.9	2.9
C.V.	39.3	42.7

+ MEANS IN A COLUMN, FOLLOWED BY A DIFFERENT LETTER ARE SIGNIFICANTLY DIFFERENT AT P < 0.05.

Standard germination of either wheat or barley was not correlated with any measured environmental parameter (Table 27). Obviously, this is because changes in germination level between treatments did not correspond to the level of weathering incurred. Hence, this is further evidence indicating the inadequacy of the standard germination test in terms of measuring seed quality and performance potential as affected by weathering.

TABLE 27. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND STANDARD GERMINATION OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

STANDARD GERMINATION	n	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
WHEAT 1989	4	0.80	0.88	0.80	0.80	-0.79	0.85
WHEAT 1990	4	0.91	0.85	0.91	0.91	-0.92	0.85
COMBINED	8	0.44	0.56	0.39	0.50	-0.36	0.54
BARLEY 1989	4	-0.81	-0.91	-0.75	-0.83	0.70	-0.92
BARLEY 1990	4	-0.91	-0.81	-0.90	-0.91	0.92	-0.89
COMBINED	8	-0.69	-0.57	-0.64	-0.68	0.67	-0.15

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME MC EXCEEDED 20%.

*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVELY.

4.1.3.4 Cold Germination

Cold germination is a stress test (Association of Official Seed Analysts, 1983) which has been used to measure seed vigor of many different crops (Christiansen, 1963; Martin et al., 1988). Germinating seeds at low temperature (i.e., 5°C) gives a better indication of the emergence potential of seed under field conditions than a standard germination test. Therefore, this test more accurately reflects conditions in the field in early spring. Cold germination has been widely used to assess seed vigor of cereals in western Canada (Das Gupta and Austenson, 1973; Sonntag, 1989; and Morrison et al., 1991). In the present study, only seed which was not visibly sprouted was used in cold germination tests.

Results of the cold germination test were recorded at two-day intervals (Figures 14 to 17). The results of the analysis of variance for each sampling date are given in Appendix Tables A6 to A9. Several points can be made from the data. First, for both crops in both years, the germination percentages during the first 4 days of the tests were significantly greater for weathered seed compared to unweathered seedlots (Appendix Tables A6 to A9). One explanation for this is that the weathered seed contained significantly greater levels of alpha-amylase than the unweathered seed (Table 20). As McDonald and Copeland

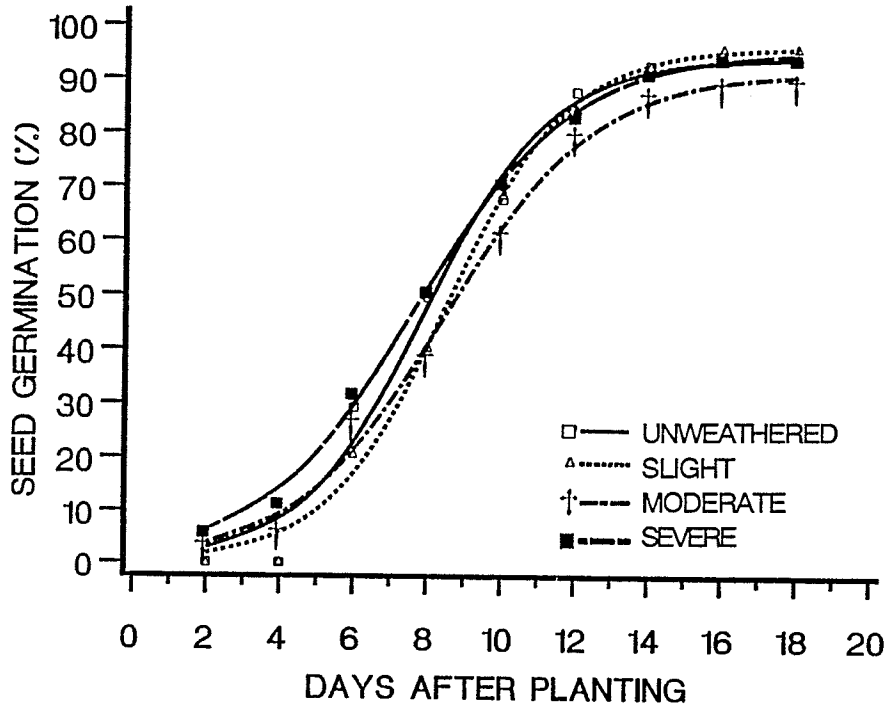


FIGURE 14. EFFECT OF WEATHERING ON COLD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

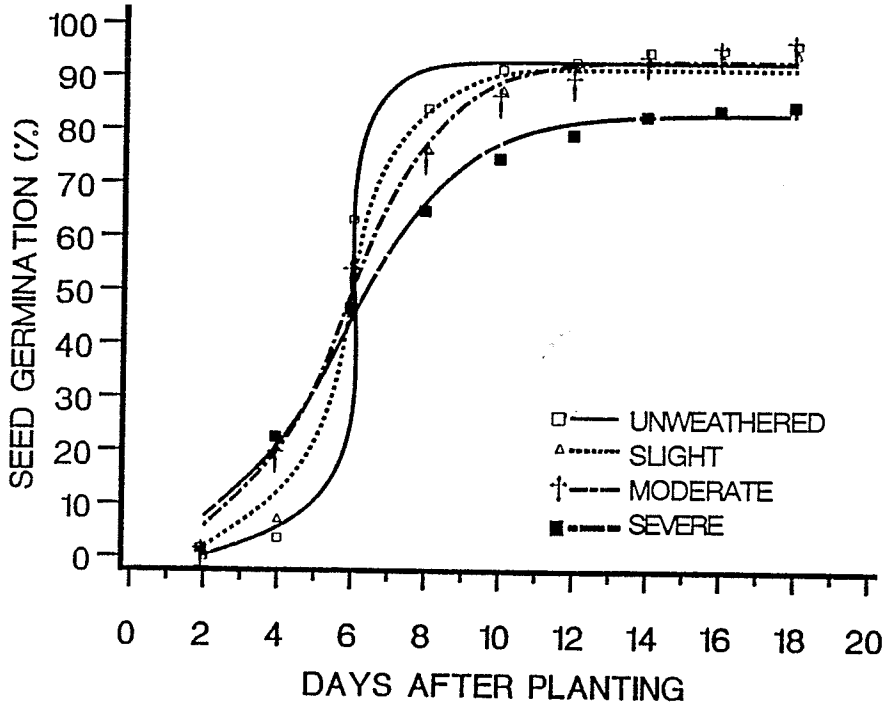


FIGURE 15. EFFECT OF WEATHERING ON COLD GERMINATION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

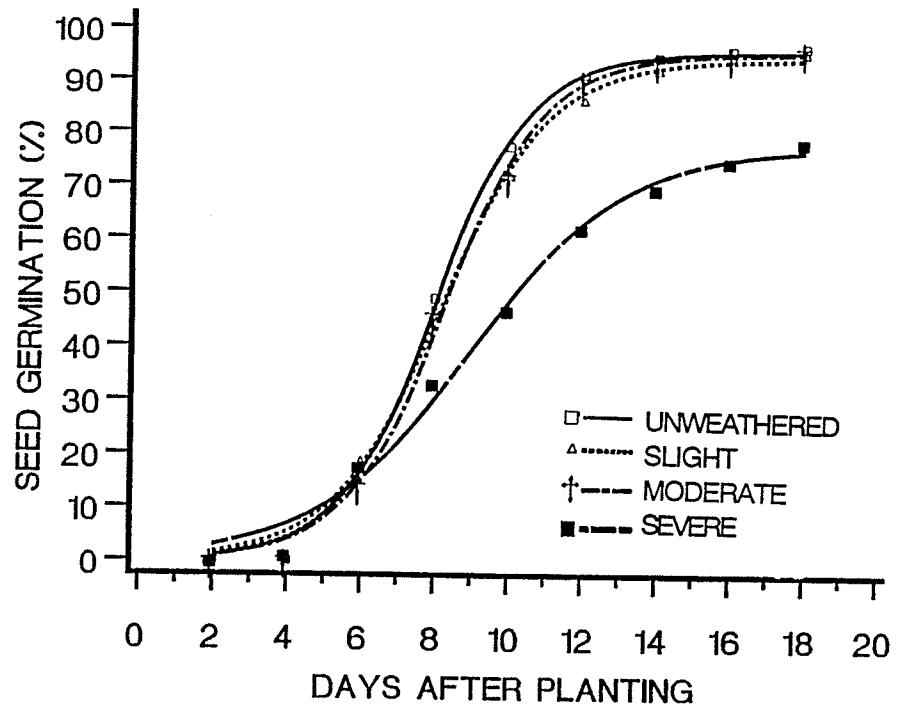


FIGURE 16. EFFECT OF WEATHERING ON COLD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990.

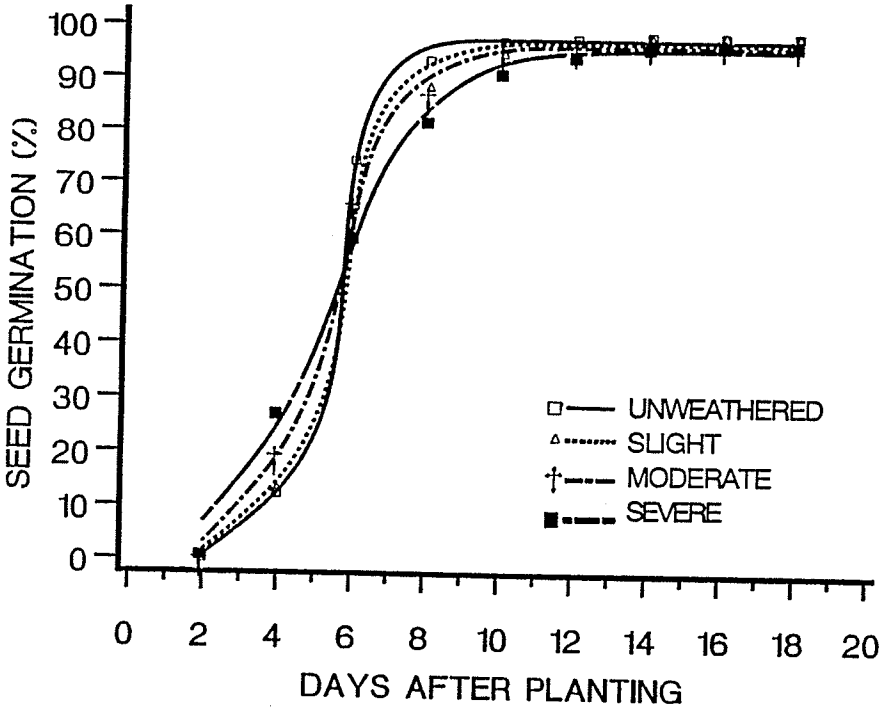


FIGURE 17. EFFECT OF WEATHERING ON COLD GERMINATION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

(1985) have shown, higher levels of this enzyme will reduce the lag phase period of germination.

It also follows that the higher levels of alpha-amylase found in weathered seed of both crops in 1989 compared to 1990 may have been responsible for the greater difference in early germination rate observed between years. For example, at 4 days after planting, the germination of weathered wheat in 1989 was 11.8% higher than the unweathered wheat seed (Figure 14) while in 1990, the difference between weathered and unweathered treatments was only 1.1% (Figure 16). The magnitude of these differences between years was similar to differences in falling number. For example, there was a difference in falling number of 246.5 and 99.7 s between weathered and unweathered wheat in 1989 and 1990, respectively (Table 20).

Similar results were observed for barley. Four days after planting, germination of weathered seed was 6.6 and 2.2 times greater than germination of the unweathered seed in 1989 and 1990, respectively (Figures 15 & 17). Once again, more rapid germination of weathered seed was attributed to higher levels of alpha-amylase in the weathered seed. For example, the difference in falling number between unweathered and weathered seedlots were 302.8 and 112.7 s in 1989 and 1990, respectively (Table 20).

Another factor which may have contributed to the more rapid germination rate for weathered seed compared to unweathered seed, is the rate of water uptake. It has been

demonstrated that small wheat seed will germinate more rapidly than large seed, even though the rate of water imbibition is equal for seed of both sizes (Lafond and Baker, 1986a). Since rate of water uptake is equal for both sized seedlots, the smaller seed must therefore have a lower overall water requirement than the large sized seed. At equal rates of uptake, the water requirement of the small sized seed is met prior to those of the large sized seed, and thus germination occurs more rapidly in the small sized seed.

Since weathering did not consistently influence seed mass in this study, any increase in the rate of water uptake in weathered seed must have been due to other factors. It has been demonstrated by Milner and Shellenberger (1953) that internally fissured, weathered wheat absorbs water more rapidly than unweathered wheat. Therefore, the higher germination rates for weathered crops, early in the test (Figures 10 to 13), may be partially attributed to higher rates of water uptake. As well, the slight reduction in kernel size observed for the weathered barley (Table 8) may also have contributed to a more rapid rate of germination for the weathered seed compared to the unweathered seed.

On the sixth day of the test, maximum differences in vigor were observed. For example, cold germination of of the severely weathered seed was only 75.0 and 80.0% of the germination of unweathered seed, in 1989 and 1990,

respectively. In both years, the greatest differences in vigor between weathered and unweathered barley occurred at this time.

Sonntag (1989) conducted cold germination tests to evaluate the performance of several dozen seedlots of Katepwa wheat and Harrington barley. However, he determined cold germination levels only once, on the 14th day of the test. Results of the present study indicate that at this point, much of the differences in germination level between treatments have been overcome. Therefore, in terms of vigor assessment of Heartland Barley, it appears that cold germination counts should be determined on the sixth day of the test.

The slightly greater difference in cold germination observed between weathered and unweathered treatments at day six in 1989 compared to 1990, may have been due to greater levels of *Fusarium* spp. infestation. However, the different weather conditions during the exposure period in the two years may also be responsible for the relative differences in vigor loss. Hence, the extended wet periods in 1989 may have been more detrimental to seed vigor than the frequent wet/dry cycles of less moisture in 1990. This is in agreement with the findings of Swanson (1941) who reported that quantity of precipitation was much more influential than frequency of precipitation in determining bulk density reduction in wheat.

Although the differences in performance level for barley treatments in 1989 diminished after the sixth day, severely weathered seed remained significantly less vigorous than the less weathered seed (Appendix Table A7). In 1990, no significant differences were observed between seed treatments after the twelfth day of the test (Appendix Table A9).

Based on the observations of cold germination in barley, it appears that the severely weathered seed in 1989 would have a significantly lower level of field emergence than the less weathered seed. With regard to the 1990 seed, it appears that the weathered treatments of that year would emerge more slowly than the unweathered seed. This may result in a lower plant population and uneven maturity.

Few differences in cold germination percentage were observed for the different treatments of wheat in 1989. Between the sixth and tenth day of the test, severely weathered seed appeared to be the most vigorous. At 12, 16 and 18 days after planting, moderately weathered seed displayed significantly lower levels of germination than the remaining seed treatments (Appendix Table A6). Therefore, there was no clear trend regarding the effect of weathering on seed vigor of wheat in 1989.

The results from the 1990 trials, however, indicate a much clearer trend. Differences in cold germination between the unweathered and most weathered seed were greatest on the 10th day of the test. This finding compares favorably with

Morrison et al., (1991), who also found that the greatest difference in performance between seedlots of wheat in cold germination tests occurred at 10 days after planting. In the present study, germination percentage on this date was 64.6% higher for unweathered compared to severely weathered seed. No significant differences were observed between slight or moderately weathered seed, these treatments were approximately 7.7% lower in germination than unweathered seed at this time (Figure 16). While the large difference in germination percentage between severely weathered seed and the less-weathered seed decreased slightly after 10 days (Figure 16), the severely weathered seed still remained significantly lower in cold germination than the other seedlots.

One question that arises from these findings is: why did weathering reduce seed vigor of wheat in 1990, but not in 1989? To answer this we must look back at the previous results regarding seed quality characteristics. There is little question that seed which is large (Kaufman and McFadden, 1963; Spilde, 1989) and has a high protein concentration (McDaniel, 1969; Ries and Everson, 1973; and Evans and Bhatt, 1977) will have superior vigor. In the present study no differences were observed in seed mass between the wheat treatments in 1989 (Table 8). Although unweathered seed had a significantly greater mass than the other seedlots in 1990 (Table 8), results of cold germination indicated no significant differences occurred

between unweathered or slight/moderately weathered seed after the 14th day of the test. However, cold germinations of slight and moderately weathered seed were different than severely weathered seed, even though mass was similar for these three seedlots. Therefore, seed mass did not appear to have a large influence on seed vigor in this study.

Seed protein concentration for wheat, however, was drastically different between the two years, (i.e., mean levels of 14.1% in 1989 compared to 9.6% in 1990). This difference in protein content may have resulted in less vigorous seed for 1990. For example, the cold germination level six days after planting for all treatments combined was 1.6 times greater in 1989 than in 1990. Hence, it appears that the low protein concentration for wheat seed in 1990 may have caused it to be more susceptible to weather-induced vigor loss. Such a finding has important implications, since present seed certification regulations do not take into account seed protein concentration.

The level of abnormally germinated seed was determined at the end of the cold germination test, and was conducted for wheat only (Appendix Tables A6 and A8). In 1989, the moderately weathered seed had significantly more abnormal germination than seed from the other treatments.

In 1990, severely weathered seed displayed the most abnormal germination (Appendix Table A8).

Correlations between the measured environmental parameters and cold germination were determined, using cold

germination data beginning at six days after planting (Table 28). Since the weathered seed outperformed the unweathered seed at two and four days after planting, these data sets were omitted from correlation analysis.

No significant correlations were observed for wheat in 1989 (Table 28). The absence of any significant relationship between environmental parameters and cold germination was attributed to lack of difference among treatments. In 1990, however, cold germination at 8 and 10 days after planting was significantly negatively correlated with precipitation (Table 28), indicating the detrimental effect of this environmental parameter on seed vigor of wheat. However, no other correlations were found to be significant. When the data from the two years was combined, all environmental parameters were significantly correlated with cold germination of wheat between the 10^{th} and 18^{th} day of the test (Table 28). Thus, implying that the cold germination test is able to detect differences in vigor of seed based on the weather conditions during the exposure period. The highest correlation was observed for precipitation on cold germination 12 days after planting (Table 28).

TABLE 28. CORRELATION COEFFICIENTS BETWEEN INDIVIDUAL ENVIRONMENTAL PARAMETERS AND COLD GERMINATION OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

COLD GERMINATION	(n)	TEMP[1]	PRECIP	SOLAR	Eact	Edef	MC20
KATEPWA WHEAT 1989							
6 D.A.P.[2]	4	0.43	0.53	0.38	0.47	-0.26	0.60
8 D.A.P.	4	0.12	0.11	0.09	0.15	-0.00	0.17
10 D.A.P.	4	0.14	-0.05	0.15	0.13	-0.15	-0.03
12 D.A.P.	4	-0.63	-0.71	-0.64	-0.63	0.66	-0.68
14 D.A.P.	4	-0.38	-0.56	-0.38	-0.39	0.36	-0.54
16 D.A.P.	4	-0.15	-0.38	-0.12	-0.17	0.07	-0.38
18 D.A.P.	4	-0.14	-0.38	-0.11	-0.17	0.06	-0.38
KATEPWA WHEAT 1990							
6 D.A.P.	4	-0.15	-0.03	-0.13	-0.15	0.17	-0.19
8 D.A.P.	4	-0.93	-0.98*	-0.94	-0.93	0.92	-0.94
10 D.A.P.	4	-0.93	-0.97*	-0.94	-0.93	0.92	-0.93
12 D.A.P.	4	-0.86	-0.92	-0.87	-0.86	0.84	-0.86
14 D.A.P.	4	-0.87	-0.93	-0.88	-0.87	0.85	-0.88
16 D.A.P.	4	-0.88	-0.94	-0.89	-0.88	0.86	-0.89
18 D.A.P.	4	-0.87	-0.93	-0.88	-0.88	0.86	-0.89
COMBINED WHEAT, 1989 & 1990							
6 D.A.P.	8	-0.18	-0.02	-0.24	-0.12	0.30	-0.04
8 D.A.P.	8	-0.58	-0.58	-0.62	-0.56	0.63	-0.54
10 D.A.P.	8	-0.73*	-0.77*	-0.75*	-0.72*	0.74*	-0.74*
12 D.A.P.	8	-0.79*	-0.84**	-0.81*	-0.79*	0.79*	-0.79*
14 D.A.P.	8	-0.80*	-0.83*	-0.82*	-0.79*	0.80*	-0.79*
16 D.A.P.	8	-0.77*	-0.82*	-0.80*	-0.76*	0.78*	-0.79*
18 D.A.P.	8	-0.75*	-0.81*	-0.77*	-0.74*	0.74*	-0.78*
HEARTLAND BARLEY 1989							
6 D.A.P.	4	-0.95	-0.93	-0.93	-0.96*	0.90	-0.98*
8 D.A.P.	4	-0.92	-0.94	-0.89	-0.93	0.85	-0.99*
10 D.A.P.	4	-0.90	-0.97*	-0.86	-0.92	0.82	-0.98*
12 D.A.P.	4	-0.88	-0.97*	-0.84	-0.90	0.80	-0.95
14 D.A.P.	4	-0.79	-0.91	-0.74	-0.82	0.68	-0.90
16 D.A.P.	4	-0.72	-0.86	-0.66	-0.75	0.60	-0.86
18 D.A.P.	4	-0.71	-0.85	-0.64	-0.74	0.58	-0.85

CORRELATIONS CONT'D

COLD GERMINATION	(n)	TEMP	PRECIP	SOLAR	Eact	Edef	MC20
HEARTLAND BARLEY 1990							
6 D.A.P.	4	-0.90	-0.84	-0.90	-0.90	0.91	-0.86
8 D.A.P.	4	-0.97*	-0.92	-0.97*	-0.97*	0.97*	-0.94
10 D.A.P.	4	-0.96*	-0.95*	-0.96*	-0.96*	0.96*	-0.93
12 D.A.P.	4	-0.99**	-0.97*	-0.99**	-0.99**	0.99**	-0.99**
14 D.A.P.	4	-0.98*	-0.95*	-0.97*	-0.98*	0.98*	-0.99**
16 D.A.P.	4	-0.92	-0.91	-0.91	-0.92	0.91	-0.95
18 D.A.P.	4	-0.90	-0.88	-0.90	-0.90	0.90	-0.94
COMBINED BARLEY, 1989 & 1990							
6 D.A.P.	8	-0.42	-0.56	-0.47	-0.46	0.41	-0.44
8 D.A.P.	8	-0.36	-0.53	-0.41	-0.40	0.34	-0.32
10 D.A.P.	8	-0.30	-0.51	-0.35	-0.35	0.28	-0.25
12 D.A.P.	8	-0.25	-0.47	-0.29	-0.30	0.22	-0.20
14 D.A.P.	8	-0.22	-0.45	-0.26	-0.27	0.18	-0.07
16 D.A.P.	8	-0.20	-0.44	-0.23	-0.25	0.16	0.01
18 D.A.P.	8	-0.24	-0.47	-0.26	-0.29	0.19	0.03

[1] TEMP=TEMPERATURE; PRECIP=PRECIPITATION; SOLAR=SOLAR RADIATION; Eact=ACTUAL WATER VAPOR PRESSURE; Edef=WATER VAPOR PRESSURE DEFICIT; MC20=TIME KMC EXCEEDED 20%

[2] D.A.P. = DAYS AFTER PLANTING.

*,** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVELY.

Forward selection stepwise regression was used to identify the environmental parameter having the greatest effect on cold germination of wheat between 10 and 18 days after planting. In all cases, precipitation exerted the greatest influence on cold germination of wheat, accounting for 60 to 70% of the observed variation in the results (Table 29). Although actual water vapor pressure (Eact) accounted for the greatest effects on the physical seed characteristics, precipitation ultimately was more influential on subsequent vigor of wheat seed. Presumably, this is because precipitation causes greater levels of seed wetting, which evidently results in greater loss of vigor.

In 1989, cold germination of barley at 6 to 10 days after planting was significantly negatively correlated with

TABLE 29. REGRESSION OF SEVERAL ENVIRONMENTAL PARAMETERS ON COLD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

DEPENDENT VARIABLE	NO.	REGRESSION EQUATION	R^2
CGERM10[1]	1a	Y = 74.17 - 0.17(PRECIP[2])	0.60
n = 8	1b	Y = 73.06 - 0.45(PRECIP) + 0.66(Eact)	0.65
	1c	Y = 72.41 - 0.85(PRECIP) + 2.79(Eact) + 2.13(Edef)	0.85
CGERM12	2a	Y = 90.76 - 0.18(PRECIP)	0.70
n = 8	2b	Y = 91.90 - 0.59(PRECIP) + 0.14(MC20)	0.79
CGERM14	3a	Y = 96.07 - 0.16(PRECIP)	0.69
n = 8	3b	Y = 96.80 - 0.42(PRECIP) + 0.09(MC20)	0.74
CGERM16	4a	Y = 97.44 - 0.14(PRECIP)	0.67
n = 8	4b	Y = 96.54 - 0.37(PRECIP) + 0.53(Eact)	0.73
	4c	Y = 95.45 - 0.57(PRECIP) + 2.33(Eact) - 0.12(SOLAR)	0.97
CGERM18	5a	Y = 97.31 - 0.11(PRECIP)	0.65
n = 8	5b	Y = 96.36 - 0.36(PRECIP) + 0.56(Eact)	0.74
	5c	Y = 95.51 - 0.52(PRECIP) + 1.97(Eact) - 0.10(SOLAR)	0.95

[1] CGERM10 = COLD GERMINATION 10 DAYS AFTER PLANTING, CGERM12 = COLD GERMINATION 12 DAYS AFTER PLANTING, ETC.

[2] PRECIP=PRECIPITATION, Eact=ACTUAL WATER VAPOR PRESSURE, Edef=WATER VAPOR PRESSURE DEFICIT, SOLAR=SOLAR RADIATION.

MC20 (Table 28). In 1990, significant correlations between cold germination and MC20 occurred at 12 and 14 days after planting. Overall, significant correlations between environmental parameters and cold germination in barley occurred more frequently in 1990 than in 1989. In addition to MC20, cold germination in 1989 was also significantly correlated with precipitation and Eact. Conversely, all environmental parameters were significantly correlated with cold germination at 12 and 14 days after planting in 1990. The most consistent relationship for barley was between

precipitation and cold germination 10 and 12 days after planting.

No significant correlations were observed for the combined 1989 and 1990 data (Table 28). This was attributed to the large differences in slope that were observed in each year (Table 30). The reasons for these different slopes were attributed to the pattern of precipitation in 1989 compared with 1990. Consequently, the influence of precipitation on cold germination was substantially reduced in 1990 compared to 1989.

TABLE 30. REGRESSION ANALYSIS OF PRECIPITATION ON COLD GERMINATION OF BARLEY AT 10 AND 12 DAYS AFTER PLANTING.

DEPENDENT VARIABLE	n	REGRESSION EQUATION	R^2
CGERM10 1989[1]	4	Y = 91.29 - 0.17(PRECIP[2])	0.94
CGERM12 1989	4	Y = 93.92 - 0.16(PRECIP)	0.95
CGERM10 1990	4	Y = 96.45 - 0.05(PRECIP)	0.90
CGERM12 1990	4	Y = 97.61 - 0.03(PRECIP)	0.95

[1] CGERM10 = COLD GERMINATION 10 DAYS AFTER PLANTING. CGERM12 = COLD GERMINATION 12 DAYS AFTER PLANTING.
[2] PRECIP=PRECIPITATION.

Simple correlations were calculated to determine the relationships between the various seed characteristics and seed vigor (i.e., cold germination) (Table 31). Results for the wheat indicated that only falling number was significantly correlated with cold germination and only on the sixth day of the test. This was a negative correlation, indicating that higher falling number values (low alpha-amylase) corresponded with lower levels of cold germination. The reason for this somewhat confusing correlation appears

to be that early on in the germination test weathered seed of high alpha-amylase germinated more rapidly than unweathered seed (Figures 14 and 16).

The greatest differences in cold germination level for wheat were found to occur on the 10th day of the test (Appendix Table A8). However, cold germination 10 days after planting was not significantly correlated with any of the other seed quality parameters measured in this study. Sonntag (1989) found that field emergence of Katepwa wheat was significantly correlated to cold germination. However, as mentioned earlier, Sonntag determined cold germination percentage 14 days after planting. In this study, cold germination at 14 days after planting was not significantly correlated with any measured seed characteristic. Therefore, our results indicate that to determine or assess vigor of Katepwa wheat, a cold germination test must be conducted, as individual seed quality characteristics alone were are not related to vigor.

TABLE 31. CORRELATION COEFFICIENTS BETWEEN SEED QUALITY CHARACTERISTICS AND COLD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

COLD GERM.	INDEPENDENT VARIABLES					
	BULK DENSITY	KERNEL DENSITY	KERNEL MASS	KERNEL HARDNESS	FUSARIUM	FALLING NUMBER
6 D.A.P.[1]	0.016	0.308	0.637	-0.505	0.667	-0.796*
8 D.A.P.	0.415	0.254	0.654	-0.437	0.120	0.013
10 D.A.P.	0.467	0.304	0.258	-0.473	0.004	0.252
12 D.A.P.	0.519	0.449	0.182	-0.516	-0.088	0.301
14 D.A.P.	0.489	0.463	0.189	-0.589	0.020	0.192
16 D.A.P.	0.466	0.430	0.165	-0.591	0.038	0.184
18 D.A.P.	0.459	0.388	0.133	-0.540	-0.012	0.246

[1] D.A.P. = DAYS AFTER PLANTING.
*, ** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVELY.

For Heartland barley, results of the cold germination test for both 1989 and 1990 indicated that the largest differences between unweathered and severely weathered seed occurred six days after planting (Appendix Tables A7 & A9). Correlation analysis demonstrated that alpha-amylase activity and cold germination six days after planting were very close to significant (i.e., P=0.057) (Table 32). No other seed quality parameters were correlated with cold germination at this time. However, falling number was significantly negatively correlated with cold germination from 8 to 18 days after planting (Table 32), indicating that the higher the alpha-amylase activity, the lower the seed vigor. Sonntag (1989) also found significant correlations between alpha-amylase activity and field-emergence of Harrington barley. Therefore, regarding the seed quality

characteristics measured in this study, alpha-amylase activity appears to be the best indicator of seed performance potential for Heartland barley.

TABLE 32. CORRELATION COEFFICIENTS BETWEEN SEED QUALITY CHARACTERISTICS AND COLD GERMINATION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

COLD GERM.	INDEPENDENT VARIABLES				
	BULK DENSITY	KERNEL DENSITY	KERNEL MASS	FUSARIUM	FALLING NUMBER
6 D.A.P.[1]	-0.131	0.505	-0.311	-0.308	0.693
8 D.A.P.	-0.145	0.506	-0.325	-0.276	0.740*
10 D.A.P.	-0.111	0.527	-0.301	-0.272	0.821*
12 D.A.P.	-0.112	0.494	-0.300	-0.249	0.827*
14 D.A.P.	-0.080	0.474	-0.256	-0.239	0.822*
16 D.A.P.	-0.070	0.443	-0.233	-0.226	0.823*
18 D.A.P.	0.018	0.477	-0.141	-0.287	0.835**

[1] D.A.P. = DAYS AFTER PLANTING.
*, ** SIGNIFICANT AT P=0.05 AND 0.01 LEVELS, RESPECTIVELY.

4.2 Experiment 2

4.2.1 Environmental Conditions

For experiment 2, the frequency and quantity of precipitation received by wheat and barley crops during the weathering period in 1989 was fairly similar (Figures 18 and 19). During the twenty day weathering period, the wheat received a total of 54 mm of precipitation, while the barley received 55 mm. In 1990, both wheat and barley crops received 29 mm of precipitation during the exposure period (Figures 20 and 23, respectively).

The actual water vapor pressure was determined in both treatments for wheat and barley. Results for wheat indicated that the water vapor pressure was slightly higher in standing crop compared to windrowed crop (Figure 20). Only directly after periods of precipitation was the vapor pressure greater in the windrowed treatment than in the standing treatment. In fact, by the end of the 40 day weathering period for wheat in 1990, the daily average water vapor pressure, cumulated over the weathering period, was 2.0% higher at spike level of standing crop compared to that within a windrow. Similarly, cumulated vapor pressure was greater within the standing wheat crop at each, harvest 1 (Aug. 29) and harvest 2 (Sept. 11) by levels of 1.6 and 2.5%, respectively.

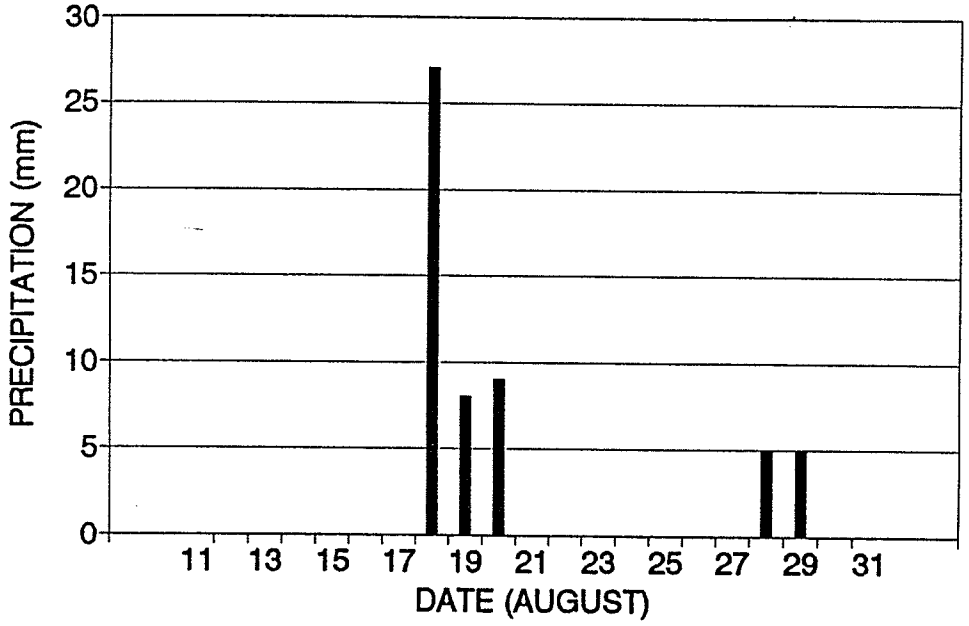


FIGURE 18. QUANTITY AND FREQUENCY OF PRECIPITATION DURING WEATHERING PERIOD FOR WHEAT IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1989.

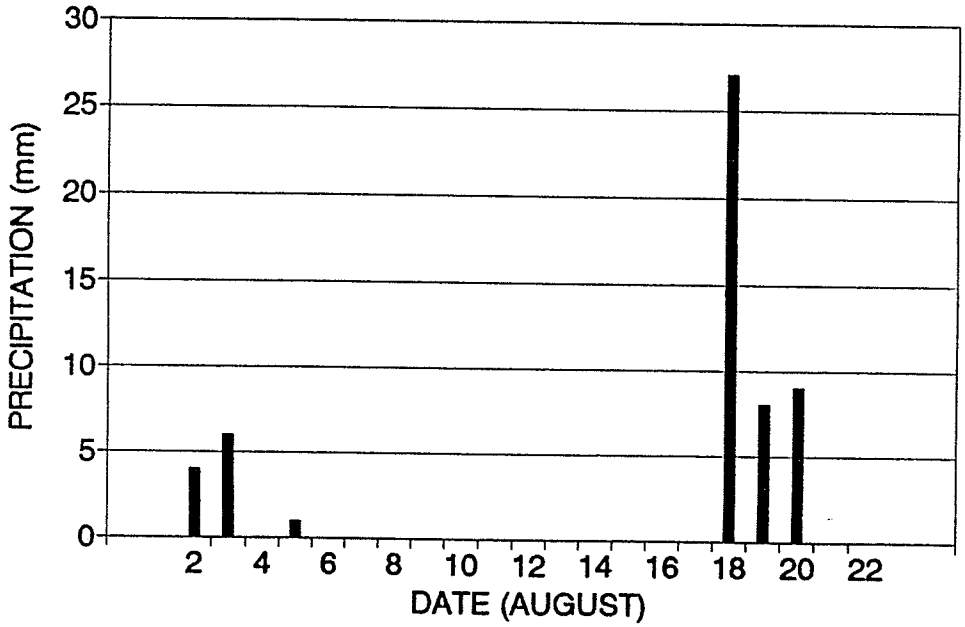


FIGURE 19. QUANTITY AND FREQUENCY OF PRECIPITATION DURING WEATHERING PERIOD FOR BARLEY IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1989.

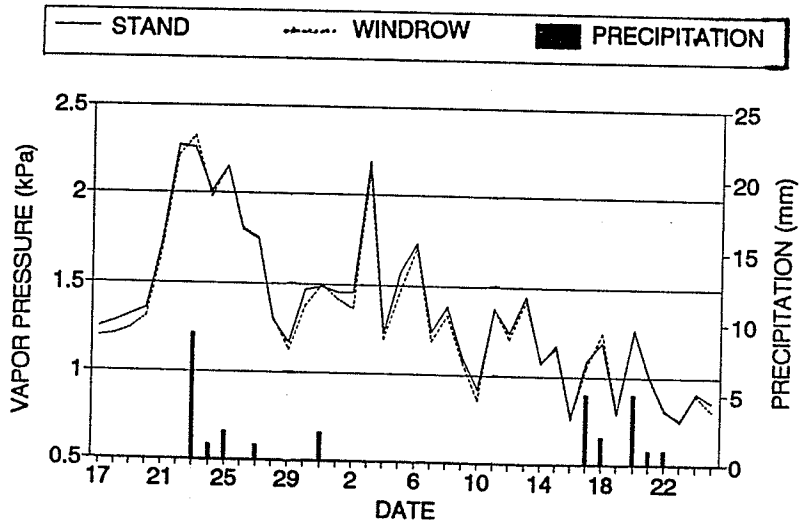


FIGURE 20. ACTUAL WATER VAPOR PRESSURE AND PRECIPITATION DURING WEATHERING PERIOD (AUG 16-SEPT 25), FOR WHEAT IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1990.

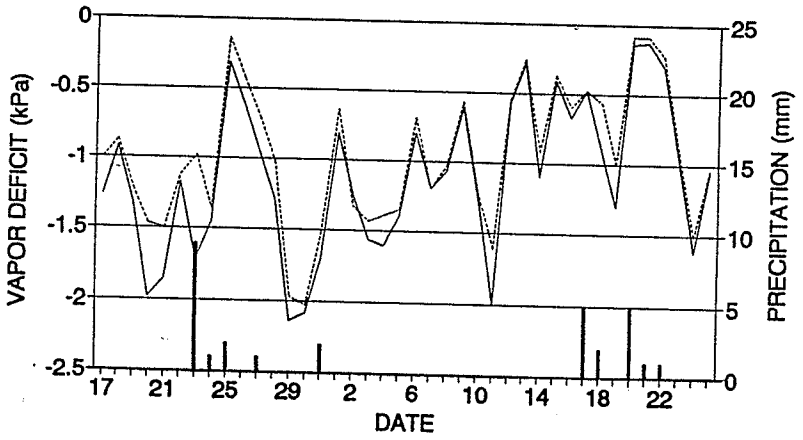


FIGURE 21. WATER VAPOR PRESSURE DEFICIT AND PRECIPITATION DURING WEATHERING PERIOD (AUG 16-SEPT 25), FOR WHEAT IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1990.

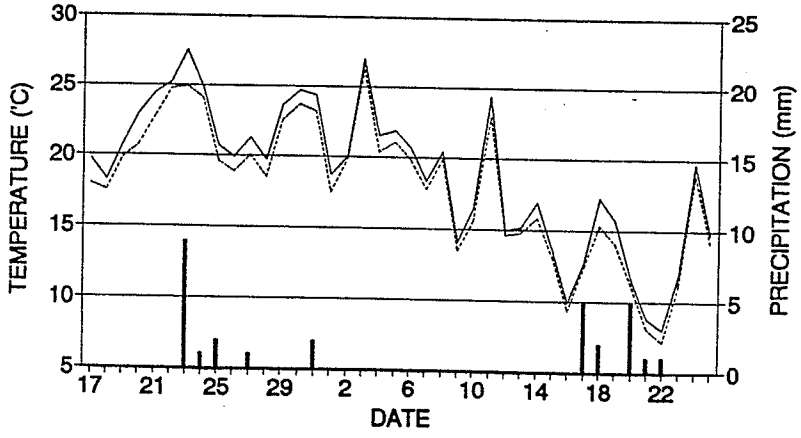


FIGURE 22. TEMPERATURE AND PRECIPITATION DURING WEATHERING PERIOD (AUG 16-SEPT 25), FOR WHEAT IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1990.

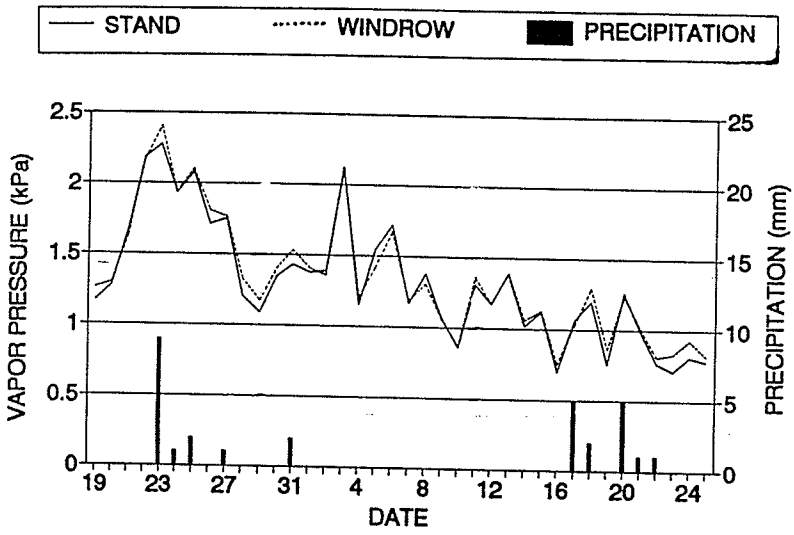


FIGURE 23. ACTUAL WATER VAPOR PRESSURE AND PRECIPITATION DURING WEATHERING PERIOD (AUG 18-SEPT 25), FOR BARLEY IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1990.

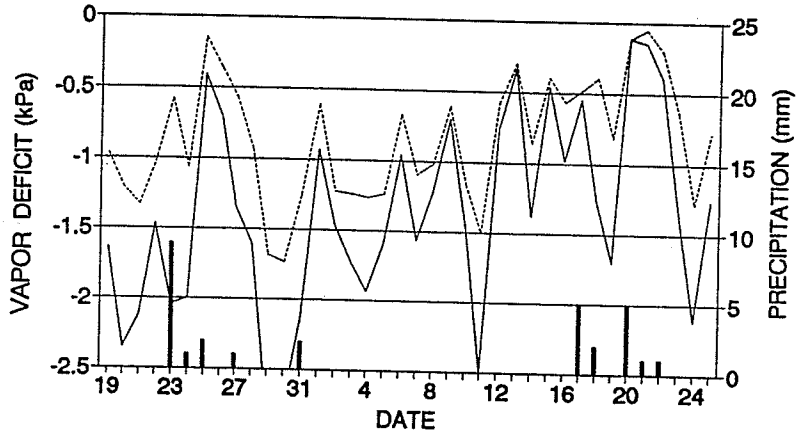


FIGURE 24. WATER VAPOR PRESSURE DEFICIT AND PRECIPITATION DURING WEATHERING PERIOD (AUG 18-SEPT 25), FOR BARLEY IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1990.

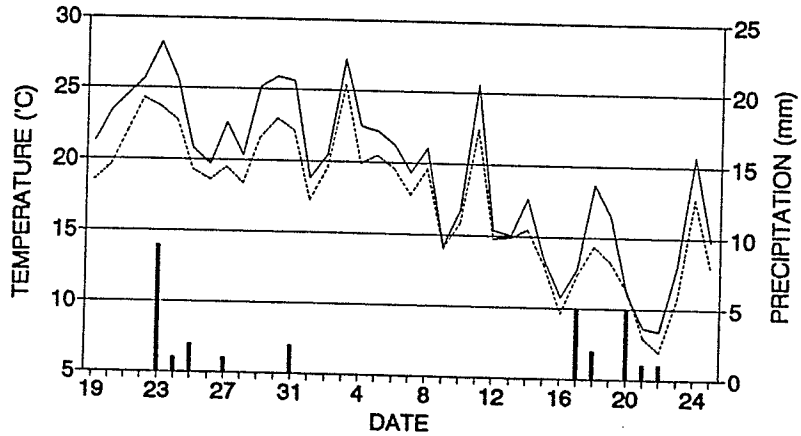


FIGURE 25. TEMPERATURE AND PRECIPITATION DURING WEATHERING PERIOD (AUG 18-SEPT 25), FOR BARLEY IN EXPERIMENT 2, PORTAGE la PRAIRIE, 1990.

On the other hand, the water vapor pressure deficit appeared to be higher for the standing treatment compared to the windrowed treatment, particularly after periods of precipitation (Figure 21). This would indicate a more rapid rate of evaporation from the standing crop in comparison to the windrowed crop. In fact, the cumulated daily average vapor pressure deficit was 15.2% greater for standing compared with windrowed wheat by the end of the weathering period. At first glance, results of vapor pressure deficit may appear to contradict those of actual vapor pressure. However, the reason for the difference is due to differences in temperature. For example, cumulated temperature was 5.4% greater in the standing crop (Figure 22). Therefore, even though the microclimate of the standing wheat crop contained higher levels of atmospheric water, the increased temperature at this location provided for an even greater capacity to contain water. Hence, there was a stronger vapor pressure deficit at spike level in the standing crop, despite greater quantities of atmospheric moisture.

Barley, unlike wheat, had a higher vapor pressure in the windrowed crop compared to the standing crop (Figure 23). At the end of the 38 day weathering period in 1990, cumulated vapor pressure was 2.2% higher in the windrow compared with the standing crop. However, the cumulated vapor pressure deficit was 63.4% greater within the microclimate of the standing compared with the windrowed crop (Figure 24). There was also a greater (11.3%)

cumulated temperature for the standing barley crop compared to the windrowed barley crop (Figure 25). This evidence indicates that the relative humidity within windrowed barley was higher than within standing barley crops.

Upon close examination of Figures 20 and 23, it is apparent for both crops that directly after periods of precipitation, the actual water vapor pressure is greater within the windrow then at spike level of the standing crop. For example, on August 23, the day in which 9 mm of precipitation fell, the respective actual water vapor pressure of windrowed wheat and barley was 2.7 and 5.7% higher than the standing crops. These results tend to support observations by Clarke (1984) and Bauer and Black (1983), that wet conditions during harvest result in slower drying for windrowed crop compared to standing crop.

The water vapor pressure deficit, which is a measure of the evaporative power of the atmosphere, has been significantly correlated with drying rates of mature wheat (Dodds and Pelton, 1969; Versavel and Muir, 1988b). Therefore, the findings of this study would indicate that the microclimate within standing crop would tend to hasten drying compared to that within a windrow, thereby lowering the risk of negative effects due to field weathering.

4.2.2 Physical Properties

4.2.2.1 Bulk Density

Bulk density of wheat in 1989 was not significantly different for the two different harvest management systems (Figure 26). However, in 1989 bulk density for the windrowed barley was 4.4% lower ($P < 0.05$) than bulk density for the standing barley (Figure 27). These results support similar observations by Bauer and Black (1983). In 1990, neither the wheat or barley displayed significant differences in bulk density between the two management systems (Figures 28 and 29). Insignificant differences may be attributed to the much lower levels of precipitation received during the exposure period in 1990 compared with 1989, (i.e., 54 and 55 mm for wheat and barley respectively, in 1989, compared to 29 mm for both crops in 1990).

In 1990, both crops displayed a significant reduction in bulk density with delayed harvest (Figures 28 and 29). However, harvest management by harvest date interaction was not significant, indicating that although weathering did decrease bulk density of both crops, the rate of decrease was not modified by harvest management.

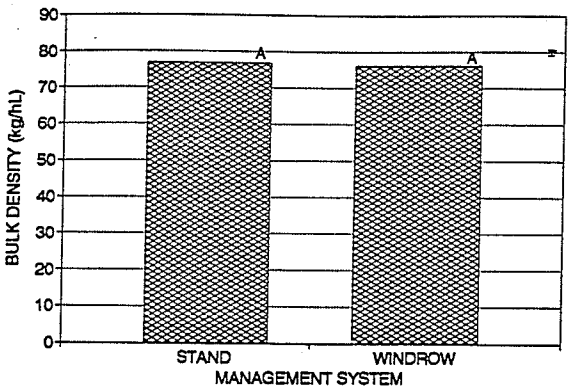


FIGURE 26. EFFECT OF HARVEST MANAGEMENT SYSTEM ON BULK DENSITY OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

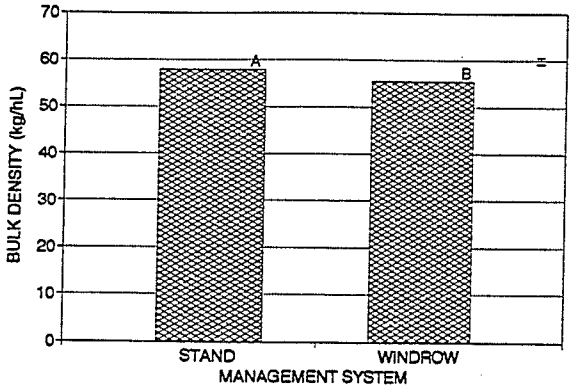


FIGURE 27. EFFECT OF HARVEST MANAGEMENT SYSTEM ON BULK DENSITY OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

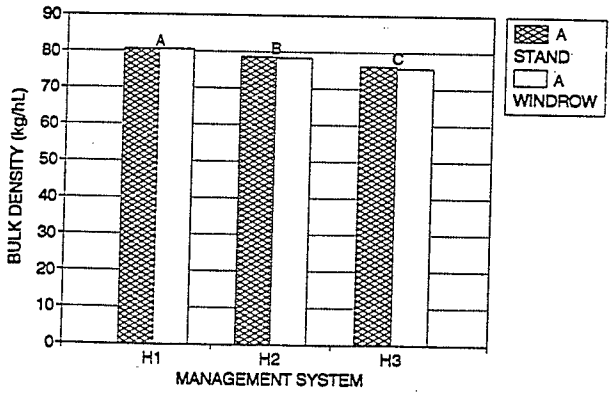


FIGURE 28. EFFECT OF HARVEST MANAGEMENT SYSTEM ON BULK DENSITY OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990, (H1=HARVEST 1, H2=HARVEST 2 etc).

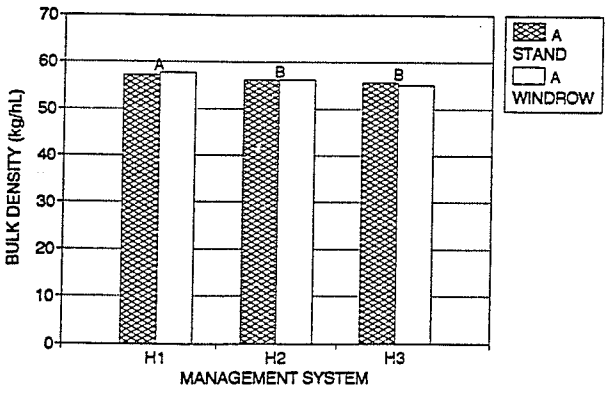


FIGURE 29. EFFECT OF HARVEST MANAGEMENT SYSTEM ON BULK DENSITY OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990 (H1=HARVEST 1, H2=HARVEST 2 etc).

4.2.2.2 Kernel Density

In 1989, kernel density of both crops was significantly affected by management system. However, while the standing barley kernels displayed a significantly greater density than the windrowed treatment (Figure 31), kernel density of the windrowed wheat was significantly higher than density of standing wheat (Figure 30).

The reason for higher kernel density in the standing barley may be explained as follows: Spikes of the mature standing crop were drooped over, and therefore during periods of precipitation the hulls surrounding the seed would shed most of the water. Hence, little moisture would be absorbed by the seed. On the other hand, the spikes within the windrow were in direct contact with straw and other spikes that were completely saturated. Therefore, the

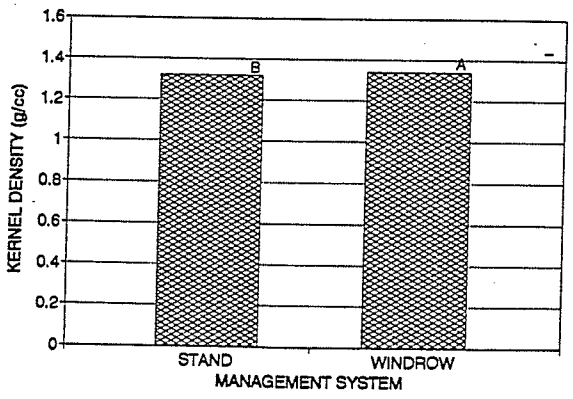


FIGURE 30. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL DENSITY OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

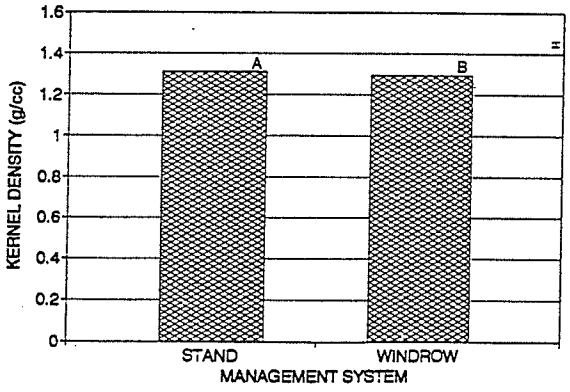


FIGURE 31. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL DENSITY OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

barley seed in the windrow imbibed much greater quantities of water than seed of standing crop.

The opposite trend, observed for wheat, may be explained based on differences in the rate at which wheat and barley kernels dry. Unlike barley, wheat seeds are encapsulated within the glumes, which can act as water reservoirs increasing kernel moisture by as much as 50% (Bauer and Black, 1983). Therefore, during periods of extended precipitation, the wheat seed of both standing and windrowed crop would be expected to become fully hydrated. Kernel density now becomes a function dependent upon the rate of seed drying. Milner and Shellenberger (1953), clearly indicated that the extent of fissuring is enhanced with more rapid seed drying rates. Hence, the greater vapor pressure deficit associated with standing crop (Figure 21), would result in greater seed drying rates compared to windrowed crop. According to Milner and Shellenberger, this would increase the degree of internal fissuring and result in reduced kernel densities for wheat.

Harvest management system had no significant effect on kernel density of either crop in 1990 (Figures 32 and 33). This was probably due to the fact that the largest rain shower received that year resulted in only 9 mm of precipitation. This may not have been enough to completely hydrate all the vegetative biomass within a windrow.

The interaction between management system and time of harvest was not significant in 1990, indicating the rate of

kernel density reduction was equal for both treatments. Again, this may be a result of the relatively dry weather conditions during the exposure period in 1990.

The greater loss in kernel density for barley compared with wheat (Figures 32 and 33) may be due to more rapid drying rates for barley. The lack of glumes on barley render less resistance to the transfer of moisture from the seed to the atmosphere. This observation has also been made by many farmers and seed producers, who are often able to harvest barley sooner than wheat following a rain shower.

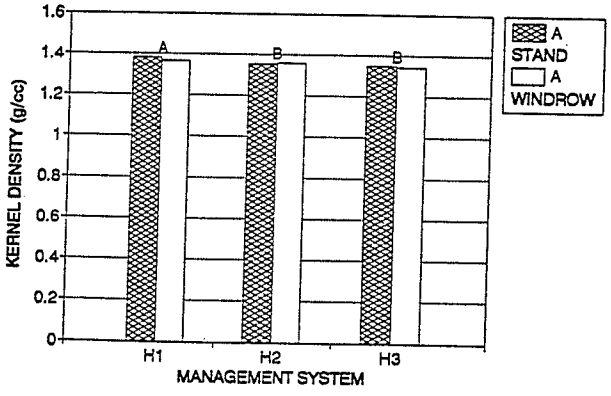


FIGURE 32. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL DENSITY OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990, (H1=HARVEST 1, H2=HARVEST 2 etc).

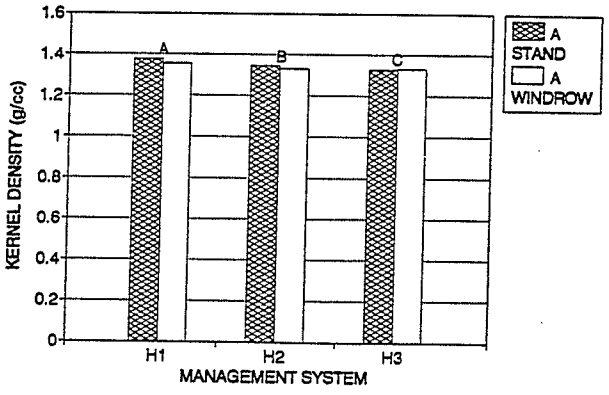


FIGURE 33. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL DENSITY OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990, (H1=HARVEST 1, H2=HARVEST 2 etc).

4.2.2.3 Kernel Mass

No differences in kernel mass were observed between harvest systems for wheat in 1989 or 1990 (Figures 34 and 36). In 1989, standing barley kernels had a significantly greater mass than those from the windrowed treatment (Figure 35), however, no significant differences were observed in 1990 (Figure 37). There were, however, significant differences between harvest dates, with seed from the first harvest having the greatest mass and seed from the second harvest the least.

It has been demonstrated that exposure to weathering had no clear effect on kernel mass in Experiment 1 and by other researchers (Czarnecki and Evans, 1986; Pool et al., 1958; and Whitcomb and Johnson, 1928). Therefore, it is unlikely that different harvest management systems would result in major differences. However, Clarke (1989) indicated that when barley is combined one to two weeks after physiological maturity, greater losses (i.e., 0.3 to 20%) may occur in standing compared with windrowed barley. These losses were attributed to shattering of the spike, where seeds fall to the ground and are excluded from the harvester. It seems probable that the largest kernels would shatter first, leaving the smaller, less ripe kernel behind. One might expect a greater kernel mass for windrowed barley as opposed to standing barley after a period of weathering.

However, the results of this study do not confirm this hypothesis.

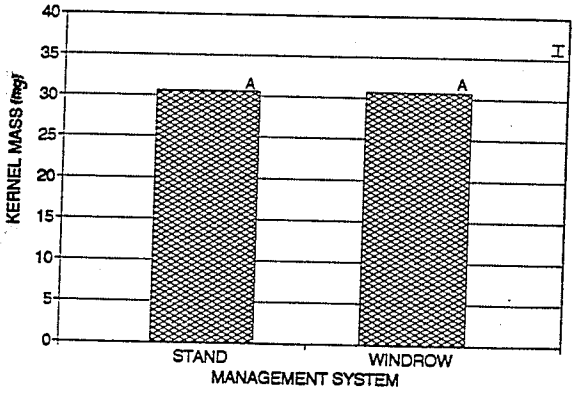


FIGURE 34. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL MASS OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

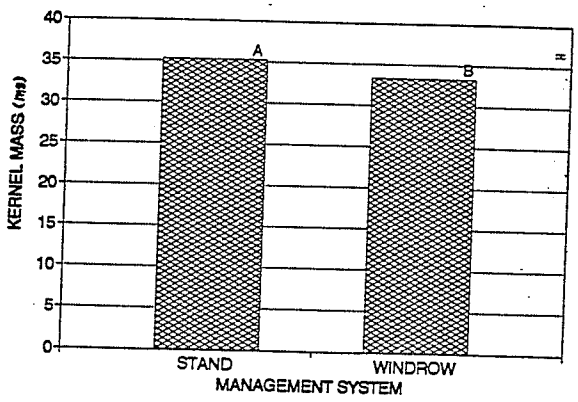


FIGURE 35. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL MASS OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

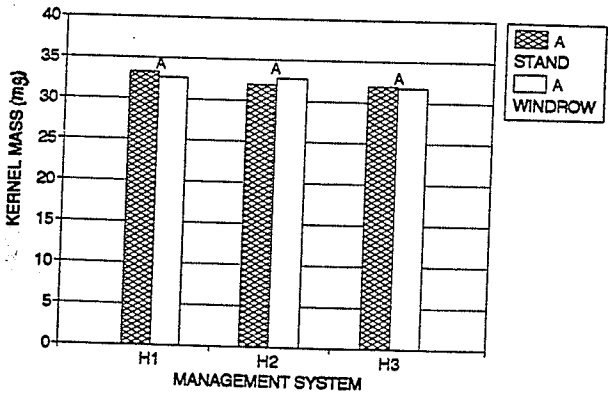


FIGURE 36. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL MASS OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990, (H1=HARVEST 1, H2=HARVEST 2 etc).

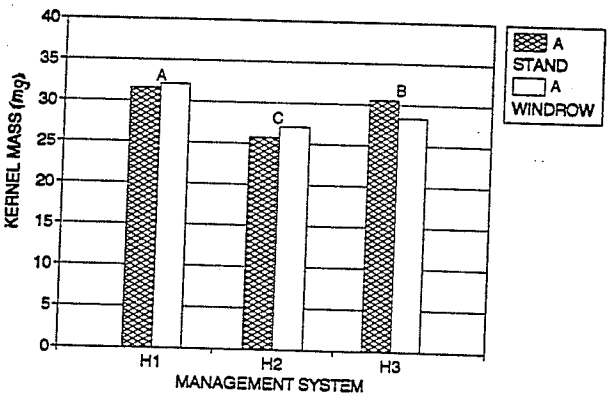


FIGURE 37. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL MASS OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990, (H1=HARVEST 1, H2=HARVEST 2 etc).

4.2.2.4 Kernel Hardness

Harvest management had no significant effect on the hardness of wheat in 1989 or 1990 (Figures 38 and 39). Although the differences were not significant, there was a trend for softer kernels in the windrowed compared with the standing wheat. Similar to results in Experiment 1, and by Czarnecki and Evans (1986), and Pool et al., (1958), significant hardness differences were observed in 1990 for each delay in harvest. However, the interaction between management system and harvest date was not significant. Thus, the results of this research project indicate that time of harvest may be more important than method of harvest in determining kernel hardness. This may be particularly important during periods of light weathering, as was the case during the harvest season of 1990.

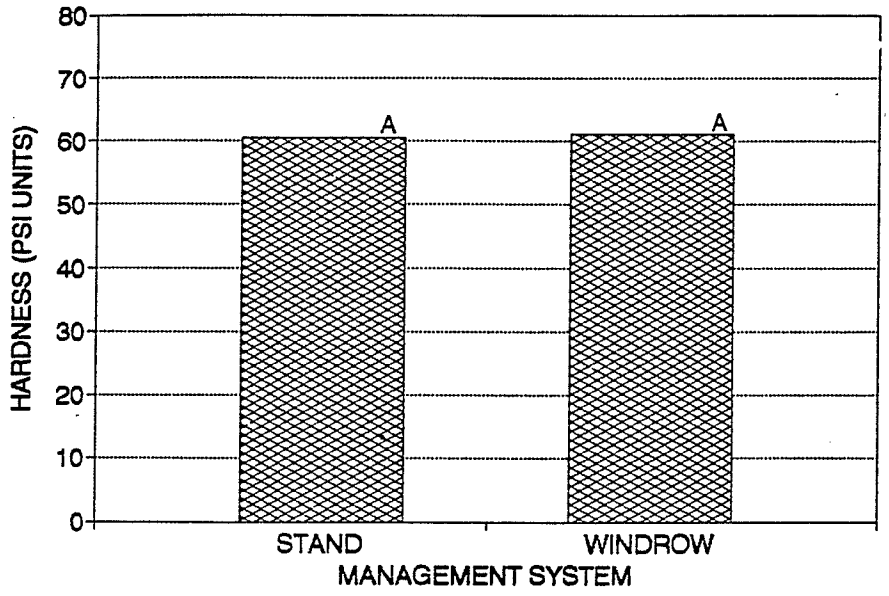


FIGURE 38. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL HARDNESS OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

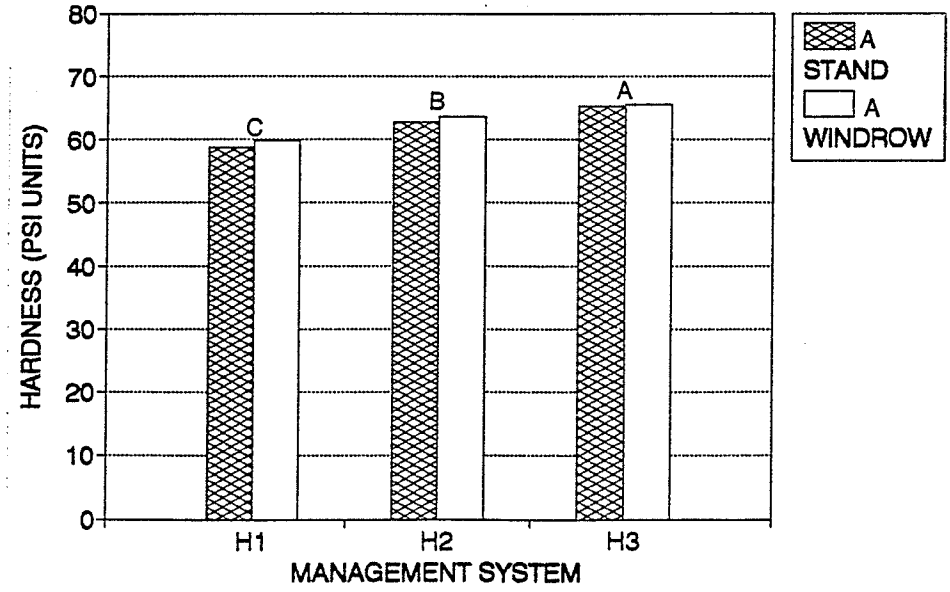


FIGURE 39. EFFECT OF HARVEST MANAGEMENT SYSTEM ON KERNEL HARDNESS OF WHEAT GROWN AT PORTAGE la PRAIRIE 1990, (H1=HARVEST 1, H2=HARVEST 2 etc).

4.2.3. Microbial Properties

Species of the six fungal genera identified in experiment 1 (*Cladosporium, Epicoccum, Nigrospora, Drechslera, Septoria,* and *Fusarium*) were again monitored in experiment 2. Seed infection level by any member of the six fungal genera for either wheat or barley were not significantly ($P < 0.05$) affected by harvest management system in either year (Figures 40 and 41, and Tables 33 and 34). However, the difference in *Fusarium* spp. infection between standing and windrowed wheat in 1989 was significant at $P = 0.057$. In this trial, *Fusarium* spp. infection in the windrowed wheat was over 60% higher than standing wheat whereas barley seed of both treatments (i.e., standing and windrowed) were infected at precisely the same level (31.8%).

Sturz and Johnston (1985) reported that fusaria inocula were located primarily in the organic fraction of the soil, and that greater numbers are present in fields which are continuously cropped compared to fallow-crop rotations. Therefore, during periods of precipitation, *Fusarium* spp. inoculum is transferred from the soil organic fraction to crop spikes via rain-splash drops. Hence, the lower level of *Fusarium* spp. infection observed on standing wheat compared to windrowed wheat may be due, at least partially, to the greater distance between inoculum source and crop spike. Extensive spike dropping and some lodging

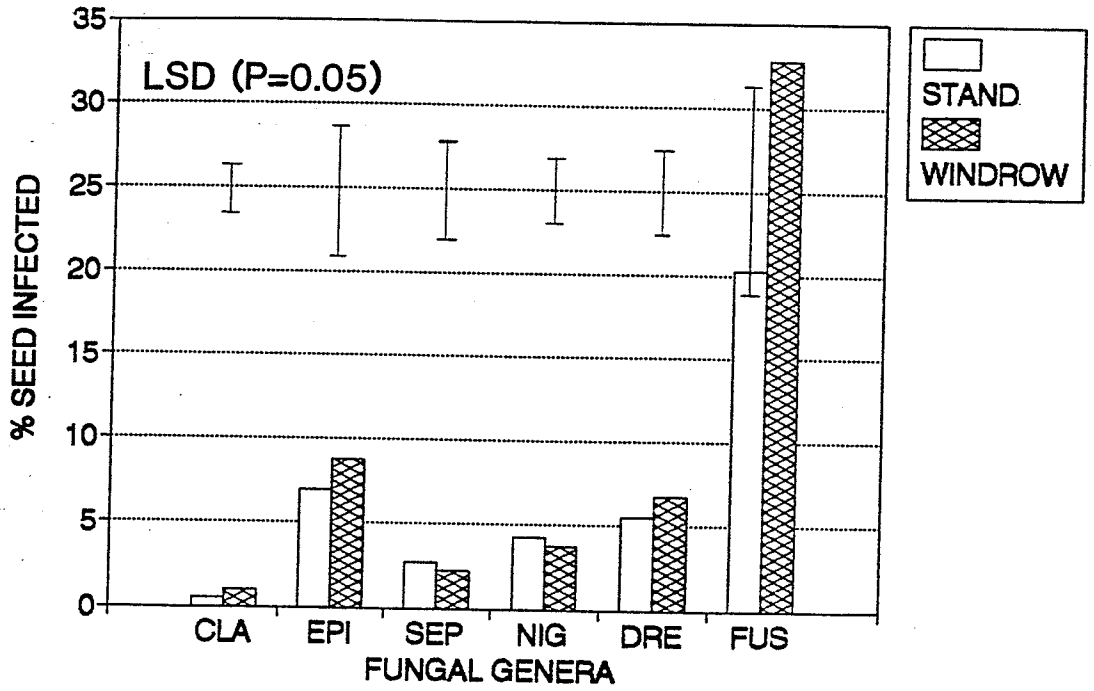


FIGURE 40. EFFECT OF HARVEST MANAGEMENT SYSTEM ON INFECTION LEVEL BY SIX DIFFERENT GENERA OF FIELD-FUNGI ON WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989, (CLA=*CLADOSPORIUM*; EPI=*EPICOCCUM*; SEP=*SEPTORIA*; NIG=*NIGROSPORA*; DRE=*DRECHSLERA*; FUS=*FUSARIUM*).

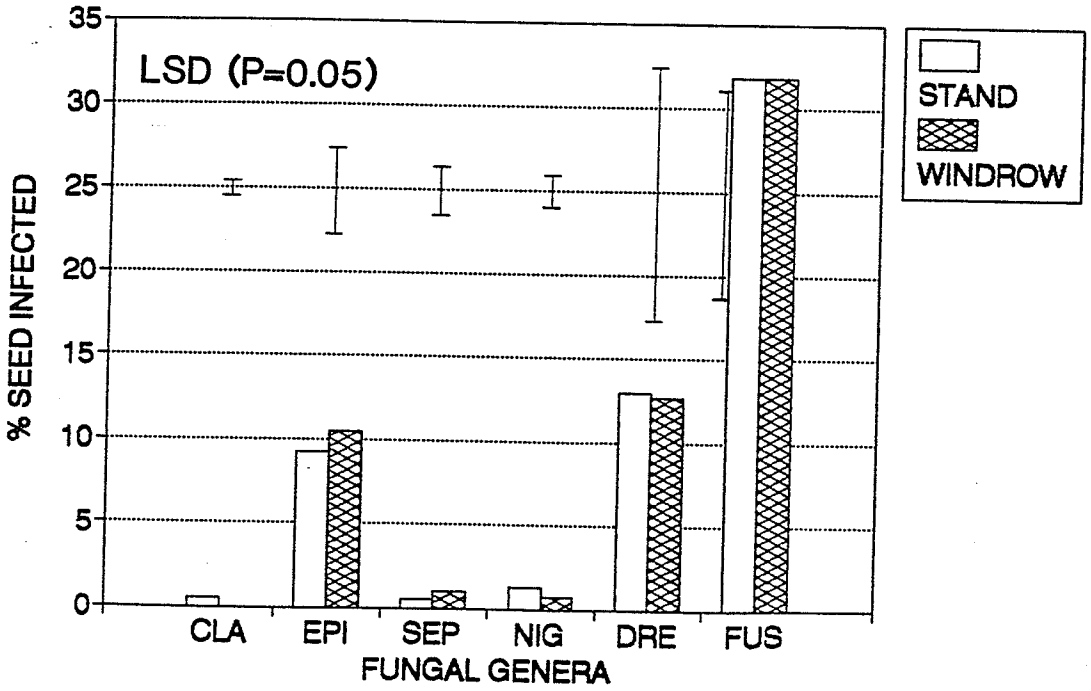


FIGURE 41. EFFECT OF HARVEST MANAGEMENT SYSTEM ON INFECTION LEVEL BY SIX DIFFERENT GENERA OF FIELD-FUNGI ON BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989, (CLA=*CLADOSPORIUM*; EPI=*EPICOCCUM*; SEP=*SEPTORIA*; NIG=*NIGROSPORA*; DRE=*DRECHSLERA*; FUS=*FUSARIUM*).

TABLE 33. EFFECT OF HARVEST MANAGEMENT SYSTEM ON INFECTION LEVEL BY SIX DIFFERENT GENERA OF FIELD-FUNGI ON WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990.

MANAGEMENT SYSTEM	H1*	H2	H3	MEAN	LSD
	CLADOSPORIUM INFECTION (%)				
STAND	4.25	5.50	4.75	4.83	
WINDROW	4.00	6.75	4.50	5.08	
MEAN	4.13	6.13	4.63		2.46
LSD				4.00	
	EPICOCCUM INFECTION (%)				
STAND	1.00	4.00	7.00	4.00	
WINDROW	2.50	3.75	5.25	3.83	
MEAN	1.75	3.88	6.13		2.98
LSD				1.96	
	SEPTORIA INFECTION (%)				
STAND	0.75	0.50	0.00	0.42	
WINDROW	0.75	0.50	0.50	0.58	
MEAN	0.75	0.50	0.25		0.73
LSD				0.31	
	NIGROSPORA INFECTION (%)				
STAND	3.00	3.00	3.25	3.08	
WINDROW	3.25	2.75	2.75	2.92	
MEAN	3.13	2.88	3.00		1.14
LSD				1.10	
	DRECHSLERA INFECTION (%)				
STAND	7.25	8.50	9.00	8.25	
WINDROW	10.75	10.75	8.00	9.83	
MEAN	9.00	9.63	8.50		3.33
LSD				1.65	
	FUSARIUM INFECTION (%)				
STAND	0.00	1.75	2.00	1.25	
WINDROW	1.25	4.00	2.25	2.50	
MEAN	0.63	2.88	2.13		1.73
LSD				1.58	

*H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively.

TABLE 34. EFFECT OF HARVEST MANAGEMENT SYSTEM ON INFECTION LEVEL BY SIX DIFFERENT GENERA OF FIELD-FUNGI ON BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

MANAGEMENT SYSTEM	H1+	H2	H3	MEAN	LSD
		CLADOSPORIUM INFECTION (%)			
STAND	14.25	9.50	8.75	10.83	
WINDROW	13.75	14.25	11.00	13.00	
MEAN	14.00	11.88	9.88		3.79
LSD				6.69	
		EPICOCCUM INFECTION (%)			
STAND	14.50	21.50	23.25	19.75	
WINDROW	14.25	19.25	21.50	18.33	
MEAN	14.38	20.38	22.38		4.58
LSD				7.51	
		SEPTORIA INFECTION (%)			
STAND	0.50	0.00	0.25	0.25	
WINDROW	0.00	0.00	0.00	0.00	
MEAN	0.25	0.00	0.13		0.29
LSD				0.51	
		NIGROSPORA INFECTION (%)			
STAND	1.00	0.75	0.75	0.83	
WINDROW	0.50	2.00	1.00	1.17	
MEAN	0.75	1.38	0.88		1.02
LSD				1.79	
		DRECHSLERA INFECTION (%)			
STAND	10.75	10.50	12.00	11.08	
WINDROW	9.00	13.00	14.75	12.25	
MEAN	9.88	11.75	13.38		3.37
LSD				2.05	
		FUSARIUM INFECTION (%)			
STAND	5.50	12.00	14.00	10.50	
WINDROW	3.75	12.50	11.50	9.25	
MEAN	4.63	12.25	12.75		3.99
LSD				3.02	

+H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively.

that occurred in barley by the end of the weathering period may be the cause of equal levels of *Fusarium* spp. infection in the standing and windrowed treatments. This lowering of the spikes in the standing treatment likely resulted in their having a similar proximity to the inoculum source as the windrowed spikes.

Although, the interaction between management system and harvest date was not significant for either crop in 1990, delayed harvest did result in significantly higher levels of *Fusarium* spp. infection on seed of both wheat and barley (Tables 33 and 34). In terms of harvest management system, there were no significant differences in *Fusarium* spp. infection level between treatments. Thus, during weathering periods as in 1990, the effect of harvest management system appeared to be less important to *Fusarium* spp. infection, than time of harvest.

Identification of individual *Fusarium* species revealed that F. sporotrichioides and F. poae were the two dominant species present in both crops in each year (Figures 42 and 43; Tables 35 and 36). An interesting pattern appeared to emerge with respect to these two *Fusarium* species. For example, based on total *Fusarium* spp. infection, over all crops and trials the level of F. sporotrichioides infection was 5.5 to 13.6% greater in the windrowed treatment versus the standing treatment. On the other hand, F. poae infected a higher percentage of the seeds in the standing treatment than the windrowed treatment, (1.5 to 9.9%). This trend

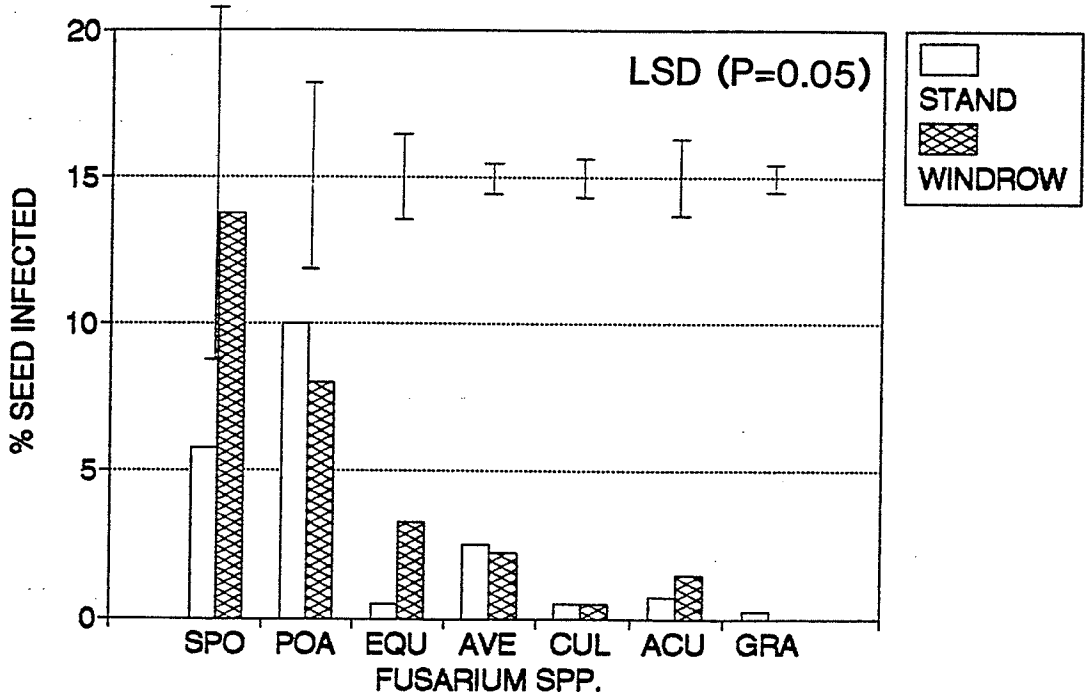


FIGURE 42. EFFECT OF HARVEST MANAGEMENT SYSTEM ON *FUSARIUM* SPP. INFECTION ON WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989, (SPO=F. SPOROTRICHIOIDES; POA=F. POAE; EQU=F. EQUISETI; AVE=F. AVENACEUM; CUL=F. CULMORUM; ACU=F. ACUMINATUM; GRA=F. GRAMINEARUM).

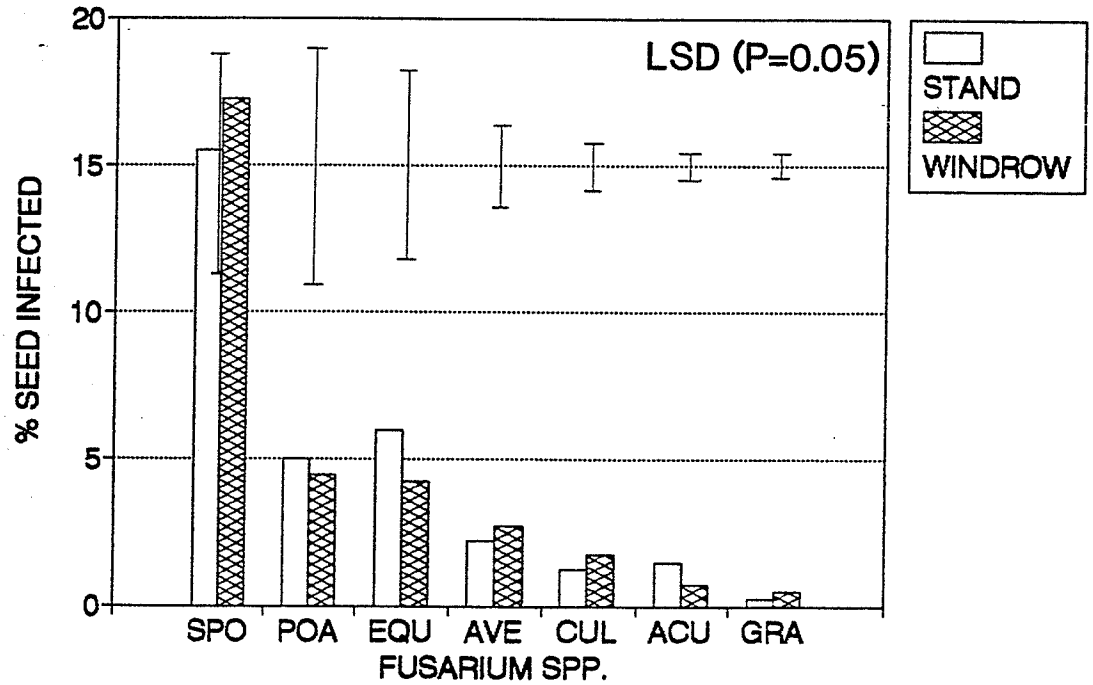


FIGURE 43. EFFECT OF HARVEST MANAGEMENT SYSTEM ON *FUSARIUM* SPP. INFECTION ON BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989, (SPO=F. SPOROTRICHIOIDES; POA=F. POAE; EQU=F. EQUISETI; AVE=F. AVENACEUM; CUL=F. CULMORUM; ACU=F. ACUMINATUM; GRA=F. GRAMINEARUM).

TABLE 35. EFFECT OF HARVEST MANAGEMENT SYSTEM ON *FUSARIUM* SPP. INFECTION ON WHEAT SEED GROWN AT PORTAGE la PRAIRIE IN 1990.

MANAGEMENT SYSTEM	H1+	H2	H3	MEAN	LSD
	F. SPOROTRICHIOIDES (%)				
STAND	0.00	0.00	1.25	0.42	
WINDROW	0.25	0.50	1.00	0.58	
MEAN	0.13	0.25	1.13		0.93
LSD				0.31	
	F. POAE (%)				
STAND	0.00	1.50	0.75	0.75	
WINDROW	0.50	3.00	0.75	1.42	
MEAN	0.25	2.25	0.75		0.98
LSD				1.06	
	F. EQUISETI (%)				
STAND	0.00	0.00	0.00	0.00	
WINDROW	0.00	0.25	0.25	0.17	
MEAN	0.00	0.13	0.13		0.22
LSD				0.53	
	F. AVENACEUM (%)				
STAND	0.00	0.25	0.00	0.08	
WINDROW	0.00	0.00	0.00	0.00	
MEAN	0.00	0.13	0.00		0.22
LSD				0.27	
	F. ACUMINATUM (%)				
STAND	0.00	0.00	0.00	0.00	
WINDROW	0.00	0.25	0.00	0.08	
MEAN	0.00	0.13	0.00		0.22
LSD				0.27	
	F. GRAMINEARUM (%)				
STAND	0.00	0.00	0.00	0.00	
WINDROW	0.25	0.00	0.25	0.17	
MEAN	0.13	0.00	0.13		0.22
LSD				0.53	

+H1, H2 and H3 represents harvest 1, harvest 2 and harvest 3, respectively.

TABLE 36. EFFECT OF HARVEST MANAGEMENT SYSTEM ON *FUSARIUM* SPP. INFECTION ON BARLEY SEED GROWN AT PORTAGE la PRAIRIE IN 1990.

MANAGEMENT SYSTEM	H1+	H2	H3	MEAN	LSD
		F. SPOROTRICHIOIDES (%)			
STAND	1.75	4.75	6.75	4.42	
WINDROW	0.75	4.50	4.75	3.33	
MEAN	1.25	4.63	5.75		2.22
LSD				2.05	
		F. POAE (%)			
STAND	2.00	3.75	3.00	2.92	
WINDROW	1.25	5.75	3.50	3.50	
MEAN	1.63	4.75	3.25		1.96
LSD				1.39	
		F. EQUISETI (%)			
STAND	1.25	2.25	2.00	1.83	
WINDROW	1.50	2.00	2.75	2.08	
MEAN	1.38	2.13	2.38		1.28
LSD				0.51	
		F. AVENACEUM (%)			
STAND	0.00	0.75	0.75	0.50	
WINDROW	0.25	0.25	0.50	0.33	
MEAN	0.13	0.50	0.63		0.70
LSD				0.31	
		F. ACUMINATUM (%)			
STAND	0.25	0.25	1.00	0.50	
WINDROW	0.00	0.00	0.00	0.00	
MEAN	0.13	0.13	0.50		0.56
LSD				0.31	
		F. GRAMINEARUM (%)			
STAND	0.25	0.00	0.00	0.08	
WINDROW	0.00	0.00	0.00	0.00	
MEAN	0.13	0.00	0.00		0.22
LSD				0.27	
		F. SEMITECTUM (%)			
STAND	0.00	0.25	0.50	0.25	
WINDROW	0.00	0.00	0.00	0.00	
MEAN	0.00	0.13	0.25		0.29
LSD				0.51	

+H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively.

occurred for both crops in 1989, and for the wheat crop in 1990. However, in the 1990 barley crop F. sporotrichioides infection was 4.1% greater for the standing treatment and F. poae infection was 10.0% greater for the windrowed treatment.

The observation of the higher level of infection by F. sporotrichioides in the windrowed treatments may be explained by the findings of Sturz and Johnston, (1985). These researchers found populations of F. sporotrichioides in the soil organic debris were five times greater than that of F. poae. Therefore, since F. sporotrichioides inoculum is located primarily in the soil organic fraction, seed of windrowed crop may be more likely to become infected than seed of standing crop.

To determine the relationship between soil inoculum level and plant disease, Sturz and Johnston (1985) also monitored the level of *Fusarium* spp. infection in the crop spikes. Although they found very low levels of F. poae inoculum in the soil organic fraction, it was a primary invader of the spikes. Sturz and Johnston (1983) indicated that F. poae was found to colonize the ears of cereal crops prior to emergence from the boot. Hence, the early colonization by F. poae indicates that inoculum of this species is capable of dispersal by air or water. The greater levels of F. poae infection on seed from standing crop compared to windrow crop in this study would tend to support this view.

F. equiseti was the only other species of *Fusarium* commonly recovered from the seed. It accounted for approximately 17% and 8% of the total *Fusarium* spp. infection of windrowed barley and wheat, respectively. However, this particular species is not considered to be pathogenic, and is found primarily on organic debris on the soil surface (Sturz and Johnston, 1985). The other five species isolated (F. culmorum, F. avenaceum, F. acuminatum, F. graminearum, and F. semitectum Berk. and Rav.) were infrequent, and as a group comprised less than 8.7% of the *Fusarium* spp. recovered.

4.2.4 Physiological Properties

4.2.4.1 Protein Concentration

Protein concentration was not significantly affected by harvest management system (Table 37). It has been demonstrated in experiment 1, and by several other researchers (Swanson, 1943; Pool et al., 1958), that increased exposure to field weathering does not affect seed protein concentration. Nor was there any difference in seed protein concentration for either wheat or barley between the three harvest dates in 1990. Therefore, the mean protein concentration over the three harvest dates was used to test the significance of the two harvest management systems (Table 37).

TABLE 37. EFFECT OF HARVEST MANAGEMENT SYSTEM ON SEED PROTEIN CONCENTRATION OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

	PROTEIN CONCENTRATION (%)			
	1989		1990	
MANAGEMENT SYSTEM	WHEAT	BARLEY	WHEAT	BARLEY
STAND	14.35a[+]	10.55a	10.06a	8.40a
WINDROW	14.08a	10.28a	10.04a	8.25a
LSD (0.05)	0.48	0.53	0.30	0.40
C.V.	1.49	2.24	3.80	2.60

[+] means in a column followed by a different letter are significantly different at $P < 0.05$.

4.2.4.2 Alpha-Amylase Activity

The Hagberg Falling Number Test (AACC Method 56-81B, 1983) was used to determine alpha-amylase activity of seed from the two harvest management systems. For both years and both crops, the windrowed treatment displayed significantly greater levels of enzyme activity (i.e., lower falling number) than did the standing treatment (Table 38 and 39). A similar trend was observed by Clarke et al. (1984), working with 18 different cultivars of wheat. These authors reported that the differences in falling number between the two treatments were significant with total rainfall as low as 47 mm during the weathering period.

TABLE 38. EFFECT OF HARVEST MANAGEMENT SYSTEM ON FALLING NUMBER OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

MANAGEMENT SYSTEM	FALLING NUMBER (s)	
	WHEAT	BARLEY
STAND	292.00a+	160.25a
WINDROW	135.25b	68.25b
LSD (0.05)	38.46	44.80
C.V.	8.00	17.43

+ means in a column followed by a different letter are significantly different a $P < 0.05$.

The explanation for greater alpha-amylase activity in windrowed seed compared to that from the standing treatment, is related to drying rates following periods of precipitation. Clarke (1984) demonstrated that seed moisture content following precipitation was greater in windrowed crop than in standing crop. Also, environmental data in the present study showed a larger vapor pressure

deficit in standing crop compared to windrowed crop (Figures 21 and 24). Hence, the slower drying rates in a windrow would provide more time for alpha-amylase generation, leading to a lower falling number.

TABLE 39. EFFECT OF HARVEST MANAGEMENT SYSTEM ON FALLING NUMBER OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

	FALLING NUMBER (s)									
	WHEAT					BARLEY				
MANAGEMENT SYSTEM	H1[1]	H2	H3	MEAN	LSD[2]	H1	H2	H3	MEAN	LSD
STAND	399.34	373.84	347.50	373.56		369.17	351.09	320.42	346.89	
WINDROW	390.50	366.92	332.67	363.36		345.42	351.25	266.84	321.17	
MEAN	394.92	370.38	340.08		11.60	357.29	351.17	293.63		8.35
LSD				9.24					3.27	

[1] H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively. [2] LSD at P < 0.05.

The results of this study indicated a significant management system by harvest date interaction for barley in 1990 (Table 39). This suggests that during periods of weathering, the rate of alpha-amylase production is greater for windrowed compared to standing barley. Again, this difference can be attributed to the lower drying rate for windrowed crop. No significant management system by harvest date interaction was observed for wheat.

4.2.4.3 Standard Germination

Seed viability, as determined by the standard germination test, was not significantly affected by harvest management system in either year (Tables 40 and 41).

TABLE 40. EFFECT OF HARVEST MANAGEMENT SYSTEM ON STANDARD GERMINATION OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

MANAGEMENT SYSTEM	GERMINATION (%)	
	WHEAT	BARLEY
STAND	98.8a+	88.5a
WINDROW	98.6a	84.4a
LSD (0.05)	1.6	7.5
C.V.	0.7	3.9

+ means in a column followed by a different letter are significantly different at P < 0.05.

In 1990, the harvest management system by harvest date interaction was found to be non-significant for both wheat and barley, indicating that harvest management systems responded similarly to field weathering. However, as in Experiment 1, the mean germination value for wheat did significantly increase with delayed harvest.

TABLE 41. EFFECT OF HARVEST MANAGEMENT SYSTEM ON STANDARD GERMINATION ON WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

MANAGEMENT SYSTEM	STANDARD GERMINATION (%)									
	WHEAT					BARLEY				
	H1[1]	H2	H3	MEAN	LSD[2]	H1	H2	H3	MEAN	LSD
STAND	89.0	90.5	93.0	90.8		87.0	85.9	84.0	85.6	
WINDROW	88.5	87.8	94.8	90.3		85.9	86.1	82.9	85.06	
MEAN	88.8	89.1	93.9		4.3	86.4	86.0	83.4		5.9
LSD				2.9					5.9	

[1] H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively. [2] LSD at P < 0.05.

The percent abnormal germination was not significantly affected by harvest management treatments in these trials (Table 42). However in 1990, the level of abnormal germination was significantly reduced for harvest 3 compared to the prior harvest dates. This reduction in abnormal germination may add support to the premise that weathering

reduces seed coat strength, allowing for easier germination. Reduced resistance to germination by the seed coat could conceptually reduce the level of abnormal germination.

TABLE 42. EFFECT OF HARVEST MANAGEMENT SYSTEM ON ABNORMAL GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

MANAGEMENT SYSTEM	1989 ABNORMALLY GERMINATED SEED (%)
STAND	1.9
WINDROW	0.8
LSD	3.0

MANAGEMENT SYSTEN	1990 ABNORMALLY GERMINATED SEED (%) H1[1]	H2	H3	MEAN	LSD[2]
STAND	8.3	6.3	3.3	5.9	
WINDROW	7.5	9.0	3.3	6.6	
MEAN	7.9	7.6	3.3		2.7
LSD				2.3	

[1] H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively. [2] LSD at P < 0.05.

4.2.4.4 Cold Germination

Cold germination tests were used to evaluate seed vigor. Results of this test for wheat and barley in 1989 are presented in Figures 44 and 45. At two and four days after planting (DAP), the wheat seed from windrowed plots displayed significantly greater germination than the standing wheat (Appendix, Table A11). This once again may be attributed to the significantly higher level of alpha-amylase activity for windrowed versus standing wheat (Table 37). However, by six DAP, wheat seed from the standing treatment demonstrated a greater mean germination level than seed from the windrowed treatment. Although the differences were not always significant, this trend was observed for the duration of the test. Statistically significant differences (i.e., $P < 0.05$) were observed at eight, 16 and 18 DAP.

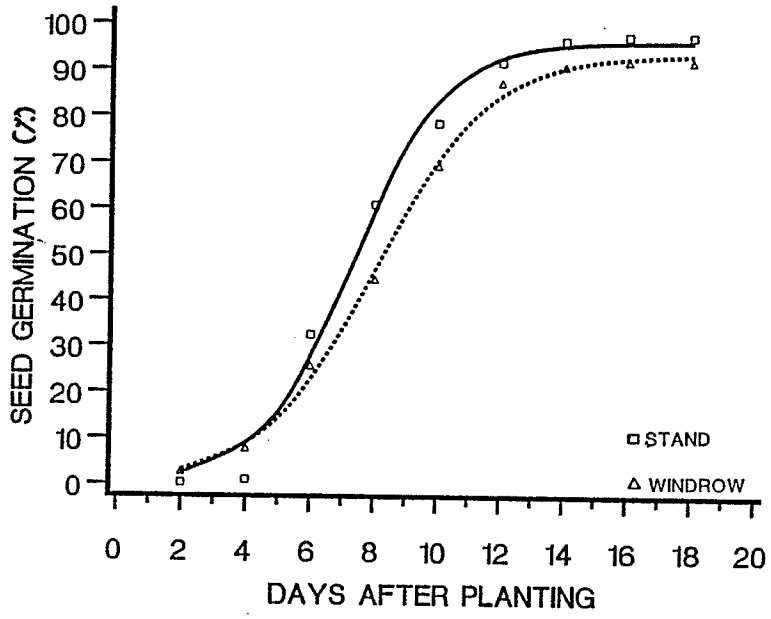


FIGURE 44. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

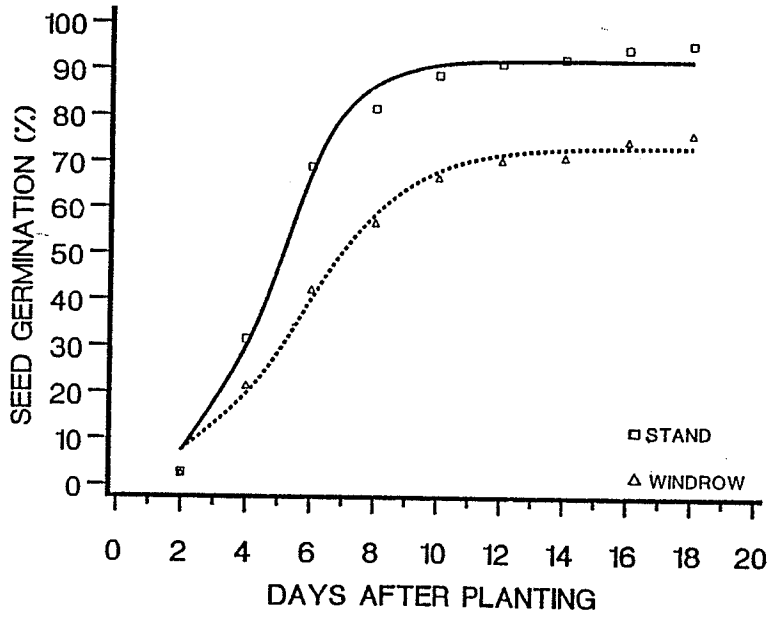


FIGURE 45. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

Even though there was a significantly greater level of alpha-amylase present in windrowed barley compared to standing barley, this was not reflected in early germination percentage (Figure 45). For example, at two DAP, both treatments displayed similar levels of germination (Appendix Table A12). From four DAP through to the end of the test, seed from the standing treatment had a significantly higher cold germination percentage, indicating that it was significantly more vigorous than seed from the windrowed treatment.

The 1990 experiment was analyzed as a split-plot and analysis of variance was determined for each two day interval. At no point during the cold germination test (18 day period), was the harvest management by harvest date interaction significant for either crop. Therefore, the cold germination level was averaged for the three harvest dates performed and plotted over time for both crops, (Figures 46 and 47).

Comparing the two years, wheat grown in 1989 appeared to be more vigorous than the wheat grown in 1990. For example, the level of germination six DAP for windrowed and standing crop in 1990 was only 45.4 and 50.9% of the germination level six DAP in 1989. This reduction between the two years may be attributed to differences in seed protein concentration (Table 37). This reduction in vigor occurred even though the weather conditions were more severe in 1989 than in 1990 (ie., 29 mm of precipitation in 1990,

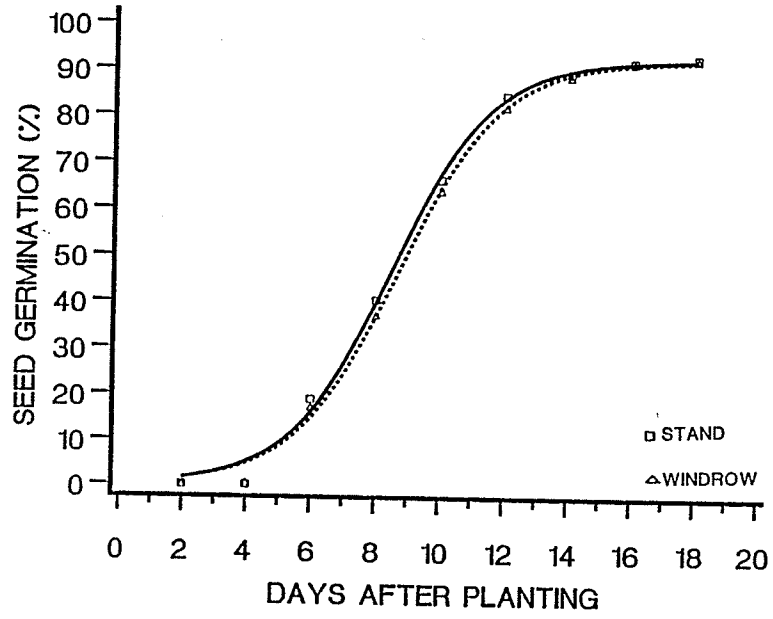


FIGURE 46. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990.

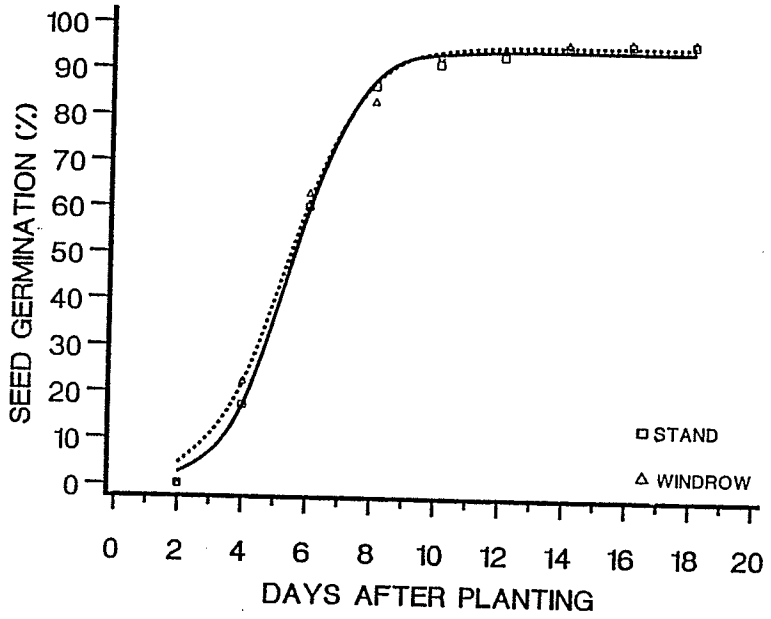


FIGURE 47. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

compared to 54 mm in 1989). Therefore, the reports indicating that seed protein content is directly related to seed vigor (McDaniel, 1969; Ries and Everson, 1973; and Evans and Bhatt, 1977) are supported by this study. In fact, given the above finding, it appeared protein content had a greater effect on seed vigor than field weathering.

As was the case for wheat in 1989, the windrowed wheat in 1990 showed a significantly greater level of cold germination 4 DAP compared to the standing wheat (Appendix, Table A12). Again, this may be related to significant differences in alpha-amylase levels (Table 39). However, at six DAP, the standing treatment had a significantly higher cold germination than the windrowed treatment. No other significant differences were observed between the two management systems in this test (Table 43). Conversely, there were significant differences between wheat seed harvested at different dates. At four and six DAP, delayed harvest resulted in greater levels of germination. At eight DAP there were no differences between seed harvested on different dates. However, during the period from 10 DAP until the end of the test, delayed harvest consistently resulted in a reduction of germination level. Therefore, during periods of little precipitation as in 1990 (total of 29 mm, largest single rain shower only 9 mm), only slight differences are observed in seed vigor as a result of different harvest systems (i.e., six DAP). In this study, the delay in harvest caused a greater loss of seed vigor

TABLE 43. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION (%) OF WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

MANAGEMENT SYSTEM	WHEAT H1[1]	H2	H3	MEAN	LSD[2]	BARLEY H1	H2	H3	MEAN	LSD
2 DAYS AFTER PLANTING										
STAND	0.0	0.0	0.0	0.0		0.0	0.0	0.8	0.3	
WINDROW	0.0	0.0	0.0	0.0		0.0	0.1	0.4	0.2	
MEAN	0.0	0.0	0.0		-	0.0	0.1	0.6		0.3
LSD				-					0.6	
4 DAYS AFTER PLANTING										
STAND	0.0	0.0	0.1	0.0		12.8	12.0	27.2	17.3	
WINDROW	0.1	0.4	0.9	0.4		17.6	20.8	29.2	22.5	
MEAN	0.1	0.2	0.5		0.2	15.2	16.4	28.2		3.2
LSD				0.1					5.0	
6 DAYS AFTER PLANTING										
STAND	14.7	16.2	25.7	18.9		59.5	61.1	61.5	60.7	
WINDROW	13.1	14.8	23.8	17.2		66.1	63.8	59.6	63.2	
MEAN	13.9	15.5	24.8		3.6	62.8	62.5	60.5		4.3
LSD				0.8					5.2	
8 DAYS AFTER PLANTING										
STAND	38.3	40.8	42.1	40.4		83.5	83.5	83.0	83.3	
WINDROW	37.0	36.5	38.3	37.2		89.6	85.2	84.5	86.4	
MEAN	37.6	38.6	40.2		3.7	86.5	84.3	83.7		3.2
LSD				5.7					3.4	
10 DAYS AFTER PLANTING										
STAND	71.5	66.3	60.8	66.2		92.8	90.3	91.1	91.4	
WINDROW	69.2	67.5	55.1	63.9		95.7	91.6	93.0	93.4	
MEAN	70.3	66.9	58.0		3.9	94.3	91.0	92.0		1.8
LSD				5.8					3.8	
12 DAYS AFTER PLANTING										
STAND	90.7	86.6	75.7	84.3		94.7	92.5	92.5	93.2	
WINDROW	90.0	84.5	71.6	82.0		96.8	93.5	95.0	95.1	
MEAN	90.3	85.5	73.6		2.5	95.8	93.0	93.7		2.0
LSD				3.5					2.3	

TABLE 43 CONT'D

14 DAYS AFTER PLANTING										
STAND	94.6	91.0	82.2	89.2		96.6	95.3	94.5	95.5	
WINDROW	94.3	91.1	80.2	88.5		97.5	95.0	96.3	96.2	
MEAN	94.5	91.0	81.2		2.4	97.0	95.1	95.4		2.1
LSD				3.2					1.8	
16 DAYS AFTER PLANTING										
STAND	95.6	93.6	86.3	91.8		97.0	96.1	95.0	96.0	
WINDROW	95.7	93.5	85.7	91.6		97.5	95.1	97.6	96.7	
MEAN	95.6	93.5	86.0		3.2	97.2	95.6	96.3		1.9
LSD				3.2					1.9	
18 DAYS AFTER PLANTING										
STAND	96.1	94.1	88.1	92.7		97.1	96.5	95.2	96.2	
WINDROW	96.2	93.8	87.7	92.6		97.8	95.2	97.6	96.9	
MEAN	96.1	94.0	87.9		3.0	97.5	95.8	96.4		1.9
LSD				3.4					1.8	

[1] H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively. [2] LSD at $P < 0.05$.

than the difference between the two systems. Therefore, it appears that timeliness of harvest was more important than harvest system for maintaining seed vigor in wheat.

No differences in cold germination between systems were observed for barley in 1990 with the exception of four DAP (Table 43). On this date, the windrowed barley had a significantly higher cold germination than the standing barley. This may once again be attributed to higher levels of alpha-amylase in the windrowed compared to standing barley (Table 39).

Similar to results for wheat, there also were significant differences between harvest dates for barley in 1990. At two and four DAP, the seed from harvest date three was significantly higher in germination that the early harvest dates. At six and eight DAP, there was no difference between harvest dates. However, on 10 and 12

DAP, cold germination was lower for harvest two and three than for date one (Table 43). No differences were observed after this time. This evidence once again points out the importance of timely harvest for maintaining seed vigor, even during periods of light weathering as in 1990.

No significant differences in percentage of abnormally germinated seeds were observed between harvest treatments in 1989 or 1990 (Table 44). However, in 1990 there was a significant increase in the level of abnormal germination with delayed harvest. This would indicate that factors other than the physical properties of the seed coat affected abnormal germination. Since the kernels were significantly softer as harvest was delayed (Figure 35), they may be more susceptible to mechanical damage at harvest. This in turn, may result in greater abnormal germination.

TABLE 44. EFFECT OF HARVEST MANAGEMENT SYSTEM ON ABNORMAL GERMINATION, (COLD) OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

MANAGEMENT SYSTEM	1989 ABNORMALLY GERMINATED SEED (%)
STAND	0.50
WINDROW	2.00
LSD	2.76

MANAGEMENT SYSTEM	1990 ABNORMALLY GERMINATED SEED (%) H1[1]	H2	H3	MEAN	LSD[2]
STAND	1.50	1.75	2.88	2.04	
WINDROW	0.50	2.88	2.63	2.00	
MEAN	1.00	2.31	2.75		1.34
LSD				1.02	

[1] H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively. [2] LSD at $P < 0.05$.

5.0 SUMMARY AND CONCLUSIONS

This study determined the effect of field weathering on seed quality and vigor of Katepwa wheat and Heartland barley. The environmental parameters having the greatest effect on seed quality and vigor were identified. In addition, two harvest systems were compared to determine if the effects of field weathering could be reduced by crop management.

The physical seed properties found to be affected by field weathering were bulk density and kernel density for both wheat and barley. As well, kernel hardness of wheat was reduced by weathering. These findings compare favorably with those of Swanson (1941), Milner and Shellenberger (1953), Pushman (1975) and Czarnecki and Evans (1986). It was determined that actual water vapor pressure within the windrow had the greatest influence on bulk density and kernel density in wheat, while water vapor pressure deficit was found to have the largest influence on kernel hardness in wheat. Previous studies have only monitored precipitation during the exposure period (Swanson, 1941; Czarnecki and Evans, 1986), assuming that this parameter is the most harmful to grain quality. The main problem with using total daily precipitation as a measure of moisture regime is that intensity or duration of rainfall is not known. These variables may influence the relative effect of rainfall on seed quality and vigor. The results of the

present study show that atmospheric moisture accounted for the largest influence on the physical seed characteristics for wheat. This finding underscores the importance of minimizing exposure to weathering, regardless of the presence or absence of precipitation.

Grain grades, as determined by the inspection division of the Canadian Grain Commission were not a good indicator of seed vigor. For example, large differences were recorded in terms of the physical, microbial and physiological characteristics for barley. However, the official grades for all treatments was 1 CW. Furthermore, the official grades assigned to the 1989 wheat indicated a large range in quality (ie., 1 CW to CW FEED). However, very few differences were observed between these treatments in terms of seed vigor. Slight, moderate and severely weathered wheat seed in 1990 were all classified as 3 CW. However, significant differences were recorded between these treatments in terms of cold germination, 10 days after planting. Therefore, based on this study, the use of official grain grade as a criteria to determine seed quality or vigor is not recommended.

Of the six fungal genera monitored, *Fusarium* spp. were the only ones to consistently respond to field weathering. In all cases, greater levels of infection were recorded on seed exposed to increased periods of weathering. Again, the actual water vapor pressure was the environmental parameter

demonstrating the greatest influence on *Fusarium* spp. infection for barley (i.e., $R^2 = 0.90$).

Of the eight species of *Fusarium* isolated, F. sporotrichioides and F. poae were the most abundant. The literature identifies F. sporotrichioides as a mycotoxin producer, while F. poae is identified as being an early invader in the Fusarium Head Blight complex (Duthie et al., 1986). However, further research is warranted in determining the specific effect of *Fusarium* spp. on seed vigor.

Protein concentration was not affected by field weathering. However, the wheat produced in 1990 had a much lower protein concentration than the wheat produced in 1989. Vigor test results in terms of cold germination, indicated that weathering did not reduce vigor for the high protein seed of 1989. However, there were significant differences in vigor between weathered treatments for the low protein seed of 1990. High protein seed is reported to be more vigorous than low protein seed (McDaniel, 1969; Ries and Everson, 1973; and Evans and Bhatt, 1977), and based on the results of the present study, it appears low protein seed, particularly wheat, may be more susceptible to weather-induced vigor loss. Therefore, it is recommended that this hypothesis be tested further, as the evidence in this study is not conclusive.

Greater levels of alpha-amylase activity were observed in seedlots which were exposed to weathering. Precipitation

was the environmental parameter having the greatest effect on alpha-amylase in barley.

It appeared that the physical strength of the seed coat in weathered wheat may have been lower than in unweathered seed. This factor, combined with greater levels of alpha-amylase within weathered seed, may explain why weathered wheat had a higher standard germination than unweathered seed. Weathered barley, however, displayed lower standard germination than unweathered barley, despite the fact that alpha-amylase activity was significantly greater within the weathered seed. The explanation for this finding may be based on mechanical resistance to germination. The hulls of barley appear to pose great resistance to germination, making germination very stressful. Hence, the effects of weathering are more clearly expressed. This hypothesis has important implications for malt barley breeders, since the main objective of malt barley is to have very high germination. Cultivars with little mechanical resistance to germination may respond more strongly to elevated seed alpha-amylase activity.

By use of the cold germination test it was found that field weathering caused significant reduction in seed vigor for Heartland barley during both years of the study, and for Katepwa wheat in one of the two years. Therefore, the results of this study indicate that barley may be more sensitive to field weathering than wheat. However, field performance of the treatments should be conducted to

determine the exact implications of planting such weathered seed. This in fact is being done by Mr. Harry Ngoma as part of his M.Sc. research project. Results of this study and Mr. Ngoma's study can then be compared, to determine the effectiveness of the cold germination test in terms of predicting field performance.

Experiment 2 demonstrated that there is potential to reduce the effects of field weathering on seed quality and vigor by allowing the crop to remain standing during periods of inclement weather rather than having it lay in windrows. For example, in 1989, wheat and barley seed which was weathered in a standing position was significantly more vigorous than seed which was weathered in windrows. However, in 1990 there was no difference in vigor between these two treatments for either crop. The weather conditions were much more severe in 1989 compare to 1990, and therefore, the effectiveness of this management practise in reducing weather-induced seed quality loss will likely depend on the severity of weather conditions during the exposure period.

The reason for less weathering damage to standing crop compared to windrowed crop was attributed to greater drying rates, particularly after periods of precipitation. The results of this study indicated that, in 1990, the water vapor pressure deficit was much greater in standing crop of wheat and barley compared to windrowed crop. As well, this was reflected in the results of the falling number test.

For both years and both crops, significantly lower falling numbers were observed for the crop which was weathered in windrows.

Fusarium spp. infection was lower on seed from standing wheat compared to windrowed wheat, probably because of proximity to innoculum source. No differences were observed for barley. Minor differences were observed between treatments in terms of the physical seed characteristics, and generally the results favored the standing treatment.

Therefore, these results illustrate a potential benefit in allowing crop to remain standing during unfavorable harvest weather. However, one possible deterrent to this practise may be increased harvest losses for standing barley crop compared to windrowed barley (Clarke, 1989). Hence, all factors should be considered by a producer in order to obtain maximum potential benefits.

LITERATURE CITED

American Association of Cereal Chemists. 1983. Approved Methods of the American Association of Cereal Chemists, Volume I. 3340 Pilot Knob Road, St. Paul, Minnesota. 55121 USA.

Anonymous. 1986. Field crop production recommendations for Manitoba. Manitoba Agriculture, 908 Norquay Building, Winnipeg, Man.

---------- 1988a. Field crop production guide for Manitoba 1988-90. Manitoba Agriculture, 908 Norquay Building, Winnipeg, Man.

---------- 1988b. Regulations and procedures for pedigreed crop production. Canadian Seed Growers' Association. Circular 6.

---------- 1989a. Field crop variety recommendations for Manitoba. Manitoba Agriculture, 908 Norquay Building., Winnipeg, Man.

---------- 1989b. Guide to chemical weed control (1989). Manitoba Agriculture, 908 Norquay Building., Winnipeg, Man.

Ashraf, C. M. and Abu-Shakra, S. 1978. Wheat seed germination under low temperature and moisture stress. Agron. J. 70:135-139.

Association of Official Seed Analysts. 1981. Rules For Testing Seeds. Jounal of Seed Tech. Vol. 6, No. 2.

Association of Official Seed Analysts. 1983. Seed Vigor Testing Handbook. Contrubution No. 32.

Austenson, H. M. and Walton, P. D. 1970. Relationships between initial seed weight and mature plant characteristics in spring wheat. Can. J. Plant Sci. 50:53-58.

Baker, R. J. and Dyck, P. L. 1975. Relation of several quality characteristics to hardness in two spring wheat crosses. Can. J. Plant Sci. 55:625-627.

Bauer, A. and Black, A. L. 1983. Rain-Induced harvest lossed in swathed and standing wheat. North Dakota Res. Rep. No. 97.

Bauer, A. and Black, A. L. 1989. Effect of windrowing spring wheat at different stages of maturity on agronomic characteristics. Agri. Expt. Sta. Bulletin 522. NDSU, Fargo, ND 58105.

Boyd, W. J. R., Gordon, A. G. and LaCroix, L. J. 1971. Seed size, germination resistance and seedling vigor in barley. Can. J. Plant Sci. 51:93-99.

Bracken, S. F. and Bailey, C. H. 1928. Effect of delayed harvesting on quality of wheat. Cereal Chem. 5:128-145.

Bremner, P. M., Eckersall, R. N. and Scott, R. K. 1963. The relative importance of embryo size and endosperm size in causing the effects associated with seed size in wheat. J. Agric. Sci. 61:139-145.

Bulisani, E. A. and Warner, R. L. 1980. Seed protein and nitrogen effects upon seedling vigor in wheat. Agron. J. 72:657-662.

Burgess, L. W. and Liddell, C. M. 1983. Laboratory manual for Fusarium Research. Fusarium Research Laboratory, Dept. of Plant Pathol. and Agricultural Entomology, Univ. of Sydney, 162 pp.

Burris, J. S. and Navratil, R. J. 1979. Relationship between laboratory cold-test methods and field emergence in maize inbreds. Agron. J. 71:985-988.

Bushuk, W. and Hlynka, I. 1960. Weight and volume changes in wheat during sorption and desorption of moisture. Cereal Chem. 37:390-398.

Ceccarelli, S. and Pegiati, M. T. 1980. Effect of seed weight on coleoptile dimensions in barley. Can. J. Plant Sci. 60:221-225.

Chin, H. F. and Aitkens, Y. 1976. Effect of seed damage on growth and development in pea, *Pisum sativum*, and wheat, *Tritcum aestivum*. Ann. Bot. 40:91-98.

Christensen, C. M. and Kaufmann, H. H. 1969. Grain storage: the role of fungi in quality loss. University of Minnesota Press, Minneapolis.

Christiansen, M. N. 1963. Influence of chilling upon seedling development of cotton. Plant Physiol. 38:520-522.

Clarke, B.E. 1953. Relationship between certain laboratory tests and the field germination of sweet corn. Proc. Assoc. Off. Seed Anal. 1953:42-44.

Clarke, J. M. 1982. Effect of awns on drying rate of windrowed and standing wheat. Can. J. Plant Sci. 62:1-4.

---------- 1984. Drying rates of standing compared to windrowed wheat. Agron. J. 76:803-806.

---------- 1989. Drying rate and harvest losses of windrowed versus direct combined barley. Can. J. Plant Sci. 69:713-720.

Clarke, J. M., Christensen, J. V. and De Pauw, R. M. 1984. Effect on falling numbers of standing and windrowed wheat. Can. J. Plant Sci. 64:457-463.

Clear, R. M. 1987. The frequency and distribution of the fungi associated with western hard red spring wheat seed degraded due to mildew. M. Sc. thesis. Dept. of Botany, Univ. of Man., Winnipeg.

Crosier, W. F. 1957. Fungi involved and methods of conducting cold tests. Proc. Assoc. Off. Seed Anal. 47:185-190.

Crowe, J. H., Crowe, L. M., Hoekstra, F. A. and Wistrom, C. A. 1989. Effects of water on the stability of Phospholipid Bilayers: The problem of imbibition damage in dry organisms. pp.1-14. In: Seed Moisture. CSSA Special Publication Number 14.

Czarnecki, E. M. 1980. Effect of weathering during delayed harvest on test weight and other grading and quality factors of wheat (*Triticum aestivum* L.). M. Sc. thesis, Dept. of Plant Sci., Univ. of Man., Winnipeg.

Czarnecki, E. and Evans, L. E. 1986. Effect of weathering during delayed harvest on test weight, seed size, and grain hardness of wheat. Can. J. Plant Sci. 66:473-382.

Das Gupta, P. R. and Austenson, H. M. 1973. Analysis of interelationships among seedling vigor, field emergence, and yield in wheat. Agron. J. 65:417-422.

De La Roche, I. A. and Fowler, D. B. 1975. Wheat quality evaluation. 1. Accuracy and precision of prediction tests. Can. J. Plant Sci. 55:241-249.

Delouche, J. C. and Caldwell, W. P. 1960. Seed vigor and vigor tests. Proc. Assoc. Off. Seed Anal. 50:124-129.

Dillman, A. C. 1930. Hygroscopic moisture of flaxseed and wheat and its relation to combine harvesting. J. Am. Soc. Agron. 22:51-74.

Dodds, M. E. 1957. The effect of swathing at different stages of maturity on the bushel weight of yield of wheat. Can. J. Plant Sci. 37:149-156.

---------- 1967. Wheat harvesting-machines and methods. In: K. F. Nielsen (ed.), Proc. Canadian Centennial Wheat Symp., Modern Press, Saskatoon.

Dodds, M. E. and Dew, D. A. 1958. The effect of swathing at different stages of maturity upon the yield and bushel weight of barley. Can. J. Plant Sci. 38:495-504.

Dodds, M. E. and Pelton, W. L. 1967. Effects of weather factors on the kernel moisture of a standing crop of wheat. Agron. J. 59:181-184.

---------- 1969. Weather factors affecting the change of kernel moisture in windrowed wheat. Agron. J. 61:98-101.

Duthie, J. A., Hall, R. and Asselin, A. V. 1986. *Fusarium* species from seed of winter wheat in eastern Canada. Can. J. Plant Pathol. 8:282-288.

Entz, M. H., Moes, J. and Stobbe, E. H. 1991. Seed vigor of Katepwa wheat: Interaction of kernel water content and threshing cylinder speed. Can. J. Plant Sci. In press.

Evans, L. E. and Bhatt, G. M. 1977. Influence of seed size, protein content and cultivar on early seedling vigor in wheat. Can. J. Plant Sci. 57:929-935.

Feather, J. T., Ruckerman, J. E. and Schaller, C. W. 1968. Effects of swathing barley on rate of drying, yield, seed quality. Calif. Agric. 1968, 22, No. 3. pp. 12-24.

Flannigan, B. 1969. Microflora of dried barley grain. Trans. Br. Mycol. Soc. 53:371-379.

Frey, K. J. and Wiggins, S. C. 1956. Growth rates of oats from different test weight seed lots. Agron. J. 48:521-523.

Haikara, A. 1983. Malt and beer from barley artificially contaminated with *Fusarium* in the field. European Brewery Convention, 19th International Congress-London, June 5-10, 1983. in J. Inst. Brew. 89:140.

Halloin, J. M. 1986. Microorganisms and seed deterioration. pp. 89-99. In: Physiology of Seed Deterioration. CSSA Spec. Pub. No. 11.

Hlynka, I. and Bushuk, W. 1959. The weight per bushel. Cereal Sci. Today 4:239-240.

Hoy, D. J. and Gamble, E. E. 1985. The effect of seed size and seed density on germination and vigor in soybean (*Glycine max* (L.) Merr.). Can. J. Plant Sci. 65:1-8.

---------- 1987. Field performance in soybean with seeds of differing size and density. Crop Sci. 27:121-126.

Johnson, W. H. 1959. Efficiency in combining wheat. Agr. Eng. 40:16-29.

Johnson, R. R. and Wax, L. M. 1978. Relationship of soybean germination and vigor tests to field performance. Agron. J. 70:273-278.

Katz, R., Collins, N. D. and Cardwell, A. B. 1961. Hardness and moisture content of wheat kernels. Cereal Chem. 38:364-368.

Kaufmann, M. L. and McFadden, A. D. 1963. The influence of seed size on results of barley yield trials. Can. J. Plant Sci. 43:51-58.

Kosmolak, F. G. 1978. Grinding time-A screening test for kernel hardness in wheat. Can. J. Plant Sci. 58:415-420.

Krieg, D. R. and Bartee, S. N. 1975. Cottonseed density: Associated germination and seedling emergence properties. Agron. J. 67:343-347.

Kruger, J. E. 1972. Changes in the amylase of hard red spring wheat during growth and maturation. Cereal Chem. 49:379.

Lafond, G. P. and Baker, R. J. 1986a. Effects of genotype and seed size on speed of emergence and seedling vigor in nine spring wheat cultivars. Crop Sci. 26:341-346.

---------- 1986b. Effects of temperature, moisture stress, and seed size on germination of nine spring wheat cultivars. Crop Sci. 26:563-567.

Lowe, L. B. and Ries, S. K. 1972. Effects of environment on the relation between seed protein and seedling vigor in wheat. Can. J. Plant Sci. 52:157-164.

Lush, W. M., Groves, R. H. and Kaye, P. E. 1981. Presowing hydration-dehydration treatments in relation to seed germination and early seedling growth of wheat and ryegrass. Aust. J. Plant Physiol. 8:409-425.

Machacek, J. E., Cherewick, W. J., Mead, H. W. and Broadfoot, W. C. 1951. A study of some seed-borne diseases of cereals in Canada. II. Kinds of fungi and prevalence of disease in cereal seed. Sci. Agric. 31:193-206.

Maranville, J. W. and Clegg, M. D. 1977. Influence of seed size and density on germination, seedling emergence, and yield of grain sorghum. Agron. J. 69:329-330.

Martens, J. W., Seaman, W. L. and Atkinson, T. G. 1984. Diseases of Field Crops in Canada. Can. Phytopath. Soc., 160 pp.

Martin, R. A. and Johnston, H. W. 1982. Effects and control of fusarium diseases of cereal grains in the Atlantic Provinces. Can. J. Plant Pathol. 4:210-216.

Martin, B.A., Smith, O. S. and O'Neil, M. 1988. Relationships between laboratory germination tests and field emergence of maize inbreds. Crop Sci. 28:801-804.

Mathewson, P. R. and Pomeranz, Y. 1978. On the relationship between alpha amylase and falling number in wheat. J. Food Sci. 43:652-653.

McCaig, T. N. and DePauw, R. M. 1983. Falling numbers and alpha-amylase in sawfly-resistant wheat. pp. 79-85. In: J. E. Kruger and D. E. LaBerge (eds), Third Int. Symp. on Pre-Harvest Sprouting in Cereals. Westview Press, Boulder Colorado.

McDaniel, R. G. 1969. Relationships of seed weight, seedling vigor, and mitochondrial metabolism in barley. Crop Sci. 9:823-827.

McDonald, M. B. and Copeland, L. O., Edits. Principles of Seed Science and Technology. 1985. Burgess Pub. Co., Minneapolis, Minnesota..

McNeal, F. H. and Berg, M. A. 1960. The evaluation of spring wheat seed from different sources. Agron. J. 52:303-304.

Mead, H. W. 1942. Environmental relationships in a seed-borne disease of barley caused by Helminthosporium sativum Pammel, King, and Bakke. Can. J. Res. C20:525-538.

Milner, M. and Shellenberger, J. A. 1953. Physical properties of weathered wheat in relation to internal fissuring detected radiographically. Cereal Chem. 30:202-212.

Mondragon, R. L. and Potts, H. C. 1974. Field deterioration of soybeans as affected by environment. Proc. Assoc. Official Seed Ana. 64:63-71.

Morrison, I. N., Nawolsky, K. M., Entz, M. H. and Smith, A.E. 1991. Differential response of wheat seedlots to trifluralin. Agron. J. 83:119-123.

Moss, H. J., Derera, N. F. and Balaam, L. N. 1972. Effect of pre-harvest rain on germination in the ear and alpha-amylase activity of Australian wheat. Aust. J. Agric. Res. 23:769-777.

Muir, W. E. and Sinha, R. N. 1988. Physical properties of cereal and oilseed cultivars grown in western Canada. Can. Agr. Eng. 30:51-55.

Peterson, C. M., Klepper, B. and Rickman, R. W. 1989. Seed reserves and seedling development in winter wheat. Agron. J. 81:245-251.

Pixton, S. W. and Warburton, S. 1968. The time required for conditioning grain to equilibrium with specific relative humidities. J. Stored Prod. Res. 4:261-265.

Pool, M., Patterson, F. L. and Bode, C. E. 1958. Effect of delayed harvest on quality of soft red winter wheat. Agron. J. 50:271-275.

Pushman, F. M. 1975. The effects of alteration of grain moisture content by wetting or drying on the test weight of of four winter wheats. J. Agric. Sci. 84:187-190.

Read, D. W. L. and Beaton, J. D. 1963. Effect of fertilizer, temperature, and moisture on germination of wheat. Agron. J. 51:287-290.

Ries, S. K., Ayers, G., Wert, V. and Everson, E. H. 1976. Variation in protein, size and seedling vigor with position of seed in heads of winter wheat cultivars. Can. J. Plant Sci. 56:823-827.

Ries, S. K. and Everson, E. H. 1973. Protein content and seed size relationships with seedling vigor of wheat cultivars. Agron. J. 65:884-886.

Roberts, H. F. 1910. Breeding for type of kernel in wheat and its relation to the grading and milling of the grain. Kansas Agr. Exp. Sta. Bull. No. 170:99-138.

Robertson, I. M. 1956. Swath harvesting: The process of drying. J. Agr. Eng. Res. 1:125-131.

SAS Institute. 1985. SAS User's Guide: Statistics. SAS Institute, Cary NC.

Schweizer, C. J. and Ries, S. K. 1969. Protein content of seed: Increase improves growth and yield. Science 165:73-75.

Scott, J. H. 1951. The bushel weight of wheat. pp. 182-204. In: J. H. Scott (ed), Flour Milling Processes, 2nd ed. Chapman and Hall. London.

Simon, E. W. and Raja Harun, R. M. 1972. Leakage during seed imbibition. J. Exp. Bot. 23:1076-1085.

Sharpe, P. F. 1927. Wheat and Flour Studies, IX Density of wheat as influenced by freezing, stage of development, and moisture content. Cereal Chem. 4:14-46.

Sonntag, C. W., 1989. Evaluation of differential performance of pedigreed seedlots of Harrington barley and Katepwa wheat from western Canada. M.Sc. Thesis, Dept. of Crop Science and Plant Ecology. University of Saskatchewan, Saskatoon.

Sonntag, C. W., Rossnagel, B. G. and Baker, R. J. 1988. Factors affecting performance of different pedigreed seedlots of Harrington barley and Katepwa wheat. pp. 212-216. In: Proceedings of Soils and Crops workshop, Saskatoon Sask.

Spilde, L. A. 1989. Influence of seed size and test weight on several agronomic traits of barley and hard red spring wheat. J. Prod. Agric. 2:169-172.

Sturz, A. V. and Johnston, H. W. 1983. Early colonization of the ears fo wheat and barley by *Fusarium poae*. Can. J. Plant Pathol. 5:107-110.

---------- 1985. Characterization of *Fusarium* colonization of spring barley and wheat produced on stubble or fallow soil. Can. J. Plant Pathol. 7:270-276.

Sutton, J. C. 1982. Epidemiology of wheat head blight and maize ear rot caused by *Fusarium graminearum*. Can. J. Plant Pathol. 4:195-209.

Swanson, C. O. 1941. Effects of moisture on the physical and other properties of wheat. Cereal Chem. 18:705-729.

----------1943. Effects of moisture on the physical and other properties of wheat. III. Degree, duration, and number of wetting treatments. Cereal Chem. 20:286-299.

Tekrony, D. M. and Egli, D. B. 1977 Relationship between laboratory indices of soybean seed vigor and field emergence. Crop Sci. 17:573-577.

Tekrony, D. M., Egli, D. B. and Phillips, A. D. 1980. Effect of field weathering on the viability and vigor of soybean seed. Agronomy J. 72:749-753.

Thomas, L. M. 1917. A comparison of several classes of American wheat and a consideration of some factors influencing quality. U.S.D.A. Bull. No. 557.

Tkachuck, R. and Kuzina, F. D. 1979. Wheat: Relations between some physical and chemical properties. Can. J. Plant Sci. 59:15-20.

Trenholm, H. L., Cochrane, W. P., Cohen, H., Elliot, J. I., Farnworth, E. R., Friend, D. W., Hamilton, R. M. G., Neish, G. A. and Standish, J. F. 1981. Survey of vomitoxin contamination of the 1980 white winter wheat crop in Ontario, Canada. J. Assoc. Off. Anal. Chem. 58:992A-994A.

Tuite, J. F. and Christensen, C. M. 1955. Grain Storage Studies XVI. Influence of storage conditions upon the fungus flora of barley seed. Cereal Chem. 32:1-11.

Versavel, P. A. and Muir, W. E. 1988a. Moisture absorption by wheat spikes. Am. Soc. of Agric. Eng. 31(4):1255-1259.

---------- 1988b. Drying of rewetted wheat spikes. Can. Agric. Eng. 30:57-60.

Welch, R. W. 1977. Seedling vigor and grain yield of cereals grown from seeds of varying protein contents. J. Agric. Sci. 88:119-125.

Whitcomb, W. O. and Johnson, A. H. 1928. Effect of severe weathering on certain properties of wheat. Cereal Chem. 5:117-128.

Whitcomb, W. O. and Johnson, A. H. 1930. Effect of severe weathering on the protein and ash contents of wheat and flour. Cereal Chem. 7:162-168.

Williams, P. C. and Sobering, D. C. 1986. Attempts at standardization of hardness testing of wheat. II. The near-infrared reflectance method. Cereal Foods World. Vol. 31, No. 6:417-420.

6.0 APPENDIX

TABLE A1. SEED MOISTURE CONTENT (%) AT THRESHING FOR WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

	WHEAT		BARLEY	
TREATMENT	1989	1990	1989	1990
1	19.61	12.83	11.52	13.57
2	12.41	11.50	10.47	13.24
3	17.66	12.91	13.17	13.57
4	15.32	12.02	24.90	11.99

TABLE A2. AVERAGE DAILY ENVIRONMENTAL PARAMETER VALUES DURING WEATHERING PERIOD FOR BARLEY IN 1989.

DATE	TEMP (°C)	Eact (kPa)	Edef (kPa)	SOLAR RAD (MJ/m²)	PRECIP[1] (mm) S	N	T
AUG 2	10.07	0.83	-0.48	9.87	0	4	4
" 3	20.13	1.66	-0.96	15.10	0	6	6
" 4	22.34	1.91	-1.01	23.28	0	0	0
" 5	15.31	1.59	-0.16	6.46	0	1	1
" 6	18.79	1.30	-1.35	25.08	0	0	0
" 7[2]	21.84	1.40	-1.73	25.64	0	0	0
" 8	22.38	1.43	-1.92	24.07	0	0	0
" 9	23.70	1.36	-2.41	25.02	10	0	10
" 10	23.83	1.73	-1.81	23.95	0	0	0
" 11	23.89	1.83	-1.61	20.07	10	0	10
" 12	24.29	2.17	-1.29	21.49	0	0	0
" 13	17.16	1.82	-0.14	3.58	0	0	0
" 14	17.35	1.45	-0.65	19.84	10	0	10
" 15	16.76	1.40	-1.01	24.34	0	0	0
" 16[3]	18.95	1.21	-1.71	23.39	0	0	0
" 17	19.64	1.68	-0.75	9.07	0	0	0
" 18	21.26	2.34	-0.23	10.80	0	27	27
" 19	17.52	1.90	-0.12	9.32	0	8	8
" 20	12.58	1.47	-0.01	5.45	0	9	9
" 21	13.85	1.61	-0.04	7.68	0	0	0
" 22	10.92	1.24	-0.16	13.59	0	0	0

[1] S = simulated precipitation, N = natural precipitation, T = total daily precipitation
[2] Treatment 2 was threshed, [3] Treatment 3 was threshed

TABLE A3. AVERAGE DAILY ENVIRONMENTAL PARAMETER VALUES DURING WEATHERING PERIOD FOR WHEAT IN 1989.

DATE	TEMP (°C)	Eact (kPa)	Edef (kPa)	SOLAR RAD (MJ/m²)	PRECIP[1] (mm) S	N	T
AUG 11	9.79	0.58	-0.83	8.92	0	0	0
" 12	25.36	1.75	-1.91	21.49	0	0	0
" 13	17.38	1.79	-0.20	3.58	0	0	0
" 14	19.05	1.33	-1.04	19.84	0	0	0
" 15	17.09	1.26	-1.08	24.34	10	0	10
" 16	18.51	1.14	-1.55	23.39	0	0	0
" 17[2]	19.91	1.62	-0.83	9.07	0	0	0
" 18	20.74	2.17	-0.31	10.80	0	27	27
" 19	17.18	1.85	-0.13	9.32	0	8	8
" 20	11.79	1.39	-0.02	5.45	0	9	9
" 21	13.56	1.52	-0.09	7.68	0	0	0
" 22	20.52	1.83	-0.91	20.38	0	0	0
" 23[3]	23.83	2.09	-1.11	20.84	0	0	0
" 24	24.45	2.22	-0.99	17.75	0	0	0
" 25	23.95	2.36	-0.71	14.42	0	0	0
" 26	20.56	1.62	-0.88	19.84	0	0	0
" 27	18.93	1.31	-1.07	16.69	0	0	0
" 28	16.39	1.63	-0.24	8.38	10	5	15
" 29	13.35	1.43	-0.12	6.69	0	5	5
" 30	12.54	1.23	-0.34	12.92	0	0	0
" 31	11.43	1.06	-0.30	11.00	0	0	0

[1] S = simulated precipitation, N = natural precipitation, T = total daily precipitation
[2] Treatment 2 was threshed, [3] Treatment 3 was threshed.

TABLE A4. AVERAGE DAILY ENVIRONMENTAL PARAMETER VALUES DURING WEATHERING PERIOD FOR BARLEY IN 1990.

DATE	TEMP (°C)	Eact (kPa)	Edef (kPa)	SOLAR RAD (MJ/m²)	PRECIP[1] (mm) S	N	T
AUG 18	7.90	0.48	-0.45	3.77	0	0	0
" 19	19.05	1.31	-1.04	19.20	0	0	0
" 20	21.09	1.34	-1.51	20.10	0	0	0
" 21	23.88	1.65	-1.78	22.26	0	0	0
" 22	25.40	2.13	-1.37	18.20	0	0	0
" 23	25.80	2.46	-1.03	21.68	0	9	9
" 24[2]	24.70	1.97	-1.57	19.38	0	1	1
" 25	20.08	2.18	-0.18	9.61	0	2	2
" 26	19.46	1.81	-0.52	12.04	0	0	0
" 27	21.19	1.83	-0.85	19.10	0	1	1
" 28	19.09	1.32	-1.16	17.03	0	0	0
" 29	23.30	1.15	-2.18	20.85	0	0	0
" 30	24.67	1.33	-2.34	20.48	0	0	0
" 31	20.88	1.81	-0.74	20.09	20	2	22
SEPT 1	16.30	1.59	-0.32	13.79	0	0	0
" 2	20.03	1.45	-1.25	16.82	0	0	0
" 3[3]	26.74	2.09	-1.64	15.19	0	0	0
" 4	21.41	1.22	-1.60	18.90	0	0	0
" 5	21.69	1.49	-1.49	14.80	0	0	0
" 6	20.78	1.69	-0.90	17.45	0	0	0
" 7	18.38	1.30	-1.20	19.20	20	0	20
" 8	18.24	1.56	-0.61	18.17	0	0	0
" 9	14.17	1.25	-0.47	10.41	0	0	0
" 10	15.91	0.97	-1.16	16.21	0	0	0
" 11	23.43	1.39	-1.77	17.66	0	0	0
" 12	15.47	1.22	-0.66	12.39	0	0	0
" 13	14.65	1.43	-0.25	5.51	20	0	20
" 14	14.49	1.31	-0.49	13.93	0	0	0
" 15	13.22	1.20	-0.34	9.18	0	0	0
" 16	10.83	0.89	-0.61	16.70	0	0	0
" 17	12.64	1.09	-0.47	7.84	0	5	5
" 18	16.00	1.30	-0.60	17.48	0	2	2
" 19	14.44	0.83	-1.07	17.11	0	0	0
" 20	11.27	1.29	-0.08	4.47	20	5	25
" 21	8.25	1.06	-0.04	5.10	0	1	1
" 22	7.37	0.86	-0.20	13.24	0	1	1
" 23	11.25	0.86	-0.76	14.94	0	0	0
" 24	18.77	0.91	-1.54	15.71	0	0	0
" 25	11.02	0.71	-0.67	10.22	0	0	0

[1] S = simulated precipitation, N = natural precipitation, T = total daily precipitation
[2] Treatment 2 was threshed, [3] Treatment 3 was threshed.

TABLE A5. AVERAGE DAILY ENVIRONMENTAL PARAMETER VALUES DURING WEATHERING PERIOD FOR WHEAT IN 1990.

DATE	TEMP. (°C)	Eact (kPa)	Esat (kPa)	SOLAR RAD (MJ/m²)	PRECIP[1] (mm) S	N	T
AUG 16	12.91	0.72	-0.98	10.45	0	0	0
" 17	17.25	1.12	-0.94	22.30	0	0	0
" 18	17.31	1.16	-0.87	9.04	0	0	0
" 19	19.70	1.19	-1.25	19.20	0	0	0
" 20	21.02	1.26	-1.57	20.10	0	0	0
" 21	22.84	1.62	-1.59	22.26	0	0	0
" 22	23.18	2.29	-0.72	18.20	15	0	15
" 23	24.12	2.37	-0.73	21.68	0	9	9
" 24[2]	23.65	1.95	-1.30	19.38	0	1	1
" 25	19.70	2.12	-0.18	9.61	0	2	2
" 26	18.83	1.79	-0.43	12.04	0	0	0
" 27	19.93	1.75	-0.68	19.10	0	1	1
" 28	18.19	1.28	-1.01	17.03	0	0	0
" 29	21.86	1.09	-1.86	20.85	0	0	0
" 30	23.43	1.33	-2.05	20.48	0	0	0
" 31	19.43	1.70	-0.59	20.09	20	2	22
SEPT 1	16.06	1.50	-0.37	13.79	0	0	0
" 2	19.45	1.37	-1.26	16.82	0	0	0
" 3[3]	25.73	2.10	-1.36	15.19	0	0	0
" 4	19.45	1.20	-1.23	18.90	0	0	0
" 5	20.33	1.45	-1.29	14.80	0	0	0
" 6	19.17	1.69	-0.60	17.45	0	0	0
" 7	16.04	1.27	-0.86	19.20	20	0	20
" 8	16.99	1.48	-0.50	18.17	0	0	0
" 9	13.15	1.12	-0.45	10.41	0	0	0
" 10	15.42	0.88	-1.12	16.21	0	0	0
" 11	22.12	1.38	-1.42	17.66	0	0	0
" 12	14.64	1.21	-0.54	12.39	0	0	0
" 13	14.36	1.45	-0.20	5.51	20	0	20
" 14	13.43	1.24	-0.40	13.93	0	0	0
" 15	12.94	1.17	-0.34	9.18	0	0	0
" 16	8.65	0.80	-0.49	16.70	0	0	0
" 17	12.45	1.06	-0.47	7.84	0	5	5
" 18	14.12	1.27	-0.38	17.84	0	2	2
" 19	12.48	0.86	-0.72	17.11	0	0	0
" 20	11.04	1.27	-0.08	4.47	20	5	25
" 21	8.13	1.03	-0.05	5.10	0	1	1
" 22	6.90	0.82	-0.19	13.24	0	1	1
" 23	11.33	0.76	-0.72	14.94	0	0	0
" 24	17.62	0.88	-1.28	15.71	0	0	0
" 25	10.22	0.73	-0.69	10.22	0	0	0

[1] S = simulated precipitation, N = natural precipitation, T = total daily precipitation.
[2] Treatment 2 was threshed, [3] Treatment 3 was threshed.

TABLE A6. COLD GERMINATION (%) OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

WEATHERING TREATMENT	DAYS AFTER PLANTING									
	2	4	6	8	10	12	14	16	18	ABN
1	0.0a*	0.0a	29.2ab	49.5a	67.7ab	87.7a	92.7a	93.5a	93.5ab	0.5a
2	0.0a	0.2a	20.7b	40.5ab	68.7ab	84.7ab	92.7a	96.0a	96.0a	1.2a
3	3.5b	6.0b	26.7ab	38.7b	61.2b	79.7c	87.0b	89.0b	89.5b	5.2b
4	7.5c	11.7c	32.2a	51.0a	71.0a	83.5b	91.5ab	94.2a	94.2a	1.5a
LSD(0.05)	2.4	2.8	11.1	10.5	8.6	3.2	4.6	3.1	4.1	2.1
C.V.	55.55	39.2	25.6	14.7	8.0	2.4	3.1	2.1	1.9	63.2

* means in a column followed by a different letter are significantly different at P < 0.05.

TABLE A7. COLD GERMINATION (%) OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

WEATHERING TREATMENT	DAYS AFTER PLANTING								
	2	4	6	8	10	12	14	16	18
1	0.0a	3.5a	63.2a	84.0a	91.5a	93.0a	95.0a	95.5a	96.5a
2	0.0a	7.2a	55.7ab	76.2ab	87.7a	92.0a	93.2a	93.7a	94.7a
3	1.2ab	19.5b	53.7bc	75.5ab	86.2a	89.5a	93.7a	95.5a	96.7a
4	2.00b	23.0b	47.2c	65.5b	75.2b	79.7b	83.2b	84.5b	85.2b
LSD(0.05)	1.6	3.7	8.1	11.3	6.0	4.6	3.9	3.8	4.6
C.V.	123.5	17.6	9.2	9.4	4.4	3.2	2.7	2.5	3.1

* means in a column followed by a different letter are significantly different at P < 0.05.

TABLE A8. COLD GERMINATION (%) OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1990.

WEATHERING TREATMENT	DAYS AFTER PLANTING									
	2	4	6	8	10	12	14	16	18	ABN
1	0.0	0.0a	17.6ab	48.8a	77.3a	90.7a	94.6a	96.0a	96.5a	0.8a
2	0.0	0.1a	18.7a	46.6a	71.8b	86.3b	92.2a	94.7a	95.5a	1.0a
3	0.0	0.2a	14.0b	45.8a	71.7b	90.2a	93.8a	95.1a	96.1a	1.0a
4	0.0	1.1b	17.8ab	33.2b	47.0c	62.2c	69.7b	74.8b	78.6b	4.3b
LSD(0.05)	-	0.6	4.1	4.1	4.6	3.7	2.9	3.7	3.0	1.5
C.V.	-	113.3	15.3	6.0	4.3	2.8	2.0	2.5	2.0	53.0

* means in a column followed by a different letter are significantly different at P < 0.05.

TABLE A9. COLD GERMINATION (%) OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1990.

WEATHERING TREATMENT	DAYS AFTER PLANTING 2	4	6	8	10	12	14	16	18
1	0.0a	12.2a	74.2a	93.5a	97.2a	97.8a	98.3a	98.3a	98.5a
2	0.0a	13.3a	65.7b	88.6ab	95.0a	97.3a	98.2a	98.7a	98.8a
3	0.0a	19.1b	65.6b	86.7bc	95.0a	96.2ab	97.2a	97.6a	97.6a
4	1.1b	27.5c	60.0b	82.2c	91.5b	94.8b	96.5a	97.0a	97.1a
LSD(0.05)	0.5	2.8	5.8	5.2	2.9	2.2	2.2	2.0	1.9
C.V.	111.8	9.7	5.5	3.7	1.9	1.4	1.4	1.2	1.2

+ means in a column followed by a different letter are significantly different at P < 0.05.

TABLE A10. SEED MOISTURE (%) AT THRESHING FOR WHEAT AND BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989 AND 1990.

	1989		1990					
			WHEAT			BARLEY		
	WHEAT	BARLEY	H1+	H2	H3	H1	H2	H3
STAND	13.7	18.9	11.3	10.9	11.8	13.3	11.5	12.4
SWATH	14.4	26.3	11.4	11.2	11.8	11.9	10.9	11.9

+ H1, H2 and H3 represent harvest 1, harvest 2 and harvest 3, respectively.

TABLE A11. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION (%) OF WHEAT GROWN AT PORTAGE la PRAIRIE IN 1989.

MANAGEMENT SYSTEM	DAYS AFTER PLANTING 2	4	6	8	10	12	14	16	18	ABN
STAND	0.2a+	1.0a	32.5a	61.0a	78.5a	91.5a	96.2a	97.2a	97.2a	0.5a
WINDROW	2.7b	7.7b	25.7b	44.7b	69.5a	87.2a	90.7a	92.0b	92.0b	2.0a
LSD (0.05)	2.0	3.5	7.1	9.0	12.1	6.0	7.0	4.7	4.7	2.7
C.V.	60.8	35.8	10.9	7.5	7.3	2.9	3.3	2.2	2.2	97.9

+ means in a column followed by a different letter are significantly different at P < 0.05.

TABLE A12. EFFECT OF HARVEST MANAGEMENT SYSTEM ON COLD GERMINATION (%) OF BARLEY GROWN AT PORTAGE la PRAIRIE IN 1989.

MANAGEMENT SYSTEM	DAYS AFTER PLANTING								
	2	4	6	8	10	12	14	16	18
STAND	2.7a[+]	31.5a	69.0a	81.5a	88.7a	91.2a	92.2a	94.5a	95.5a
WINDROW	2.5a	21.5b	42.2b	56.7b	66.7b	70.5b	73.2b	74.7b	76.2b
LSD (0.05)	3.7	6.6	6.2	14.3	11.8	6.6	4.3	2.3	2.7
C.V.	63.6	11.1	5.0	9.2	6.7	3.6	2.3	1.2	1.4

[+] means in a column followed by a different letter are significantly different at $P < 0.05$.