EVALUATION OF FORAGE ESTABLISHMENT AND GROWTH

UNDER CONSERVATION TILLAGE

by

Carla Allen

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

ISBN 0-612-12950-0

Name CARLA ALLEN

Dissertation Abstracts International is arranged by broad, general subject categories. Please select the one subject which most nearly describes the content of your dissertation. Enter the corresponding four-digit code in the spaces provided.

AGRONOMY | 0285 | U·M·I

SUBJECT TERM | SUBJECT CODE

Subject Categories

THE HUMANITIES AND SOCIAL SCIENCES

COMMUNICATIONS AND THE ARTS
Architecture 0729
Art History 0377
Cinema 0900
Dance 0378
Fine Arts 0357
Information Science 0723
Journalism 0391
Library Science 0399
Mass Communications 0708
Music 0413
Speech Communication 0459
Theater 0465

EDUCATION
General 0515
Administration 0514
Adult and Continuing 0516
Agricultural 0517
Art 0273
Bilingual and Multicultural 0282
Business 0688
Community College 0275
Curriculum and Instruction 0727
Early Childhood 0518
Elementary 0524
Finance 0277
Guidance and Counseling 0519
Health 0680
Higher 0745
History of 0520
Home Economics 0278
Industrial 0521
Language and Literature 0279
Mathematics 0280
Music 0522
Philosophy of 0998
Physical 0523
Psychology 0525
Reading 0535
Religious 0527
Sciences 0714
Secondary 0533
Social Sciences 0534
Sociology of 0340
Special 0529
Teacher Training 0530
Technology 0710
Tests and Measurements 0288
Vocational 0747

LANGUAGE, LITERATURE AND LINGUISTICS
Language
General 0679
Ancient 0289
Linguistics 0290
Modern 0291
Literature
General 0401
Classical 0294
Comparative 0295
Medieval 0297
Modern 0298
African 0316
American 0591
Asian 0305
Canadian (English) 0352
Canadian (French) 0355
English 0593
Germanic 0311
Latin American 0312
Middle Eastern 0315
Romance 0313
Slavic and East European 0314

PHILOSOPHY, RELIGION AND THEOLOGY
Philosophy 0422
Religion
General 0318
Biblical Studies 0321
Clergy 0319
History of 0320
Philosophy of 0322
Theology 0469

SOCIAL SCIENCES
American Studies 0323
Anthropology
Archaeology 0324
Cultural 0326
Physical 0327
Business Administration
General 0310
Accounting 0272
Banking 0770
Management 0454
Marketing 0338
Canadian Studies 0385
Economics
General 0501
Agricultural 0503
Commerce-Business 0505
Finance 0508
History 0509
Labor 0510
Theory 0511
Folklore 0358
Geography 0366
Gerontology 0351
History
General 0578
Ancient 0579
Medieval 0581
Modern 0582
Black 0328
African 0331
Asia, Australia and Oceania 0332
Canadian 0334
European 0335
Latin American 0336
Middle Eastern 0333
United States 0337
History of Science 0585
Law 0398
Political Science
General 0615
International Law and Relations 0616
Public Administration 0617
Recreation 0814
Social Work 0452
Sociology
General 0626
Criminology and Penology 0627
Demography 0938
Ethnic and Racial Studies 0631
Individual and Family Studies 0628
Industrial and Labor Relations 0629
Public and Social Welfare 0630
Social Structure and Development 0700
Theory and Methods 0344
Transportation 0709
Urban and Regional Planning 0999
Women's Studies 0453

THE SCIENCES AND ENGINEERING

BIOLOGICAL SCIENCES
Agriculture
General 0473
Agronomy 0285
Animal Culture and Nutrition 0475
Animal Pathology 0476
Food Science and Technology 0359
Forestry and Wildlife 0478
Plant Culture 0479
Plant Pathology 0480
Plant Physiology 0817
Range Management 0777
Wood Technology 0746
Biology
General 0306
Anatomy 0287
Biostatistics 0308
Botany 0309
Cell 0379
Ecology 0329
Entomology 0353
Genetics 0369
Limnology 0793
Microbiology 0410
Molecular 0307
Neuroscience 0317
Oceanography 0416
Physiology 0433
Radiation 0821
Veterinary Science 0778
Zoology 0472
Biophysics
General 0786
Medical 0760

EARTH SCIENCES
Biogeochemistry 0425
Geochemistry 0996
Geodesy 0370
Geology 0372
Geophysics 0373
Hydrology 0388
Mineralogy 0411
Paleobotany 0345
Paleoecology 0426
Paleontology 0418
Paleozoology 0985
Palynology 0427
Physical Geography 0368
Physical Oceanography 0415

HEALTH AND ENVIRONMENTAL SCIENCES
Environmental Sciences 0768
Health Sciences
General 0566
Audiology 0300
Chemotherapy 0992
Dentistry 0567
Education 0350
Hospital Management 0769
Human Development 0758
Immunology 0982
Medicine and Surgery 0564
Mental Health 0347
Nursing 0569
Nutrition 0570
Obstetrics and Gynecology 0380
Occupational Health and Therapy 0354
Ophthalmology 0381
Pathology 0571
Pharmacology 0419
Pharmacy 0572
Physical Therapy 0382
Public Health 0573
Radiology 0574
Recreation 0575
Speech Pathology 0460
Toxicology 0383
Home Economics 0386

PHYSICAL SCIENCES
Pure Sciences
Chemistry
General 0485
Agricultural 0749
Analytical 0486
Biochemistry 0487
Inorganic 0488
Nuclear 0738
Organic 0490
Pharmaceutical 0491
Physical 0494
Polymer 0495
Radiation 0754
Mathematics 0405
Physics
General 0605
Acoustics 0986
Astronomy and Astrophysics 0606
Atmospheric Science 0608
Atomic 0748
Electronics and Electricity 0607
Elementary Particles and High Energy 0798
Fluid and Plasma 0759
Molecular 0609
Nuclear 0610
Optics 0752
Radiation 0756
Solid State 0611
Statistics 0463

Applied Sciences
Applied Mechanics 0346
Computer Science 0984

Engineering
General 0537
Aerospace 0538
Agricultural 0539
Automotive 0540
Biomedical 0541
Chemical 0542
Civil 0543
Electronics and Electrical 0544
Heat and Thermodynamics 0348
Hydraulic 0545
Industrial 0546
Marine 0547
Materials Science 0794
Mechanical 0548
Metallurgy 0743
Mining 0551
Nuclear 0552
Packaging 0549
Petroleum 0765
Sanitary and Municipal 0554
System Science 0790
Geotechnology 0428
Operations Research 0796
Plastics Technology 0795
Textile Technology 0994

PSYCHOLOGY
General 0621
Behavioral 0384
Clinical 0622
Developmental 0620
Experimental 0623
Industrial 0624
Personality 0625
Physiological 0989
Psychobiology 0349
Psychometrics 0632
Social 0451

EVALUATION OF FORAGE ESTABLISHMENT AND GROWTH

UNDER CONSERVATION TILLAGE

BY

CARLA ALLEN

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

General Abstract

Evaluation of Forage Establishment and Growth Under Conservation Tillage

Carla Allen, Department of Plant Science, University of Manitoba. Major Professor, Dr. Martin Entz.

A first study investigated the feasibility of establishing forages under zero-tillage (ZT) on arable land. One experiment, conducted under favourable post-seeding moisture and heavy crop residue conditions, compared establishment, plant development, growth, and dry matter (DM) production of alfalfa (*Medicago sativa* L.) and meadow bromegrass (*Bromus biebersteneii* Rhem and Shult.) under ZT and conventional tillage (CT) following three different annual crops. Forage crop establishment and DM production (averaged over forage species) were lower under ZT than CT when the preceding crop was wheat (*Triticum aestivum* L.), however, no significant differences were observed when the preceding crop was either field pea (*Pisum sativum* L.) or canola (*Brassica napus* L). Alfalfa emergence was unaffected by previous crop type, however, emergence of meadow bromegrass was reduced when wheat was the previous crop. Plant development of both forage species was temporarily delayed under ZT when wheat was the previous crop. No treatment effects were observed for year after establishment DM production or basal area cover.

A second experiment, conducted under conditions of post-seeding drought and average residue, assessed the impact of spring wheat straw management on establishment, development,

and DM production of alfalfa and meadow bromegrass under CT and ZT. Superior establishment of both alfalfa and meadow bromegrass under ZT was attributed to higher levels of soil water under ZT. Straw management (removal vs. returned to land) had no effect on establishment of either forage species.

A second study described agronomic and physiological responses of sod-seeded alfalfa subjected to various seed treatments in sprayed and non-sprayed timothy (*Phleum pratense* L.) and Kentucky bluegrass (*Poa pratensis* L.)/bromegrass (*Bromus inermis* Leyss.) swards. Chemical sod-suppression increased alfalfa establishment and DM production approximately ten-fold at Gladstone and three-fold at Portage la Prairie. The greater response at Gladstone was attributed to the more competitive resident vegetation. Sod-suppression did not affect year after establishment DM production at Portage la Prairie. Alfalfa seedlings growing in the non-sprayed area at Gladstone were unable to achieve the critical DM production per plant (1.1 g) in the establishment year. The relative growth rate (RGR) of alfalfa plants in the sprayed area was consistently greater than the RGR of plants in the non-sprayed area at Gladstone. However, similar RGR's between the sprayed and non-sprayed area were observed at time 2 in 1992 at Portage la Prairie. It was concluded that sod-suppression was not essential for successful establishment at Portage la Prairie but it was at Gladstone. Alfalfa plant development and height were significantly greater in the sprayed compared to the non-sprayed area. Suppressing the resident vegetation resulted in increased light penetration to the soil surface and increased soil water content.

Alfalfa emergence was significantly reduced in the 40 kg P_2O_5 ha^{-1} and insecticide treatments, however, both the 30 and 40 kg P_2O_5 ha^{-1} of significantly increased alfalfa DM at Gladstone in 1991.

Table of Contents

2.3 Literature Review (cont'd)

Acknowledgements

Upon completion of this manuscript, there are a number of people that I would like to acknowledge for their support in one form or another.

Thanks to my supervisor, Dr. Martin Entz, for his refreshing approach to life. With his encouragement and never-ending enthusiasm I learned the scientific method. Thanks also to my committee members Drs. Smith, Townsend, and Vessey for their input.

Thanks to Keith Bamford and Alvin Iverson for their technical expertise. I must thank Pam Ominski, Dean Richards, Terry Buss, and Gary Bergen for their efforts during the data collection portion of this project. Without your dedicated assistance, this project would never have flown.

Thanks to Suzanne, my fellow grad student and roommate, who I knew I could rely upon.

Thanks to my family, the best summer students anyone could ask for.

Finally, special thanks to Chris. You convinced me that I had the ability and drive to do this. I dedicate this to you.

List of Tables

List of Figures

Preface

This thesis was written in manuscript style. Each manuscript contains a separate abstract, introduction, literature review, and conclusions section. The two manuscripts are followed by a general discussion. Practical implications of both studies are summarized in a recommendations section. The first manuscript has been accepted for publication in Canadian Journal of Plant Science and appeared in the July 1994 issue (74:521-529).

1.0 Zero-tillage Establishment of Alfalfa and Meadow Bromegrass as Influenced by Previous Annual Grain Crop

1.1 Abstract

Conventional forage establishment techniques (i.e. use of pre-seeding tillage) can result in soil erosion and inefficient water use during the establishment period, and may result in poor plant establishment. Using a zero-tillage (ZT) system may overcome these limitations. The first experiment, conducted under favourable post-seeding moisture conditions, compared establishment, plant development, growth, and dry matter production of alfalfa and meadow bromegrass under ZT and conventional tillage (CT) following three different annual crops. Significant previous crop X tillage system interactions in both years, indicated that forage crop establishment and dry matter production were lower under ZT than CT when the preceding crop was wheat, however, no significant differences were observed when the preceding crop was either field pea or canola. Significant previous crop X forage species interactions for crop establishment indicated that while alfalfa was unaffected by previous crop type, emergence of meadow bromegrass was reduced when wheat was the previous crop. Significant previous crop X tillage system interactions for plant development indicated that development of both forage species was temporarily delayed under ZT when wheat was the previous crop. No treatment effects were observed for year after establishment dry matter production.

A second experiment, conducted under conditions of post-seeding drought, assessed the impact of spring wheat straw management on establishment of alfalfa and meadow bromegrass under CT and ZT. Superior establishment of both alfalfa and meadow bromegrass under ZT was attributed to higher levels of soil water under ZT. Straw management (removal vs. returned to land) had no effect on either forage species. Results of these studies indicate that ZT is a feasible alternative for establishing forage crops, even where levels of previous crop residue are very high.

1.2 Introduction

It is well known that the quality of soils in many agricultural regions of the world has been declining steadily over time. Much of this decline is attributed to excessive tillage. Soil properties negatively affected by tillage include soil organic matter quality and quantity, soil tilth, and soil physical structure (Aguilar et al. 1988; Blevins et al. 1983; Ketcheson 1980; Perfect et al. 1990). The long-term productivity of soil has become a primary concern to agricultural scientists and producers in many cropping regions in the world.

Twenty-nine percent of the land on the Canadian Prairies is now considered susceptible to moderate and severe wind or water erosion (Dumanski 1986). In 1989, the Prairie Farm Rehabilitation Association (PFRA) estimated that soil degradation cost Canadian producers approximately $100 million annually (PFRA 1989). Simulated soil erosion studies in Manitoba (Ives and Shaykewich 1987) indicated that adding large amounts of fertilizer only partially overcame the yield decrease due to soil erosion. Like many resources, soil is non-renewable. Therefore, in the interest of long-term productivity, agriculture practices must ensure the conservation of soil.

The inclusion of perennial forages in crop rotations is viewed as an important step towards soil conservation and improvement (Shiflet and Darby 1985; Higgs et al. 1990; Zentner and Campbell 1988). Including perennial forages in the rotation increases soil organic matter (Campbell et al. 1990), improves soil structure and soil fertility (Heichel 1978; Thiagalingam et al. 1991), and reduces soil erosion (Stinner and House 1989). Once established perennial forages improve soil but conventional seedbed preparation techniques (eg. a number of pre-seeding tillage operations) create a soil surface susceptible to erosion, especially prior to canopy closure (Sturgul et al. 1990). Pre-seeding tillage also dries out the seedbed (Unger et al. 1971), reducing establishment in dry years.

Establishment is perhaps the most difficult phase of the forage production system. Forage seedlings are especially vulnerable to soil moisture deficits because the small seeds are sown near the surface (Sheaffer 1989). In conventional seeding with alfalfa, it is common for only one third of the seeds to produce seedlings (Decker et al. 1973). Improvements in forage establishment techniques would reduce the reluctance of producers to include forages in their rotations (Tesar and Marble 1988).

Zero-tillage offers the following advantages for forage establishment: (1) a firm seedbed for shallow seeding; (2) soil surface is less likely to dry out; and (3) residue protects seedlings from sand-blasting and desiccation by wind (Koch 1992).

Both alfalfa and meadow bromegrass are routinely seeded in arable lands in western Canada. Alfalfa is grown mainly for hay and pasture, while meadow bromegrass is most desirable as a pasture grass (Smoliak 1981). Forage production in Manitoba is estimated at 2.1 million hectares annually (Anonymous, 1987). The objectives of this study were 1) to evaluate, in detail, the establishment, development, and yield of alfalfa and meadow bromegrass under zero- and conventional tillage following field pea, canola, and spring wheat, and 2) to investigate the effect of spring wheat straw management on the establishment of alfalfa and meadow bromegrass under zero- and conventional tillage.

1.3 Literature Review

In this discussion zero-tillage refers to the system of crop production where previous crop residues are retained on the soil surface and no pre-seeding tillage operations are used and with minimal soil disturbance occurring during the seeding operation.

1.3.1 Environmental Parameters

Both soil temperature and soil water content are affected by tillage (Lal 1989). Therefore, crop response to tillage can result from changes in the soil environment. Frequently, however, aerial environmental factors influence crop establishment more strongly, thereby masking tillage effects.

1.3.1.1 Soil Temperature

Previous research has determined that soil temperature is lower in a zero-tillage compared with a conventional system, especially in spring (Gauer et al. 1982; Wall and Stobbe 1985). Lower soil temperatures in the absence of tillage are attributed to surface crop residues shading the soil from direct solar radiation and insulating against heat conduction downward through the soil profile (Russel 1939; Potter et al. 1985). Aase and Siddoway (1980) indicated that heat flow into soil was 30% less in the presence of wheat stubble compared to bare soil.

Air temperature is another environmental factor which can greatly influence crop establishment under zero-tillage. Through heat convection, air temperature affects soil temperature, and therefore, indirectly affects the rate of crop germination and emergence.

Another factor that can lead to lower soil temperatures under zero-tillage is greater soil water content, since soil water content and soil temperature are negatively correlated (Carter and Rennie 1985). As a result, lower soil temperatures (ranging from 1 to 5°C lower) under zero- compared to conventional tillage have been reported in northern cropping regions (Carter and Rennie 1985).

Soil temperature requirements for seed germination determine whether a species is easy or difficult to establish under certain conditions (Townsend and McGinnies 1972). Being relatively temperature-insensitive for germination, alfalfa should be adaptable to establishment under zero-tillage (Townsend and McGinnies 1972). No research has examined the temperature requirements for meadow bromegrass germination and establishment.

1.3.1.2 Soil Water Content

In many agricultural regions, insufficient precipitation is the greatest limiting factor to crop production. Maximum crop water use efficiency involves maintaining soil characteristics favourable for rapid infiltration of precipitation and retaining the water in the soil profile (Stewart and Steiner 1990).

Higher levels of soil-surface water content are considered one of the great advantages of the zero-tillage system over conventional seedbed preparation systems (Mueller-Warrant and Koch 1980). The following factors contribute to the increased soil water content in the absence of tillage: enhanced water infiltration (Lindstrom and Onstad 1984), reduced soil water evaporation (Phillips 1981), and improved water storage (Cochran et al. 1982). The greatest differences in soil water content between zero- and conventional tillage are usually observed in the top 8 cm of soil (Blevins et al. 1971). Phillips et al. (1980) determined that as much as 0.75 cm more water was present in the top 15 cm layer of soil under zero- than conventional tillage. Lafond et al. (1992) reported that zero-tillage increased soil water content by 9% in the 0 to 60 cm soil layer and by 6% in the 0 to 120 cm soil layer.

The amount of soil water conserved under zero-tillage is dependent upon the amount of residue that is returned to the soil (Unger et al. 1971). Nyborg and Mahli (1989) found that where straw was returned, soil water content in the top 15 cm layer of soil under zero-tillage was significantly greater (approximately 2%) than that under conventional tillage. When the straw had been removed, no significant differences in soil water content were detected between zero- and conventional tillage.

Seasonal distribution of precipitation also influences soil water conservation with zero-tillage. For instance, Unger (1990) indicated that the water-conserving ability of surface crop residues was more readily expressed with frequent, compared to infrequent, precipitation events.

1.3.2 Conventional Forage Establishment

1.3.2.1 Clear Seeding

Establishment is perhaps the most difficult phase of the forage production system. The risk of crop establishment failure is greater for forage crops than any other major crop (Sheaffer 1989). This phenomenon is attributed to the fact that forages have small seeds and relatively non-vigorous seedlings. Clear seeding refers to the practice of establishing forages into an extensively tilled, weed free seedbed. Because forage seedlings are poor competitors with weeds, extensive tillage is required for pre-seeding weed control or for applying pre-plant soil incorporated herbicides (Dodds et al. 1984). However, this method of forage establishment leaves the soil surface highly susceptible to wind and water erosion. In addition, pre-seeding tillage dries the soil, and therefore, forage seeds are especially vulnerable to soil moisture deficits (Sheaffer 1989). Inadequate soil water for germination and emergence is one reason why only one third of alfalfa seeds actually produce seedlings (Decker et al. 1973).

1.3.2.2 Companion Crop

The most popular method of forage establishment in prairie Canada is to underseed the forage with a nurse or companion crop (Mupondwa et al. 1993). The companion crop is seeded, generally at half the usual seeding rate (Smoliak 1981), to protect the fragile forage seedlings from wind erosion and desiccation by wind (Koch 1992). Companion crops also provide an economic return from the land during the forage establishment year (Decker et al. 1973). However, establishment with a companion crop is not attractive because it reduces forage establishment and significant forage yield losses can occur the year after establishment (Waddington and Bittman 1983). In Alberta, establishment with a companion crop is not recommended as it reduces forage seedling vigour and increases the mortality of forage seedlings (Smoliak 1981). Therefore, the use of companion crops does not decrease the risk of establishment failure. Under zero-tillage, the previous crop residue on the soil surface would protect forage seedlings without competing for light, nutrients, and soil water. The surface crop residue would act as an 'inert' companion crop.

1.3.3 Forage Crop Responses to Zero-tillage

1.3.3.1 Crop Establishment

Previous research has indicated that forage crops can be successfully established in a zero-tillage production system. For example, Hart and Dean (1986) found no effect of tillage system (zero- vs. conventional) on date of emergence or stand density of several forage grasses, alfalfa, or cicer milkvetch (*Astragalus cicer* L.) when barley (*Hordeum vulgare* L.) was the previous crop. Similarly, Forney et al. (1985) obtained successful stand establishment of alfalfa (greater than 300 plants m^{-2}) under zero-tillage with sorghum (*Sorghum bicolor* Moench.) and foxtail millet (*Setaria italica* Beauv.) as previous crops.

The higher soil water levels that are frequently observed with zero-tillage serve to enhance crop establishment, especially in areas where post-seeding precipitation is not always assured. Wolf and Edmisten (1989) observed increased seedling emergence of alfalfa and attributed this to increased soil water content under zero-tillage. Under zero-tillage extra soil moisture and the presence of surface residues can alleviate soil crusting (White and Robson 1989) which can severely impair the emergence of small seeded crops.

Increased soil compaction is a common concern in zero-tillage production. Stout et al. (1990) reported higher seedling emergence of alfalfa under zero-tillage compared with conventional tillage because the increased bulk density under zero-tillage improved the soil to seed contact. Increased soil compaction associated with zero-tillage would be beneficial for forage establishment because shallow seeding is important for successful establishment. Beveridge and Wilsie (1959) determined that alfalfa seedling emergence decreased from 61 to 27% as seeding depth increased from 1.2 to 2.5 cm. Wolf and Edmisten (1989) indicated that increased soil compaction under zero-tillage alleviated winter heaving and enhanced over-winter survival of alfalfa in the first year.

Cochran et al. (1977) indicated that one of the barriers limiting wide-scale adoption of zero-tillage crop production was heavy crop residues from previous crops. Surface residues can adversely affect forage crop emergence by shading (Wolf and White 1992) or by creating allelopathic effects from the production of phytotoxic substances (Hicks et al. 1989). The presence of allelopathic effects depends on the level of crop residue returned to the soil (Hicks et al. 1989). Insect predation may be another factor affecting crop establishment. Bahler et al. (1987) found that successful zero-till alfalfa establishment in oat (*Avena sativa* L.) stubble was achieved only if weeds and invertebrate pests were controlled. Therefore, it appears that successful establishment of forages under zero-tillage requires careful management of the previous crop residue.

1.3.3.2 Crop Development

Alfalfa growth and development is divided into five different stages; vegetative, bud, bloom, pod development, and ripening (Metcalfe 1973b). Alfalfa seedlings are morphologically different than other broadleaved crops. In the early stage of alfalfa development, cotyledons are the first structures to emerge. Since the cotyledons (terminal meristem) are located above the soil surface, alfalfa seedling development may be more strongly influenced by air rather than soil temperature. A single unifoliate leaf emerges shortly after the cotyledons. The "true" leaves of alfalfa are pinnately trifoliate. For proper herbicide timing, alfalfa staging is based on the number of fully emerged trifoliate leaves (Manitoba Agriculture 1994).

During the vegetative growth stage, alfalfa shoots elongate usually reaching a height of 60 to 90 cm. As many as 5 to 25 new shoots can develop from buds in the crown region of alfalfa (Hanson and Barnes 1973). Alfalfa progresses from vegetative to reproductive growth and begins to develop buds. After flowering, seeds form in pods which begin to ripen. For maximum forage quality, alfalfa is harvested in the early bloom stages (Hanson and Barnes 1973). Alfalfa is a perennial, and therefore, if grazed or cut will regrow and begin vegetative growth and development once again.

Meadow bromegrass development is similar to that of other species in the gramineae family. Meadow bromegrass growth and development is grouped into six stages; early vegetative, tillering, jointing, boot, heading, and ripening (Metcalfe 1973b). Early vegetative stages of meadow bromegrass development consist of leaves only. Stem elongation is absent. The tillering stage begins as tillers develop from buds in the crown region. As the meadow bromegrass seedling continues to grow, stem elongation occurs (jointing). Meadow bromegrass attains the boot stage when the inflorescence is enclosed in the flag leaf. As the inflorescence emerges, the plant reaches the heading stage with immature seeds present. Meadow bromegrass is a perennial bunch type grass, and therefore, when harvested or grazed will regrow.

Monitoring crop development is an effective method for determining tillage effects on crop productivity. Crop development is influenced by air and soil temperature, soil water content, and light conditions. All of these are influenced by tillage. Lower rates of crop development for annual crops under zero- compared with conventional tillage have been attributed to lower soil temperatures under zero-tillage (Carter and Rennie 1985). Delayed development of corn (*Zea mays* L.) established under zero-tillage with 3600 kg ha^{-1} oat residue was correlated with reduced soil temperatures (Allmaras et al. 1964). In this study, an average soil temperature reduction of 1.2°C was reported in the top 10 cm for the first six weeks after planting (Allmaras et al. 1964). Several studies have reported no effect of tillage system on annual crop development (Lafond and Leoppky 1988; Gauer et al. 1982).

Research examining the influence of soil temperature on alfalfa and meadow bromegrass seedling development is lacking. However, Evenson and Rumbaugh (1972) investigated the effect of wheat mulch on soil temperatures and subsequent fall regrowth of alfalfa. Wheat mulch applied at 6700 kg ha^{-1} reduced soil temperature by as much as 9°C and delayed maturity of alfalfa significantly. The authors noted that early spring development and time to flower was also slower in the mulched plots. The researchers attributed the slower rate of alfalfa development to the decreased soil and air temperatures in the mulched plots.

Other studies have indicated that crop development is affected under zero-tillage due to altered light conditions. Huggins and Pan (1991) found that branching in two winter legume species was reduced because shading by the wheat stubble significantly lowered the photosynthetically active radiation and red/far-red ratios. Cowett and Sprague (1963) indicated that the number of stems produced by alfalfa was positively correlated with light intensity.

Under shaded conditions plant morphology has also been altered. Pritchett and Nelson (1951) found that the thickness of stems of alfalfa and bromegrass was directly proportional to light intensity. Increased tillering of bromegrass was also found to be closely related to light level. Therefore, management of the crop residue in zero-tillage production is an important tool to optimize seedling development.

1.3.3.3 Crop Growth

1.3.3.3.1 Dry Matter Production

Plant dry matter production is controlled by the growth rate, length of growing season, and plant population density. For example, Brown and Stafford (1970) increased seeding-year alfalfa yields in Maine from 4600 to 5000 kg ha^{-1} by increasing seeding rates from 9 to 18 kg ha^{-1}. First-year alfalfa yields ranged from 2500 to 3000 kg ha^{-1} when established with an oat companion crop in the northern area of North Dakota (Dodds et al. 1984). This is a typical yield for a first-year alfalfa stand in the Northern Great Plains. Second-year alfalfa stands allow for two cuttings and typically yield approximately 2800 kg ha^{-1} per harvest (Metcalfe 1973a). Meadow bromegrass typically produces approximately 700 kg ha^{-1} in the year of establishment (underseeded to a companion crop) and 2600 kg ha^{-1} in the second year of production in western Canada (Waddington and Bittman 1984).

Several studies have reported enhanced dry matter production in forage crops that were established with zero-tillage. Wolf and Edmisten (1989) determined that alfalfa establishment-year yields were greater from zero- compared to conventional tillage plantings due to an increased growth rate. They found no difference in yield during the second season. Wolf et al. (1985) determined that alfalfa dry matter yields were 600 and 300 kg ha^{-1} greater under zero- compared to conventional tillage in the year of and year after planting, respectively. The previous study used rye (*Secale cereale* L.) and millet (*Setaria faberii* Herrm.) as previous crops. Stout et al. (1990) observed increased establishment-year alfalfa dry matter production (as much as 500 kg ha^{-1}) when established under zero-tillage with a corn-silage companion crop compared to conventional methods.

Several researchers have attributed higher crop dry matter yields under zero-tillage to increased soil moisture levels (Blevins et al. 1971; Gauer et al. 1982; Lafond et al. 1992). Blevins et al. (1971) observed an increase in corn dry matter production by 1200 kg ha^{-1} under zero- compared to conventional tillage. Lafond et al. (1992) found increases in dry matter production of spring wheat, flax (*Linum usitatissimum* L.), and field pea under zero-tillage. The researchers attributed increased soil moisture levels under zero-tillage to increased snow trapping and reduced evaporation during the early part of the growing season. This evidence suggests that zero-tillage crop production represents a means of short-term drought tolerance because of the increased soil moisture levels. Shanholtz and Lillard (1969) found that zero-tillage corn production allowed the crop to effectively counter drought for one to two weeks. No information is available on dry matter yields of alfalfa and meadow bromegrass under zero-tillage following annual crops as influenced by soil moisture levels.

Plant dry matter production can be adversely affected by shading of soil by the surface residue and previous crop stubble. This is especially important for alfalfa, since alfalfa plants are relatively intolerant to low light intensities (Fick et al. 1988). Kendall and Stringer (1985) determined that grasses are more tolerant of shading than legumes, and therefore, meadow bromegrass may respond differently to shading than alfalfa. Stout et al. (1990) observed a 70% reduction (40 gm^{-2}) in alfalfa dry matter production at the fifth trifoliate leaf stage when grown under zero- compared to conventional tillage following a corn and rye silage crop. They attributed this to shading of the emerging seedlings by the corn and rye litter on the plots. However, no light measurements were taken in this study. Wolf et al. (1985) observed that first year alfalfa yields were similar when grown under zero-tillage following rye and millet compared to conventional establishment. Sheaffer (1989) determined that prompt cereal straw removal was essential prior to successful zero-tillage alfalfa establishment. It has been suggested that straw removal is not necessary if wheat residue returned is less than 2000 kg ha^{-1} (Willard and Lewis 1947; Decker et al. 1973).

Other studies have shown that the presence of previous crop residues under zero-tillage can affect plant dry matter production in other ways besides shading. The production of phytotoxic substances can inhibit the growth rate of adjacent plants. Cochran et al. (1977) determined that in the presence of high pea or lentil residue, dry matter production in wheat plants was reduced by as much as 50%. In this study, wheat and barley were much less inhibitory than pea and lentil. Willard and Lewis (1947) found that when wheat was grown as a companion crop, returning the straw after combining injured the alfalfa and reduced hay quality in the following year. This was attributed to allelochemicals being released from the decaying wheat residue and adversely affecting the alfalfa.

1.3.3.3.2 Crop Height

Crop height is affected by plant density, soil water content, and light intensity and duration. Smoliak (1981) determined that alfalfa must reach a height of approximately

25 cm or the bud stage, to accumulate enough reserves to be vigorous. The lower the light intensity, the more rapid is the rate of stem elongation which results in greater plant height during the early stages of growth (Pritchett and Nelson 1951). Similarly, Huggins and Pan (1991) found that winter pea (*Pisium sativum* subsp. *arvense* L.) and winter lentil (*Lens colinaris* Medik.) plants exhibited greater stem elongation when established with zero- compared to conventional tillage. They attributed this response to wheat stubble intercepting more than 90% of the photosynthetically active radiation (PAR) which stimulated stem elongation. In this study, PAR levels in the presence of wheat stubble were approximately 100 *u*moles $m^{-2}s^{-2}$. The researchers determined there was a significant shading effect since 400 *u*moles $m^{-2}s^{-2}$ is the approximate irradiance at which photosynthesis saturates for C_3 plants. Gist and Mott (1957) indicated that under shaded conditions (50% of full sunlight) alfalfa root growth was more negatively affected than shoot growth. Again, it appears that shading had a stimulating effect on alfalfa height. Previous crop stubble that shades emerging forage seedlings may intercept incoming solar radiation which may have a beneficial affect on plant height. This stimulating effect would increase the ability of seedlings to successfully establish under zero-tillage.

1.3.4 Conclusions

The potential to facilitate zero-tillage forage production is an important step towards soil conservation. Since the establishment period is often the most difficult phase in the forage production system, facilitating zero-tillage production would reduce the reluctance of producers to include such crops in rotation. Soil temperature, soil moisture, percent light interception, and level of previous crop residue (allelopathy) are influenced by tillage. Previous studies have indicated that these factors are altered under zero-tillage and can have beneficial and adverse effects on an annual crop's productivity. Limited information is available on zero-tillage alfalfa establishment into annual crop residue (stubble). Most zero-tillage research on alfalfa has investigated the feasibility of establishment into chemically suppressed vegetation. Virtually no information is available on the establishment of meadow bromegrass under zero-tillage. The suitability of alfalfa and meadow bromegrass to zero-tillage depends on how these two forages respond in terms of emergence, growth, development, and dry matter production.

1.4 Methods and Materials

1.4.1 Experiment One

1.4.1.1 General

This experiment was conducted in 1990 and 1991 at the University of Manitoba Plant Science field research station, Portage la Prairie, MB (50°N, 98°W) on a Neuhorst clay loam soil. The experimental design was a split-split plot with tillage system (CT and ZT) as the mainplot, previous crop (spring wheat, canola, and field pea) as the subplot, and forage species (alfalfa and meadow bromegrass) as the sub-subplot. The sub-subplots were 4 m x 10 m and each treatment was replicated 4 times.

The CT treatment consisted of two passes (in opposite directions) with a double disk in the fall and a light cultivation, harrowing, and packing immediately prior to seeding in spring. No tillage operations were performed on the ZT plots. The ZT and CT treatments had been in place for 6 and 3 years, respectively. Subplots of spring wheat (cv. Katepwa), canola (cv. Westar), and field pea (cv. Victoria) were harvested in August of 1989 and 1990 using a plot combine. The residue from each crop was returned to the plot. Once uniformly distributed over the plot, the residue was chopped using a rotary mower set at a height of approximately

12 cm. The average length of the straw residue after chopping was 20 to 25 cm.

1.4.1.2 Crop Management

Alfalfa (cv. OAC Minto) was seeded at a rate of 354 (approximately 7 kg ha^{-1}) and 404 (approximately 8 kg ha^{-1}) viable seeds m^{-2} in 1990 and 1991, respectively. The alfalfa was inoculated with *Rhizobium meliloti* prior to seeding. Meadow bromegrass (cv. Regar) was seeded at a rate of 301 and 264 viable seeds m^{-2} in 1990 and 1991, respectively. Seeding date was May 27 in 1990 and May 22 in 1991. Certified seed of both forage species was used. Forages were seeded using a Noble Model 2000 hoe-drill (Nobleford, AB) (seed distributed through a seed distribution cone) with a row spacing of 15 cm to a depth of 1.5 cm in 1990 and 2.5 cm in 1991.

Based on soil tests and provincial recommendations for forage establishment, the entire plot area received a broadcast application of 10 kg ha^{-1} nitrogen and 45 kg ha^{-1} of P_2O_5 prior to seeding in 1990 and 1991 (Table A3.1). The same fertilizer rates were applied in early spring the year after establishment. Weeds were controlled with appropriate herbicides which included an application of glyphosate at 890 g a.i. ha^{-1} immediately prior to seeding in spring. Weed control was less than optimum in 1990 as annual broadleaf weeds invaded the plot approximately one month after seeding.

These weeds were cut along with the 98 days after seeding (DAS) forage harvest. No weed problems were encountered the year after establishment (i.e. in 1991). Weed control was excellent in the experiment established in 1991.

1.4.1.3 Measurements

The amount of residue returned from each previous crop was determined by measuring total aerial biomass immediately prior to harvest (Poppe 1991). Percent residue cover on the CT and ZT plots was determined immediately after seeding using the line-transect method (Sloneker and Moldenhauer 1977). Two samples were taken within each main plot.

Immediately prior to seeding, the amount of solar radiation intercepted by the previous crop stubble was measured using a Licor Model LI-185B quantum meter with a line quantum sensor (1 m long) at solar noon. Quantum flux (uE m^{-2} s^{-1}) was measured at the soil surface and approximately 1 m above the stubble height. Percent interception of photosynthetically active radiation was then calculated.
Daily maximum and minimum air temperature and daily precipitation were monitored throughout the growing season for both experiments using a Campbell Model CR-10 datalogger (Campbell Scientific Inc., Logan, Utah).

Volumetric soil water content between 0 and 10 cm (measured in 1991 only) was determined for each subplot at the time emergence counts were taken. Soil cores approximately 10 cm in diameter were dried for 48 hours at 70°C. One sample was taken from each subplot.

Stand establishment was monitored every seven to ten days until approximately 30 DAS. Plant population density was determined by counting the number of plants in the same 0.45 m^2 area. Percent emergence was calculated as plants per unit area divided by number of viable seeds per unit area.

Plant development stage was measured on 10 randomly selected plants in each sub-subplot. Alfalfa development stage was measured by counting the number of fully emerged trifoliate leaves. Development stage of meadow bromegrass was determined using the Haun growth stage scale (on mainstem) (Haun 1973), and by counting the number of tillers per plant.

Aerial dry matter (DM) production was determined on randomly selected 0.45 m^2 areas in each sub-subplot 31, 51, and 98 DAS in 1990 and 32, 60, and 134 DAS in 1991. Cutting height was 3 cm. Samples were dried at 70°C for a minimum of 48 hours before weighing. In 1991, the entire plot area was cut 60 DAS, and therefore, the DM harvest 134 DAS represents regrowth. Aerial DM production the year after establishment was determined in mid-June (10% bloom for alfalfa; heading stage for meadow bromegrass) from a 1 m^2 sample within each sub-subplot.

The basal area (crown area estimation only) was assessed in early spring in the year after establishment (1991 study only) using the point-quadrat method (Lodge and Gleeson 1984). The sampling area in each sub-subplot was 1 m^2.

1.4.2 Experiment Two

1.4.2.1 General

This experiment examined the effect of spring wheat (cv. Roblin) straw management on the establishment of alfalfa and meadow bromegrass under CT and ZT. The experiment, which was conducted in 1992 only, was again established on a Neuhorst clay loam at Portage la Prairie, MB. The experimental design was a split-split plot with straw management (-returned and -removed) as the main-plot, tillage system (CT and ZT) as the subplot, and forage species (alfalfa and meadow bromegrass) as the sub-subplot.

1.4.2.2 Straw Management

The wheat straw management treatments were applied in the fall of 1991. In the straw-returned treatment, wheat straw was chopped and spread using a field-scale combine. After chopping, the straw was 10 to 15 cm in length. In the straw-removed treatment, wheat straw was windrowed behind the combine, then baled.

1.4.2.3 Crop Management

Tillage operations and forage cultivars used were the same as in experiment 1. Inoculated alfalfa was seeded at a rate of 404 viable seeds m^{-2} and meadow bromegrass was seeded at 301 viable seeds m^{-2}. This experiment was seeded on May 20, 1992.

1.4.3 Measurements

Sub-subplots were evaluated for percent residue cover and percent light interception immediately prior to seeding using the techniques described in experiment 1. The amount of wheat straw returned to the plot area was estimated based on wheat grain yield and harvest index data (Poppe 1991).

Volumetric soil water was determined for the 0 to 10 cm and 10 to 30 cm soil depth increments in each subplot at seeding and at intervals during the crop emergence period. Soil cores approximately 10 cm in diameter were dried for 48 hours at 70°C.

Plant emergence and population density, and plant development stage were determined using methods described in experiment 1. Plant establishment and development were determined 12, 15, 22, 29, and 35 DAS.

Aerial DM production was determined 70 DAS on randomly selected 1 m^2 areas (alfalfa: 6-7 trifoliate stage; meadow bromegrass: Haun stage 4.6 with the third tiller visible). Samples were dried for a minimum of 48 hours at 70°C before weighing.

1.4.4 Statistical Analysis

All data were subjected to analysis of variance (Statistical Analysis Systems Institute, 1986). Mean separations were conducted using the Fisher Protected least significant difference (LSD) test at the $p=0.05$ level, after GLM indicated significant ($P < 0.05$) differences. Significant interaction ($P < 0.05$) mean separations (for two-way and three-way interactions) were calculated using the technique described by Gomez and Gomez (1984). Homogeneity of error variances was checked using the maximum F test (Rohlf and Sokal 1969), however, since error variances for most parameters in both experiments were not homogeneous, site-years were analyzed separately.

1.5. Results and Discussion

1.5.1 Experiment One

1.5.1.1 Environmental Parameters

In 1990 and 1991, precipitation during the establishment period was close to or above the long-term average while air temperature was slightly above average (Table 1.1). Therefore, conditions for crop establishment were ideal in both years of the study. No significant treatment effects on soil water content between 0 and 10 cm were observed in 1991 (Table 1.2). Therefore, the soil water-conserving benefits of the ZT system (Gauer et al. 1982) were not expressed in this study.

1.5.1.2 Residue Cover

In 1990, residue returned averaged 5900, 7700, and 8600 kg ha^{-1}, for canola, field pea and wheat, respectively. In 1991, residue returned averaged 5000, 4500, and 7600 kg ha^{-1} for canola, field pea and wheat, respectively. The average aerial non-grain yield of hard red spring wheat in south-central Manitoba is approximately 6500 kg ha^{-1}. In the present study, the amount of previous crop residue returned was similar in the CT and ZT treatments.

Table 1.1 Monthly mean air temperature and precipitation at Portage la Prairie, Manitoba in 1990, 1991, and 1992, and the 30-year average (1961-1990)[z]

	Temperature (C)					Precipitation (mm)			
	1990	1991	1992	Avg		1990	1991	1992	Avg
May	10.2	14.1	12.8	11.6		34.0	59.0	12.6	54.3
June	18.0	18.8	15.4	17.1		133.6	75.0	44.0	75.0
July	19.2	19.5	16.3	19.8		53.6	95.0	109.0	76.9
September	14.0	12.2	10.8	12.5		19.2	68.0	50.0	49.2
AVG	16.3	17.0	14.3	15.9	Total	283.0	307.0	264.6	334.2

[z]Environment Canada Atmospheric Environment Service, Winnipeg, Manitoba. R3C 3V4. The 30-year average (1961-1990) is the most recent period for which data have been compiled.

Table 1.2 Influence of tillage system and previous crop type on soil water content in 0 to 10 cm depth at Portage la Prairie in 1991.

Tillage System (TS)	Previous Crop (PC)	Available Soil Water		
		2 DAS	8 DAS	17 DAS
			cm	
CT	Canola	2.5	2.6	3.7
CT	Pea	2.7	2.6	3.6
CT	Wheat	2.7	2.8	3.8
ZT	Canola	2.6	2.5	3.6
ZT	Pea	2.8	2.9	3.7
ZT	Wheat	2.6	2.6	3.6
L.S.D.^{z}		NS	NS	NS

^{z}L.S.D. refers to two-way interaction only.

Table 1.3 Influence of tillage system and previous crop type on percent residue cover and percent light interception at Portage la Prairie in 1991.

Tillage System (TS)	Previous Crop (PC)	Light Interception	Residue Cover
		%	
CT	Canola	0.0	25
CT	Pea	0.0	17
CT	Wheat	0.0	31
ZT	Canola	2.2	80
ZT	Pea	1.9	66
ZT	Wheat	7.5	92
L.S.D.		2.7^{z}	6.6^{Y}

^{z}L.S.D. refers to effect of previous crop type under ZT only.
^{Y}L.S.D. refers to two-way interaction only.

The percent residue cover and percent light interception values in 1991 are given in Table 1.3. Under ZT, wheat had the highest residue cover, which resulted in significantly greater light interception than for canola or pea. Measurements of both previous crop residue mass and percent residue cover clearly point out that ZT forage establishment in this study was assessed under high residue conditions, especially for wheat.

1.5.1.3 Crop Establishment

Percent emergence of alfalfa and meadow bromegrass was approximately two to seven times higher 9 DAS in 1990 than in 1991 (Table 1.4 and 1.5). Superior emergence in 1990 was attributed to greater precipitation and higher air temperatures immediately after seeding, and a slightly shallower seeding depth. In 1990, percent emergence of alfalfa decreased during the period 9 to 21 DAS (presumably due to intracrop competition and competition from weeds), while percent emergence of meadow bromegrass increased over the same time period. This suggests that alfalfa reached its maximum emergence percentage earlier than meadow bromegrass. In 1991, percent emergence of both forage species increased between 9 and 25 DAS (Table 1.5). Total emergence averaged 43% in 1990 and 31% in 1991, comparable to the levels observed by Decker et al. (1973).

Table 1.4 Influence of tillage system and previous crop type on percent emergence of alfalfa and meadow bromegrass at Portage la Prairie in 1990. Highlights of analysis of variance are included.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	9 DAS	16 DAS	21 DAS
			----% emergence---		
CT	Canola	Alfalfa	89	54	42
CT	Canola	Brome	40	63	67
CT	Pea	Alfalfa	62	37	27
CT	Pea	Brome	35	48	52
CT	Wheat	Alfalfa	57	42	40
CT	Wheat	Brome	33	58	55
ZT	Canola	Alfalfa	61	54	38
ZT	Canola	Brome	30	56	67
ZT	Pea	Alfalfa	61	60	34
ZT	Pea	Brome	40	63	68
ZT	Wheat	Alfalfa	43	42	26
ZT	Wheat	Brome	15	14	12
L.S.D.[z]			NS	NS	NS
TS			NS	NS	NS
PC			NS	NS	NS
FS			**	NS	*
TS X PC			NS	NS	NS
TS X FS			NS	NS	NS
PC X FS			NS	NS	*
TS X PC X FS			NS	NS	NS

*, ** Significant at 0.05 and 0.01 probability levels, respectively.
NS=nonsignificant
[z]L.S.D. refers to the three-way interaction only.

Table 1.5 Influence of tillage system and previous crop type on percent emergence of alfalfa and meadow bromegrass at Portage la Prairie in 1991. Highlights of analysis of variance are included.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	9 DAS	19 DAS	25 DAS
			-----% emergence----		
CT	Canola	Alfalfa	14	15	36
CT	Canola	Brome	9	19	34
CT	Pea	Alfalfa	25	24	34
CT	Pea	Brome	9	17	38
CT	Wheat	Alfalfa	20	23	36
CT	Wheat	Brome	6	14	47
ZT	Canola	Alfalfa	15	17	29
ZT	Canola	Brome	4	17	33
ZT	Pea	Alfalfa	26	15	27
ZT	Pea	Brome	3	13	26
ZT	Wheat	Alfalfa	14	20	29
ZT	Wheat	Brome	2	10	10
L.S.D.[z]			NS	NS	16
TS			NS	NS	*
PC			*	NS	NS
FS			***	***	***
TS X PC			NS	NS	NS
TS X FS			NS	NS	NS
PC X FS			NS	*	*
TS X PC X FS			NS	NS	*

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.
NS=nonsignificant
[z] L.S.D. refers to the three-way interaction only.

Significant previous crop X forage species interactions were observed 21 DAS in 1990 and 19 and 25 DAS in 1991. In both years, the basis for the interaction was the same: percent emergence of alfalfa was unaffected by previous crop type, while percent emergence of meadow bromegrass was lower following wheat compared with canola or field pea (Table 1.4 and 1.5). These results for alfalfa in the present study differ from those of Wolf and White (1992) who found that heavy trash had to be removed for successful establishment of alfalfa under ZT conditions. The lower emergence percentage of meadow bromegrass following wheat in the present study may be attributed to the higher level of previous crop residue which resulted in increased light interception (Table 1.3). High levels of cereal crop residue can reduce soil temperature during the crop emergence period (Gauer et al. 1982), and can physically impede the emerging crop (Cochran et al. 1977).

A significant three way (tillage X previous crop X forage species) interaction for crop establishment was observed on the third sampling date (25 DAS) in 1991. The interaction was attributed to a differential response of alfalfa and meadow bromegrass to previous crop type in the ZT system. Percent alfalfa emergence was unaffected by tillage type or previous crop (Table 1.5). While there was no significant difference in percent emergence of meadow bromegrass following the three previous crops in the CT system, percent emergence of meadow bromegrass was significantly lower following wheat compared with field pea or canola in the ZT system (Table 1.5). These results once again point out that meadow bromegrass was more negatively affected by wheat residue than alfalfa, however in this instance, the negative effect of wheat was observed only in the ZT system. Possible causes for lower establishment of meadow bromegrass following wheat are root diseases (no leaf diseases were observed on any of the meadow bromegrass plots), or allelopathic chemicals released from decaying wheat residue (Cochran et al. 1977). It is also possible that alfalfa and meadow bromegrass differ in their response to shading or to soil temperature depression due to ZT. Hicks et al. (1989) reported a 21% reduction in cotton (*Gossypium spp.* L.) emergence in the presence of wheat stubble. Limiting the amount of wheat residue overcame the negative effects.

All alfalfa treatments achieved a plant population density of approximately 100 plants m^{-2} (considered an optimum plant population for establishment year alfalfa hay crops (Meyer 1985)).

1.5.1.4 Crop Development

Crop development stage was monitored in the 1991 experiment only. Because different development scales were used for each forage species, alfalfa and meadow bromegrass were analyzed separately (each analyzed as a split plot). A significant tillage X previous crop interaction 19 DAS indicated that alfalfa plant development was similar under CT and ZT when field pea and canola were the previous crops, however when wheat was the previous crop, development of alfalfa was significantly greater under CT compared to ZT (Table 1.6). Tillage X previous crop interactions ($P<0.05$) for both alfalfa and meadow bromegrass plant development 32 DAS indicated that plant development was similar for all three previous crops under CT, however under ZT, plant development was reduced when wheat was the previous crop (Table 1.6). Tiller production per meadow bromegrass plant 32 DAS was also significantly ($P<0.05$) affected by previous crop type (3.6 tillers per plant for meadow bromegrass following field pea and canola vs. 2.6 tillers per plant for meadow bromegrass following wheat), however, no tillage X previous crop interaction was detected (Table 1.7).

Results of this study indicate that development of both alfalfa and meadow bromegrass were delayed in the ZT system when wheat was the previous crop. This is similar to the findings of Huggins and Pan (1991), who observed less branching and decreased shoot mass in winter lentil that had been zero-tilled into wheat stubble. They attributed the negative response to the shading effect of the wheat stubble which significantly reduced photosynthetically active radiation. A similar explanation may apply in the present study since light interception was highest in the ZT wheat residue treatment (Table 1.3).

Table 1.6 Influence of tillage system and previous crop type on trifoliate number of alfalfa and Haun stage of meadow bromegrass at Portage la Prairie in 1991.

Tillage System (TS)	Previous Crop (PC)	19 DAS	25 DAS	32 DAS	60 DAS
		-alfalfa trifoliate leaf number--			
CT	Canola	1.3	3.6	9.0	49.8
CT	Pea	1.6	4.8	10.9	57.3
CT	Wheat	1.8	4.5	10.9	54.8
ZT	Canola	1.3	3.9	10.1	54.0
ZT	Pea	1.1	4.0	12.3	50.0
ZT	Wheat	1.0	3.6	6.6	59.0
L.S.D.[z]		0.7	NS	2.0	NS
		-meadow bromegrass (Haun stage)--			
CT	Canola	2.0	3.6	4.7	6.1
CT	Pea	2.3	3.4	4.8	6.2
CT	Wheat	2.0	3.6	4.9	5.6
ZT	Canola	2.0	3.1	4.7	6.5
ZT	Pea	2.1	3.0	4.6	6.1
ZT	Wheat	2.0	3.0	4.1	6.2
L.S.D.[z]		NS	NS	0.2	NS

[z]L.S.D. refers to the two-way interaction.

Table 1.7 Influence of tillage system and previous crop type on tiller number of meadow bromegrass 32 DAS at Portage la Prairie in 1991.

Tillage System (TS)	Previous Crop (PC)	Tiller number
CT	Canola	3.8
CT	Pea	3.8
CT	Wheat	3.3
ZT	Canola	3.3
ZT	Pea	3.5
ZT	Wheat	2.0
L.S.D.[z]		NS

[z]L.S.D. refers to two-way interaction only.

The strong positive relationship between soil temperature and plant development is well documented (Ritchie and NeSmith 1991). Therefore, observations of slower plant development under ZT following wheat (Table 1.6 and 1.7) suggest that soil temperature was lower under ZT, and that reduced soil temperature under ZT may have played a role in reducing plant development rate under ZT in this study.

1.5.1.5 Dry Matter Production

In 1990, significant previous crop X forage species interactions for DM production were detected 31 and 51 DAS. In both cases, the reason for the interaction was significantly lower DM production for meadow bromegrass when wheat was the previous crop (Table 1.8). Dry matter production of alfalfa, on the other hand, was unaffected by previous crop type on these sampling dates (Table 1.8). A significant tillage X previous crop interaction for DM production 98 DAS was attributed to the fact that yields of both forage species were similar under CT and ZT when field pea and canola were the previous crops, however, when wheat was the previous crop, forage yields were reduced under ZT (Table 1.8). The magnitude of the DM yield depression by ZT 98 DAS in 1990 was much greater for meadow bromegrass than for alfalfa (Table 1.8).

Dry matter production was higher in 1991 than in the previous year (Table 1.8 and 1.9). Lower forage DM production in 1990 was attributed to invasion of annual weeds approximately 30 DAS.

In 1991, significant tillage X previous crop interactions for DM production were detected on all sampling dates. Once again, the basis for these interactions was the fact that forage DM production was reduced in the ZT system when wheat was the previous crop, but unaffected by previous crop in the CT system (Table 1.9)

Results of experiment 1 indicated that, in terms of DM production, both forage species were negatively affected by the heavy residue in the ZT wheat treatment (Table 1.8 and

Table 1.8 Influence of tillage system and previous crop type on dry matter production of alfalfa and meadow bromegrass at Portage la Prairie in 1990. Highlights of analysis of variance are included.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	31 DAS	51 DAS	98 DAS
			-------kg	ha^{-1}	-------
CT	Canola	Alfalfa	16	388	2371
CT	Canola	Brome	69	656	1490
CT	Pea	Alfalfa	11	263	2321
CT	Pea	Brome	65	542	1561
CT	Wheat	Alfalfa	6	326	2495
CT	Wheat	Brome	44	393	1923
ZT	Canola	Alfalfa	10	238	2336
ZT	Canola	Brome	37	475	2155
ZT	Pea	Alfalfa	8	529	2030
ZT	Pea	Brome	44	358	1836
ZT	Wheat	Alfalfa	4	176	1773
ZT	Wheat	Brome	18	153	418
L.S.D.[z]			NS	NS	NS
TS			NS	NS	NS
PC			*	*	*
FS			***	***	**
TS X PC			NS	NS	*
TS X FS			NS	NS	NS
PC X FS			*	*	NS
TS X PC X FS			NS	NS	NS

*,**, *** Significant at 0.05, 0.01, and 0.0001 probability levels, respectively.
NS=nonsignificant
[z]L.S.D. refers to the three-way interaction only.

Table 1.9 Influence of tillage system and previous crop type on dry matter production of alfalfa and meadow bromegrass at Portage la Prairie in 1991. Highlights of analysis of variance are included.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	32 DAS	60 DAS	134 DAS
			-------kg ha^{-1}-------		
CT	Canola	Alfalfa	244	6542	6514
CT	Canola	Brome	47	2685	7454
CT	Pea	Alfalfa	388	5907	6342
CT	Pea	Brome	58	2503	7030
CT	Wheat	Alfalfa	536	8173	7594
CT	Wheat	Brome	77	2653	7634
ZT	Canola	Alfalfa	402	6651	7460
ZT	Canola	Brome	50	2516	7285
ZT	Pea	Alfalfa	438	7304	7617
ZT	Pea	Brome	52	2969	7903
ZT	Wheat	Alfalfa	174	6715	6354
ZT	Wheat	Brome	24	287	3120
L.S.D.^{z}			NS	NS	NS
TS			NS	NS	NS
PC			NS	*	NS
FS			***	***	NS
TS X PC			*	*	*
TS X FS			NS	NS	NS
PC X FS			NS	NS	NS
TS X PC X FS			NS	NS	NS

*,**, *** Significant at 0.05, 0.01, and 0.0001 probability levels, respectively.
NS=nonsignificant
^{z}L.S.D. refers to the three-way interaction only.

1.9). Therefore, even though stand establishment of alfalfa was not seriously affected by the very heavy wheat residues (Table 1.4 and 1.5), DM yield was. Stout et al. (1990) also observed lower DM production of alfalfa established under ZT. In their study, lower yields of alfalfa following corn or rye were attributed to shading of the emerging seedlings by the heavy crop residue. A similar explanation may apply in the present study (Table 1.3).

1.5.1.6 Year after Establishment Dry Matter Production

Second year forage DM yields were determined for both the 1990 and 1991 studies. The lack of significant tillage X previous crop interactions for this parameter (Table 1.10) indicated that any negative effects due to previous crop type observed in the establishment year did not carry over into the second year. Similar year after establishment DM yields in 1990 and 1991 also indicated that the annual weeds present in the 1990 establishment year did not have any lasting negative effects on forage production.

Based on the results of second year DM production, it appeared that the ZT system had no long-term effects on forage yield, even when the preceding crop was wheat. These results differ from those where companion crops were used in the establishment year. For example, Waddington and Bittman (1983) working in the Black soil zone of Saskatchewan, reported that a wheat companion crop reduced second year (first cut) yield of both alfalfa (38%) and smooth Bromegrass (42%), compared to where no companion crop was used. Therefore, ZT establishment of forages into heavy crop residue in the present study had fewer consequences for second year forage DM production than the use of a companion crop in the Saskatchewan study.

1.5.1.7 Basal Area Estimation

The absence of significant treatment differences for amount of basal stem area (Table 1.10) suggests that compensatory growth occurred in plots where low plant population densities were observed in the establishment year. The fact that no treatment effects were observed on year after establishment dry matter production and basal area estimation suggests that both forages were able to overcome any negative effects in the establishment year sustained from previous crop residues.

Table 1.10 Influence of tillage system and previous crop type on year after establishment dry matter production and basal area of alfalfa and meadow bromegrass at Portage la Prairie.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	Dry Matter Yield 1990[z]	Dry Matter Yield 1991	Basal Area 1991
			-----kg ha^{-1}-----		----%----
CT	Canola	Alfalfa	6632	6050	15.3
CT	Canola	Brome	4961	4255	17.3
CT	Pea	Alfalfa	6458	5768	18.8
CT	Pea	Brome	4976	4680	16.5
CT	Wheat	Alfalfa	6931	6008	17.0
CT	Wheat	Brome	3976	3820	16.5
ZT	Canola	Alfalfa	6442	6383	19.5
ZT	Canola	Brome	4905	4863	16.3
ZT	Pea	Alfalfa	6571	5535	18.0
ZT	Pea	Brome	5765	4560	17.5
ZT	Wheat	Alfalfa	6233	5840	19.0
ZT	Wheat	Brome	5248	3900	12.3
L.S.D.[y]			NS	NS	NS

[z]Year shown represents year of establishment.
[y]L.S.D. refers to the three-way interaction only.

1.5.2 Experiment Two

1.5.2.1 Environmental Parameters

Conditions in 1992 were drier and cooler than in the two previous years (Table 1.1). Only 9 mm of precipitation was received during the period 11 days prior to seeding and 26 DAS.

1.5.2.2 Residue Cover

The amount of wheat straw spread in the straw return treatment in 1992 was estimated at 6600 kg ha^{-1}. Therefore, experiment two was conducted under lower residue conditions than experiment one. The levels of percent residue cover and percent light interception are shown in Table 1.11. Approximately eight percent of the incoming solar radiation was intercepted by the standing stubble and surface residue in the ZT plots. The amount of residue cover was not affected by straw removal in the ZT plots, however in the CT plots, straw removal significantly reduced residue cover.

1.5.2.3 Crop Establishment

Because no significant interactions involving forage species were observed in experiment two, crop establishment

Table 1.11 Influence of straw management and tillage system on percent light interception and percent residue cover at Portage la Prairie in 1992.

Straw Management (SM)	Tillage System (TS)	Light Interception	Residue Cover
		-------------- % --------------	
Removed	CT	0.0	31
Removed	ZT	8.1	85
Returned	CT	0.0	40
Returned	ZT	8.2	86
L.S.D.		5.2[z]	3.0[y]

[z]L.S.D. refers to effect of straw management under ZT only.
[y]L.S.D. refers to the two-way interaction only.

data was expressed as plant population density instead of percent emergence. Significant tillage effects for plant population density in this experiment were observed on each sampling date. In every instance, plant stand was greater under ZT compared with CT (Figure 1.1 and Table 1.12). At 35 DAS, plant population densities (averaged over forage species) were approximately 200 plants m^{-2} in the ZT treatment and approximately 75 plants m^{-2} in the CT treatment. The higher plant population densities in the ZT treatment would not only be expected to produce higher quality forage (Meyer 1985), but would also compete better with weeds.

Superior forage plant establishment under ZT in this experiment was attributed to higher levels of soil water during the post-seeding period (Figure 1.2). For example,

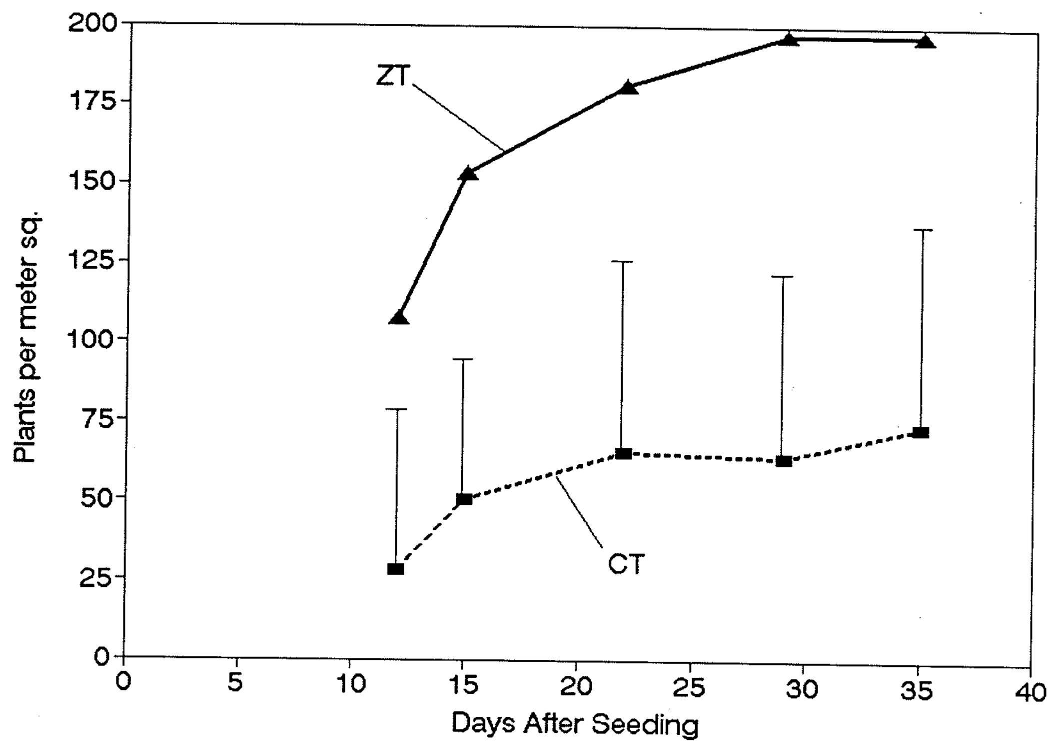


Figure 1.1 Influence of tillage system on forage plant population averaged over straw management treatments and forage species at Portage la Prairie in 1992. Vertical bars represent L.S.D. (0.05).

Table 1.12 Influence of straw management and tillage system on plant population density of alfalfa and meadow bromegrass at Portage la Prairie in 1992. Highlights of analysis of variance are included.

Straw Management (SM)	Tillage System (TS)	Forage Species (FS)	12 DAS	15 DAS	22 DAS	29 DAS	35 DAS
			-----------	-----------	plants m^{-2}	-----------	-----------
Removed	CT	Alfalfa	51	86	111	102	100
Removed	CT	Brome	19	43	53	56	59
Removed	ZT	Alfalfa	135	188	215	221	221
Removed	ZT	Brome	43	85	99	102	116
Returned	CT	Alfalfa	39	52	73	71	115
Returned	CT	Brome	5	21	25	26	20
Returned	ZT	Alfalfa	147	218	270	308	294
Returned	ZT	Brome	82	123	139	158	155
L.S.D.[z]			NS	NS	NS	NS	NS
SM			NS	NS	NS	NS	NS
TS			*	*	*	*	*
FS			**	**	**	***	***
SM X TS			NS	NS	NS	NS	NS
SM X FS			NS	NS	NS	NS	NS
TS X FS			NS	NS	NS	NS	NS
SM X TS X FS			NS	NS	NS	NS	NS

*,**, *** Significant at 0.05, 0.01, and 0.0001 probability levels, respectively.
NS=nonsignificant
[z]L.S.D. refers to the three-way interaction only.

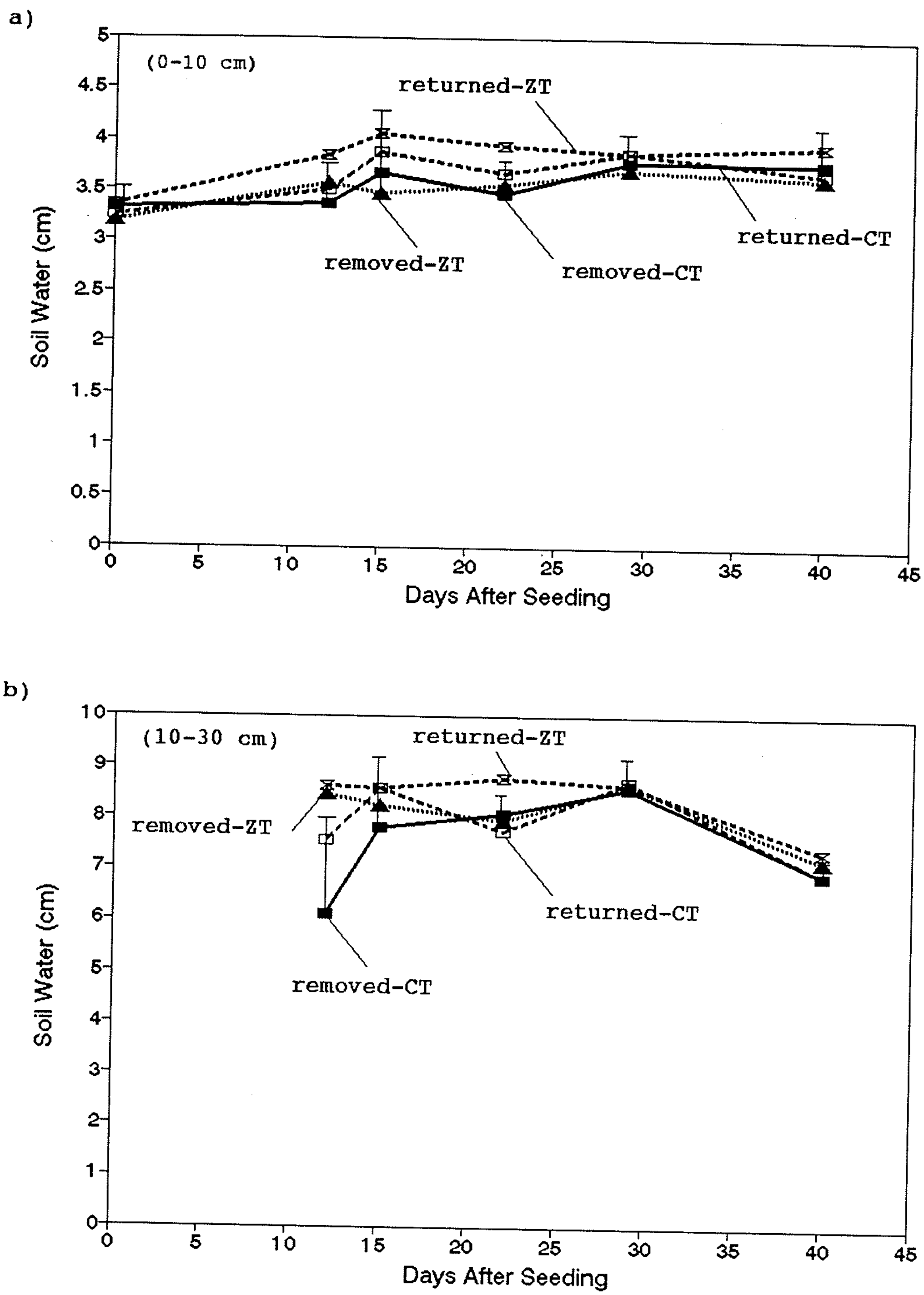


Figure 1.2 Influence of tillage system and wheat straw management treatment on volumetric soil water content in the a) 0 to 10 and b) 10 to 30 cm depths during the crop emergence period at Portage la Prairie in 1992. Vertical bars represent L.S.D. (0.05).

plant population density of alfalfa ($r=0.99^*$) and meadow bromegrass ($r=0.97^*$) 35 DAS was correlated with volumetric soil water content in the 10 and 30 cm soil depth during the establishment period.

1.5.2.4 Crop Development

Forage plant development stage was measured 22, 30, and 40 DAS. Forage species were again analyzed separately. A significant straw management X tillage interaction for alfalfa 22 DAS, indicated that while straw management did not affect trifoliate number of alfalfa under CT, trifoliate number per plant in the ZT treatment was higher where straw had been returned (Table 1.13). These results are opposite to those from the 1991 experiment, where high residue under ZT reduced plant development (Table 1.6). A possible explanation for the different responses is that, in 1991, phenological development under ZT was limited by soil temperature, while in 1992, development rate of alfalfa was affected more by soil water (Figure 1.2). No significant treatment effects for Haun stage were observed for meadow bromegrass in this study (Table 1.13). Observations of plant development indicate that while alfalfa responded positively to ZT, meadow bromegrass was unaffected.

Table 1.13 Influence of straw management and tillage system on trifoliate leaf number of alfalfa and Haun stage of meadow bromegrass at Portage la Prairie in 1992.

Straw Management (SM)	Tillage System (TS)	22 DAS	29 DAS	35 DAS
		--------alfalfa (trifoliate leaf number)-------		
Removed	CT	0.7	2.8	3.8
Removed	ZT	0.7	2.9	4.4
Returned	CT	0.5	2.4	3.6
Returned	ZT	1.1	3.0	4.4
L.S.D.[z]		0.5	NS	NS
		--------meadow bromegrass (Haun stage)--------		
Returned	CT	1.7	2.7	3.3
Returned	CT	1.7	2.8	2.5
Returned	ZT	1.6	2.5	2.8
Returned	ZT	1.6	2.6	3.4
L.S.D.[z]		NS	NS	NS

[z]L.S.D. refers to the two-way interaction only.

1.5.2.5 Dry Matter Production

No significant differences in forage DM production 70 DAS (10% bloom stage of alfalfa; heading stage for meadow bromegrass) were observed for either the tillage or straw management treatments (Table 1.14). The absence of treatment differences for DM production, despite large differences in plant population densities, was attributed to compensatory growth of plants in the CT treatments. This compensatory growth was made possible by the adequate precipitation between the final emergence count and the DM assessment (Table 1.1). Had conditions in 1992 remained dry, it is probable that DM yields would have been higher in the ZT treatments.

1.6 Conclusions

This study provided a detailed analysis of establishment, seedling development and growth of alfalfa and meadow bromegrass under ZT and CT. The performance of both forage species was unaffected or enhanced by ZT when canola or field pea were the preceding crops. However, when the preceding crop was wheat, results were variable. Under conditions of high post-seeding precipitation and above average levels of wheat straw residue, establishment and early growth of meadow bromegrass, and to a lesser extent, alfalfa, was often reduced under ZT. However, under conditions of low post-seeding

Table 1.14 Influence of straw management and tillage system on dry matter production of alfalfa and meadow bromegrass at Portage la Prairie in 1992.

Straw Management (SM)	Tillage System (TS)	Forage Species (FS)	Dry Matter Yield
			----kg ha^{-1}----
Removed	CT	Alfalfa	1886
Removed	CT	Brome	517
Removed	ZT	Alfalfa	1394
Removed	ZT	Brome	401
Returned	CT	Alfalfa	1698
Returned	CT	Brome	396
Returned	ZT	Alfalfa	1741
Returned	ZT	Brome	381
L.S.D.[z]			NS

[z]L.S.D. refers to the three-way interaction only.

precipitation and average wheat straw residue levels, establishment and seedling development of both alfalfa and meadow bromegrass was enhanced by ZT. Similar to previous studies (eg. Lafond et al. 1992), superior crop performance under ZT under dry conditions in the present study was attributed to greater soil water conservation.

Meadow bromegrass appeared to be less well adapted to ZT than alfalfa when the preceding crop was wheat. For example, in 1990 and 1991 (wet conditions and high residue levels), meadow bromegrass was more negatively affected by ZT than alfalfa. In 1992 (drier conditions and average residue levels), meadow bromegrass did not always benefit from ZT to the same extent as alfalfa.

Despite some negative effects of ZT on establishment and first year growth of meadow bromegrass, and to a lesser extent alfalfa, no differences between tillage system or previous crop type were observed for alfalfa or meadow bromegrass DM yield in the year after establishment. These observations indicate that ZT is a feasible alternative for establishing alfalfa and meadow bromegrass, even when the preceding crop is wheat. The ZT system should provide many of the establishment year benefits of a companion crop (eg. protection from blowing soil) with less competition for resources, especially water.

2.0 Agronomic and Physiological Responses of Sod-seeded Alfalfa

2.1 Abstract

Few previous sod-seeding studies have described, in detail, the physiological response of alfalfa growing in areas where the resident vegetation is suppressed or left unsuppressed. This experiment examined the effects of sod-suppression and various seed treatments on the establishment, development, growth, and dry matter production of alfalfa sod-seeded into two different resident swards: timothy (Portage la Prairie) and Kentucky bluegrass/bromegrass mixture (Gladstone). Significant sod-suppression effects on alfalfa emergence and DM production were detected at both locations and indicated that alfalfa emergence and DM production were greater in the sprayed compared to the non-sprayed area. Suppressing the resident vegetation resulted in increased light penetration to the soil surface and increased soil water content. The use of sod-suppression increased alfalfa establishment and DM production approximately 10-fold at Gladstone and three-fold at Portage la Prairie. Sod-suppression did not affect year after establishment DM at Portage la Prairie. Therefore, it was concluded that sod-suppression was not essential for successful establishment at this location. Alfalfa seedlings in the non-sprayed area at Gladstone in 1992 were unable to achieve the critical DM

production of 1.1 g per plant within 12 weeks of seeding in the establishment year. Relative growth rates (RGR's) were significantly greater in the sprayed compared to the non-sprayed area at all times in both years at Gladstone. It was therefore concluded that sod-suppression was essential for successful establishment at Gladstone. A significant seed treatment effect for alfalfa emergence indicated that the 40 kg P_2O_5 ha^{-1} and insecticide treatments, especially carbofuran, reduced alfalfa emergence. The application of 30 and 40 kg P_2O_5 ha^{-1} significantly increased alfalfa DM at Gladstone in 1991, however, there was no significant difference between the two rates. The application of both phosphorous rates also increased resident sod DM production at Portage la Prairie. Under post-seeding drought conditions, pre-soaking seed treatments resulted in increased alfalfa emergence. Despite the adverse effects of some seed treatments, all seed treatments in both the sprayed and non-sprayed areas resulted in a sufficient plant population to form a productive stand (> 100 plants m^{-2})

2.2 Introduction

There are currently 1.6 million hectares of native and tame pastures in Manitoba (Anonymous 1987). Producers often designate land for pasture because it is not suitable for annual crop production (ie. presence of stones, high soil salinity, adverse topography, and risk of soil erosion). The productivity of many Manitoba pastures has declined over time due to over-grazing, encroachment of less productive or unpalatable species, and poor soil fertility. A pasture's declining productivity can be reversed with the introduction of a more desirable forage species. Pasture dry matter production can be increased by as much as 250% when legumes are introduced into low production pastures (Bryan 1985; Taylor and Allinson 1983).

Conventional pasture renovation, which consists of breaking the pasture with tillage, fallowing and reseeding is often not desirable because: 1) it is expensive, 2) it is not feasible due to topography, stones or risk of erosion, 3) establishment is not always successful and 4) grazing is severely limited during the renovation period (Malik and Waddington 1990). An alternative method is to direct-seed, highly productive forage legumes, such as alfalfa, into the resident sward with minimal soil disturbance (Rogers et al. 1983). This technique is often referred to as sod-seeding. Pasture renovation with sod-seeding offers several advantages over conventional renovation: 1) reduced erosion, 2) keeping rocks below the soil surface, 3) conservation of soil water, 4) reduced expenditures of time and liquid fuel, and 5) ability to improve areas which are too steep or inaccessible for traditional tillage methods (Barney and Pass 1987; Wolf et al. 1989).

Sod-seeding is not a new practice. However while some attempts in the past have been successful, others have met with only limited success. Sod-seeding establishment failures are often attributed to heavy sward competition (Kunelius et al. 1982), allelopathic effects by the resident sod (Eltun et al. 1985), seedling diseases (Godfrey et al. 1986), and seedling predation by insects, nematodes, and molluscan pests (Vough et al. 1981). Barker (1990) suggested that the value of direct-seeding as a means of pasture renovation was questionable because seedling establishment and gains in productivity are usually poor. As Barney et al. (1988) indicated, stand establishment under sod-seeding will remain erratic and unpredictable until a greater understanding of the factors affecting establishment is achieved. The objective of this study was to evaluate the effect of sod-suppression, seed-placed phosphorous, seed-placed insecticides, and pre-soaking seed treatments on the establishment, development, and aerial dry matter production of sod-seeded alfalfa.

2.3 Literature Review

2.3.1 Background

The inclusion of alfalfa in grazing lands can, because of its nitrogen fixing ability, increase forage production (Bryan 1985; Taylor and Allinson). Alfalfa is often referred to as the "Queen of Forages" because it has the highest feeding value of all commonly grown forages (Barnes and Gordon 1972). The inclusion of alfalfa in a pasture mixture is known to improve livestock weight gains (Kreuger and Vigil 1979; Koch 1991).

2.3.1.1 Alfalfa in Grass Pastures

Mixtures of forage legumes and grasses are higher in protein and generally higher yielding than forage grasses alone (Smoliak 1981). However, while a high legume percentage in an alfalfa/grass mixture increases pasture productivity, a pasture mixture with too high of an alfalfa component increases bloat hazard in ruminant animals (Jackobs 1963). Therefore, the proportions of alfalfa and grass in pasture mixtures must be based on maximizing forage value without endangering the health of the grazing animal. In western Canada, a pasture mixture with a maximum of 50% alfalfa is recommended for a continuous grazing system (Smoliak 1981).

2.3.1.2 Limitations to Sod-seeding Establishment

2.3.1.2.1. Background

The objective of pasture renovation is to upgrade the quality and quantity of herbage production (Decker et al. 1973). Renovating a pasture with sod-seeding has several advantages over conventional pasture renovation (ie. where pre-seeding tillage is used). Pasture establishment without tillage is often less expensive (Koch 1991), leaves stones beneath the soil surface (Tesar and Marble 1988), extends the length of the grazing season (Kunelius et al. 1982), reduces the risk of soil erosion, and conserves soil water (Mueller-Warrant and Koch 1980).

There are certain factors that limit forage establishment under sod-seeding. Soil insect predators present in the soil can kill sod-seeded legumes and reduce stand persistence (Willis and Thompson 1969; Sheaffer et al. 1982; Byers et al. 1983). However, the major constraint to establishing sod-seeded legumes is competition for resources (water, nutrients, light) with the resident vegetation (Sheaffer 1989). Previous studies have attributed reduced establishment under sod-seeding to competition from the resident vegetation for light (Wilkinson and Gross 1964), nutrients (Mouat and Walker 1959; Williams 1986), and soil water (Groya and Sheaffer 1981; Mueller and Chamblee 1984). McConnaughy and (1987) showed that seedlings need space around them to improve their chances of establishment.

The level of competition for light, nutrients, and soil water depends on the resident vegetation and environmental conditions. For example, bunch type grasses (eg. timothy, crested wheatgrass (*Agropyron desertorum* L.), orchard grass (*Dactylis glomerata* L.)) do not form thick sods, and therefore, would not be expected to be as competitive as rhizomatous grasses (eg. bromegrasses, intermediate wheatgrass *Agropyron intermedium* (Host) Beauv.), Kentucky bluegrass). This decreased competitiveness makes bunch grasses more suitable in mixtures with legumes (Smoliak 1981). Van Riper (1964) found that alfalfa dry matter production was greater when grown in association with orchard grass compared to bromegrass or intermediate wheatgrass. The increased dry matter production was attributed to greater soil water availability during the establishment period when alfalfa was sod-seeded with orchard grass. Groya and Sheaffer (1981) reported that sod-seeded alfalfa seedlings competed more successfully with Kentucky bluegrass than with smooth bromegrass, and attributed this to less shading of the soil surface by the Kentucky bluegrass vegetation.

2.3.1.2.2 Soil Water

Alfalfa requires a well drained soil with good waterholding capacity for maximum production (Eck et al. 1977). While mature alfalfa plants are relatively drought tolerant (Smoliak 1981), alfalfa is particularly vulnerable to soil water deficits during the establishment period because the small seeds are sown near the soil surface (Sheaffer 1989). Dehydration after legume seeds absorb sufficient water for germination and radicle emergence is common, and results in seedling mortality (Cardwell 1984). Germination and emergence of alfalfa sod-seeded into a Kentucky bluegrass sod was influenced more strongly by the amount and distribution of precipitation immediately following seeding than soil and air temperature (Taylor et al. 1969). Bowes and Zentner (1992) also concluded that adequate soil water was the most important factor controlling the establishment of sod-seeded alfalfa in a bluegrass sward.

Once germinated, sod-seeded seedlings continue to face competition for soil water from the resident sward (Waddington et al. 1992; Mueller and Chamblee 1984; Wolf et al. 1989). Taylor et al. (1969) attributed stand reduction and stand failures of sod-seeded alfalfa to inadequate soil water availability. However, by chemically suppressing bands of resident vegetation and placing the seed in the centre of the band, alfalfa emergence was increased approximately 15%. This increase in alfalfa establishment was attributed to enhanced soil water conservation within the chemically suppressed bands. Waddington et al. (1992) working with crested wheatgrass sods found that the amount of available soil water increased as the suppressed strip of resident vegetation increased in width. The researchers reported that a band 50 cm wide was optimum for alfalfa establishment. While many researchers have illustrated that control of sod is important to obtain successful establishment of sod-seeded legumes, Martin et al. (1983) reported that under low rainfall conditions (approximately less than 3 cm for fourteen days post-seeding) even grass suppression with glyphosate or paraquat may not ensure successful legume establishment.

The conservation of soil water begins shortly after an application of glyphosate because upon contact of the herbicide, plant transpiration rates are reduced (Shaner 1978). In this study, transpiration in bean (*Phaseolus vulgaris* L.) plants was reduced 40% approximately 29 hours after an application of glyphosate. This theory was verified by Trimmer and Linscott (1986) who found that the use of sod-suppression increased soil water content by 1.44 cm in the upper 20 cm during the first ten days after treatment. This study also indicated that thirty days after treatment, glyphosate-treated sods used less soil water (1.1 cm less in top 20 cm) than those treated with paraquat.

2.3.1.2.3 Light

Quantity and quality of intercepted light affects seed germination, rate of emergence, plant development, and dry matter production. Therefore, under sod-seeding, shading of alfalfa seedlings by indigenous vegetation could affect seedling establishment by reducing light available for growth.

Crop development is strongly influenced by temperature (Ritchie and NeSmith 1991), however, light conditions are also important (Mitchell 1953). Alfalfa seedlings introduced into a pasture sod are exposed to a different micro-environment (ie. shaded conditions) than alfalfa seedlings established with clear seeding. As a result, seedling development may be affected. Wilkinson and Gross (1964) found that the rate of trifoliate leaf appearance of ladino clover was reduced when grown in competition with orchard grass. The orchard grass plants were initially able to completely shade the ladino clover seedlings, and therefore, clover seedling development lagged. Evers (1989) found that leaf number of berseem clover was reduced significantly when grown in reduced light intensities.

The importance of light for stem production in alfalfa was established by Cowett and Sprague (1963). In their study, alfalfa plants growing in full sunlight and 30% shade averaged 9 and 6.5 stems per plant, respectively. Pritchett and Nelson (1951) found that light intensity was also positively related to alfalfa stem thickness. Cooper (1967) observed that under shaded conditions, alfalfa and birdsfoot trefoil (*Lotus corniculatus* L.) partitioned more dry matter into shoots than roots. This response would severely limit the ability of a shaded seedling to compete with indigenous vegetation for soil water or nutrients. This response was demonstrated by Wilkinson and Gross (1964) who found that berseem clover plants seeded into an orchard grass sod were more sensitive to soil water stress because shaded plants developed shallower root systems. Gist and Mott (1957) reported that drought tolerance of alfalfa was attributed to its extensive root system that developed only in the presence of adequate light. They suggested that shading may indirectly result in death of alfalfa plants due to their inability to obtain adequate soil water during drought periods. Groya and Sheaffer (1981), on the other hand, reported that under shaded conditions (smooth bromegrass and Kentucky bluegrass sods) eliminating any differences in available soil water did not significantly improve sod-seeded alfalfa or white clover establishment. Therefore, reduced legume establishment under shaded conditions was related to factors other than competition with the indigenous vegetation for soil water.

Crop height is also influenced by availability of light. Evers (1989) indicated that as the degree of shading increased (15 to 35% shade), height of berseem clover plants was increased due to petiole elongation. However, beyond 35% shading (50 and 65% shade) plant height was reduced dramatically. In a similar study, alfalfa and smooth bromegrass growing in 63% shade exhibited greater internode elongation and increased height compared with unshaded controls (Pritchett and Nelson 1951). However, plant height was adversely affected when these forage species were exposed to lower light intensities (85 and 91% shade).

Biological nitrogen fixation refers to the ability of plants to convert atmospheric nitrogen, through a symbiotic relationship with nodule forming rhizobia bacteria, into a nitrogen source that can be readily utilized by the plant. These rhizobia are dependent on sugars from the plant, and therefore, any factors affecting the plant's photosynthetic capacity will affect nitrogen fixation. McKee (1962) suggested that poor vigour of legume seedlings in a grass sod may be attributed to a lack of nitrogen because of poor nodulation. Evers (1989) found that nodule number and weight in berseem clover were decreased by 14% and 38%, respectively when grown under 85% full sunlight. The researcher noted that the younger the clover seedling, the more detrimental the reduction in light became. In a similar study, alfalfa nodulation decreased as light intensity decreased from 27 to 15% of full green house light and was completely inhibited when grown in 9% of full green house light (Pritchett and Nelson 1951). Inhibition of alfalfa nodulation was reversed by placing the alfalfa plants back in full light. These results indicate that reducing competition for light may play an important role in the ability of introduced alfalfa to assimilate atmospheric nitrogen.

Shading will also affect other environmental parameters such as air and soil temperature. As shading increases, soil and air temperatures decrease (Cooper 1966). Lower air and soil temperatures would decrease the rate of germination and plant development. Olusuyi and Raguse (1968) observed lower percent emergence of Ladino clover when air temperature was 15°C compared to 20°C. Similarly, Wolf and Blaser (1971) reported that alfalfa leaf development was delayed significantly when grown at 10°C compared to 32°C. Olsen et al. (1981) reported that by eliminating the resident tall fescue (*Festuca arundinacea* Schreb.) sward and corresponding shading effects, sod-seeded alfalfa development and growth was enhanced. In this study, one of the barriers limiting sod-seeding establishment was the presence of insect predators that existed in the indigenous sod. Welty et al. (1981) attributed increased sod-seedling ladino clover establishment to the fact that, with sod-suppression, sunlight was able to penetrate to the soil surface, dry out the furrow and provide a less favourable environment for slugs (*Deroceras* spp.).

2.3.1.2.4 Soil Nutrients

In addition to competing with the introduced seedlings for available soil water and light, the resident vegetation also competes for available soil nutrients. The ability of a plant species to compete for certain soil nutrients, such as phosphorous, depends indirectly upon the cation-exchange capacity in the root and the rate of plant growth (Mouat and Walker 1959). Mattson (1926) indicated that the Donnan distribution of ions in the root-external solution system may control the uptake of cations and anions. Therefore, a system containing two plant-root colloids should show a greater activity of phosphate in the lower cation-exchange capacity (CEC) root than that in the higher CEC. Drake et al. (1951) found that the cation-exchange capacity of dicotyledons was approximately double that of monocotyledons. Therefore, legumes will be poor competitors for certain soil nutrients when growing in association with grass species. This theory may explain why sod-seeded alfalfa generally responds well to the addition of synthetic fertilizers (Gray et al. 1953; Williams et al. 1985; Bryan 1985). Another reason sod-seeded alfalfa responds well to the addition of fertilizer is that most pasture and rangeland soils are deficient in soil nutrients.

2.3.1.2.5 Insect Predators

Germinating legume seeds and seedlings are an attractive, succulent food source for insect pests that inhabit sods. Byers et al. (1983) stated that many scientists attribute legume establishment failure to soil water factors and grass competition, when in fact, insects and slugs are partly or solely responsible. Godfrey et al. (1986) attributed a 44% decrease in alfalfa seedling density to soil-borne insects three weeks after sod-seeding.

Root lesion nematodes (*Pratylenchus penetrans* (Cobb) Filipj. Schuur-Stekh.) (Sheaffer et al. 1982), slugs (Byers et al. 1985), snails (*Polygyra spp.*), grasshoppers (*Melanoplus spp.*) and crickets (*Gryllus spp.*) (Rogers et al. 1985) have all been implicated in sod-seeded legume establishment failures. Sub-lethal feeding damage by soil insects can create an entry point for *Fusarium spp.*, causing root rot. Sheaffer et al. (1982) found that the extent of root invasion by the *Fusarium* fungus was determined by prior activity of the root lesion nematode. This nematode-fungal association has been reported for alfalfa in other studies (Welty et al. 1980; Willis and Thompson 1969) as well.

2.3.1.2.6 Conclusions

There are a number of factors responsible for the erratic establishment of forages with sod-seeding. Competition for light and soil water from the existing sward appear to be the main factors. Therefore, management factors that reduce or eliminate shading and increase available soil water for germination and early growth should enhance seedling emergence, development, growth, and aerial dry matter production of sod-seeded alfalfa plants. Controlling insects and correcting soil nutrient deficiencies should also improve the success of sod-seeded alfalfa.

2.3.2 Management Factors Affecting Sod-seeded Alfalfa

2.3.2.1 Chemical Suppression of Resident Sward

Paraquat and glyphosate are two herbicides that have been investigated most thoroughly for their ability to enhance establishment of sod-seeded alfalfa by suppressing the resident vegetation prior to seeding (Tesar and Marble 1988). If an effective non-systemic herbicide such as paraquat is applied to the resident sward, only temporary sod-suppression is achieved and eventually the resident vegetation will resume growth (Vogel et al. 1983). Glyphosate, a systemic herbicide, is more effective than paraquat (Wolf et al. 1989), although in some instances it only suppresses grasses (Tesar and Marble 1988). Vogel et al. (1983) sod-seeded alfalfa into a smooth bromegrass sod and obtained forage stands that were 50% and 100% alfalfa when the resident sod was sprayed with paraquat (0.6 kg a.i. ha^{-1}) and glyphosate (1.7 kg a.i. ha^{-1}), respectively. Therefore, paraquat suppressed the smooth bromegrass while glyphosate killed the resident vegetation. The level of sod-suppression obtained with herbicides depends on the uptake pattern of the target species and the herbicide dosage.

Successful sod-seeding establishment has depended upon suppression of the resident vegetation in some studies while in others, satisfactory establishment has been obtained in the absence of vegetation suppression. For example, Zarnstorff et al. (1990) reported adequate stands of alfalfa (491 plants m^{-2}) were obtained when sod-seeded into a tall fescue sward without suppression. It should be noted however, that seedling responses to sod-seeding measured in the establishment year may not be good indicators of dry matter production potential or long-term survival of the sod-seeded plants.

The effects of sod-suppression with herbicides are most frequently evaluated on the basis of yield (aerial dry matter production), and it is well documented that chemical suppression of resident vegetation increases dry matter production of sod-seeded alfalfa (Vogel et al. 1983; Belanger and Winch 1985; Zarnstorff et al. 1990). Roth et al. (1985) found that yields of sod-seeded alfalfa following sod-suppression with glyphosate were equivalent to or better than yields when alfalfa was seeded into a tilled seedbed.

Rogers et al. (1983) reported 2564 kg ha^{-1} dry matter produced in the presence of sod-suppression with paraquat compared to 183 kg ha^{-1} produced without suppressing the resident vegetation. Zarnstorff et al. (1990) reported a two-fold increase in alfalfa dry matter production (6770 vs. 3270 kg ha^{-1}) in the seeding year when herbicides were used to suppress tall fescue. Similarly, Belanger and Winch (1985) reported a two to three-fold increase in alfalfa dry matter production in the establishment year when the resident bromegrass sod was suppressed with glyphosate. These researchers concluded that sod-suppression was essential to obtain adequate dry matter production in the establishment year.

Crop growth is frequently characterized by measuring crop height, since crop height and dry matter accumulation are often highly correlated (Deibert and Utter 1989). Factors affecting height of seedlings established by sod-seeding include shading from the resident vegetation as well as below ground competition for soil water and nutrients. Taylor et al. (1972) found that by killing a Kentucky bluegrass sod with paraquat, white clover and alfalfa plant height were significantly greater in the sprayed compared to the non-sprayed area. They attributed the response to reduced shading of the legume seedlings and, in part, to a higher soil water content in the herbicide treated plots.

2.3.2.2 Seed-Placed Phosphorous

Legumes require relatively large amounts of phosphorous to maximize growth (Smoliak 1981). A readily available supply of phosphorous within reach of young seedlings is essential for normal root development and seedling establishment

(Woodhouse and Griffith 1973).

Seeding-placed phosphorous is known to increase establishment of sod-seeded legumes. For example, Williams et al. (1985) reported improved stand establishment of white clover with the addition of 50 kg P_2O_5 ha^{-1} when it was placed below the seed. Similarly, Bryan (1985) concluded that the application of 67 kg ha^{-1} phosphorous significantly increased red clover and birdsfoot trefoil seedling establishment. However, Malik and Waddington (1990) reported that the placement of phosphorous up to 60 kg P_2O_5 ha^{-1} with sod-seeded alfalfa and cicer milkvetch did not improve stand establishment even though soil tests indicated phosphorous deficiencies. Therefore, the addition of phosphorous in sod-studies has produced inconsistent results.

The addition of phosphorous to enhance development rate of sod-seeded alfalfa has not been reported in the literature. However, Sheard (1980) found that the application of 30 kg ha^{-1} of phosphorous enhanced seedling development in conventionally seeded alfalfa and birdsfoot trefoil, even on soils testing high in available phosphorous. In an earlier study, Sheard et al. (1971) indicated that without the application of phosphorous fertilizer, alfalfa was unable to rapidly develop a root system. The authors concluded that since alfalfa development is influenced by two major environmental conditions, temperature and soil water, which cannot be predicted at the time of seeding, the practice of seed-applying phosphorous, which will hasten early seedling development, must become an accepted procedure.

Several studies found that applying phosphorous increased both crop dry matter production and height. Sheard (1980) found that dry matter accumulation of alfalfa, birdsfoot trefoil, and bromegrass were increased as much as five-fold with a seed-placed band application of 30 kg ha^{-1} of phosphorous. Rhem (1984) reported a linear increase in dry matter yield of several warm season grasses to additions of P_2O_5 between 0 and 24 kg ha^{-1}. Williams (1986) found that white clover yield was increased from 13 to 242 kg ha^{-1} when 100 kg P_2O_5 ha^{-1} was placed below the seed in the seedrow. Black and Wright (1972) reported a three-fold increase in total forage dry matter production when 90 kg P_2O_5 ha^{-1} was applied to rangeland pasture. Therefore, positive responses to forage dry matter production have been reported from applications of phosphorous.

Williams et al. (1985) found that the addition of 50 kg ha^{-1} of phosphorous increased the height of white clover (7.6 cm) compared to the unfertilized control (5.7 cm). Sheard et al. (1971) reported large increases in height of alfalfa and birdsfoot trefoil with a seed-placed band application of 20 kg ha^{-1} of phosphorous. In a later study, Sheard (1980) reported that placing 45 kg ha^{-1} with the seed decreased alfalfa and bromegrass height compared to 30 kg ha^{-1}. Although no explanation for this observation was given, the higher rate of phosphorous being seed-placed may have been toxic to the seedlings.

2.3.2.3 Seed-placed Insecticides

The most widely reported insecticide used in sod-seeding is carbofuran. Carbofuran, a carbamate insecticide, is recommended for alfalfa establishment in the United States (Wolf 1988).

Dowling and Linscott (1983) observed three times as many alfalfa seedlings in carbofuran (1.1 kg a.i. ha^{-1}) treated plots compared to untreated plots. Similarly, Sheaffer et al. (1982) found significantly greater populations of alfalfa and birdsfoot trefoil in the presence of 2.2 kg a.i. ha^{-1} carbofuran compared to the control plots. In the latter study, the increase in plant stand was attributed to the control of root lesion nematodes. Belanger and Winch (1985) also reported a positive effect of carbofuran on plant stand of alfalfa and birdsfoot trefoil, however, no correlation between the application of carbofuran and nematode populations was observed. Grant et al. (1982) found that the application of carbofuran resulted in greater initial alfalfa seedling densities but did not significantly affect the rate of seedling loss. Thus, inconsistent responses to the application of insecticides with sod-seeded alfalfa establishment have been reported in the literature.

The possibility that pesticides in soil may have an adverse effect on the Rhizobium-legume symbiosis is of obvious concern in alfalfa production. Belanger and Winch (1985) reported that carbofuran had no affect on nodule number in alfalfa yet increased the amount of nitrogen fixation per nodule. Since this increased fixation was observed in a nematode-free environment, the authors concluded that a direct physiological effect on the plant component of the plant-rhizobium was responsible. Kulkarni et al. (1974) indicated that soil applied carbofuran did not affect nodule number or the leghaemoglobin content of groundnut (*Arachis hypogaea* L.), and therefore, nitrogen fixation was not affected. Rodell et al. (1977) observed phytotoxic effects of carbofuran on soybean (*Glycine max* L.), such as leaf discoloration and spotting, when the insecticide was soil applied. However, no adverse effects were observed in the plant's ability to fix nitrogen.

The use of insecticides in sod-seeding appears to also influence the rate of seedling development. For example, Pless et al. (1971) indicated that two classes of insecticides, organophosphates and carbamates, promoted plant development. In this study, tobacco (*Nicotaina tabacum* L.) plants grown on soil treated with carbofuran matured two weeks earlier than non-treated plants. Carbofuran applied to caucasian bluestem (*Bothriochloa caucasia* (Trin.) C.E. Hubard) and switchgrass (*Panicum virgatum* L.) resulted in a 32%

increase in plant development compared to control plots (McKenna et al. 1991). Therefore, previous research has suggested that insecticides may have the ability to enhance plant development.

Lee (1976) suggested that the ability of carbofuran to promote plant development may be related to the relationship of carbofuran metabolites and a plant's indole-acetic acid (IAA) concentration. Indole-acetic acid is a growth promoting hormone that occurs naturally in plants. Lee (1976) found that one metabolite of carbofuran, 3-hydroxy-carbofuran phenol, affected the enzyme system, IAA oxidase, which catalyses the oxidation of IAA. The metabolite essentially interrupted IAA oxidation and levels of the hormone increased in the pea stems. Pea stem growth stimulation was attributed to the enhanced levels of IAA. In the absence of IAA, no stimulation of plant growth was observed. On the other hand, Kehr et al. (1982) reported no effect of carbofuran on alfalfa seedling development, even though insect predators (aphids, leafhoppers, and plant bugs) were controlled. Byers et al. (1985) observed enhanced development of red clover but no response in alfalfa seedling development in the presence of 2.2 kg a.i. ha^{-1} carbofuran granules. Therefore, the effect of carbofuran on the development of sod-seeded alfalfa is not yet fully understood.

The use of insecticides for sod-seeding establishment also affects dry matter accumulation and plant height. For example, Dowling and Linscott (1983) noted increased yield (as high as 50%) of sod-seeded alfalfa with the application of carbofuran. These researchers noted that the enhancing effect of carbofuran on alfalfa yield was still observed the year after establishment. In a similar study, Belanger and Winch (1985) found that dry matter production of sod-seeded alfalfa and birdsfoot trefoil was enhanced in the presence of carbofuran. Since no effect of carbofuran on soil nematodes was observed, the researchers attributed the improved dry matter production to a positive physiological effect of carbofuran on plant growth. Pless et al. (1971) found that tobacco dry matter production was significantly increased (approximately 15%) with the application of carbofuran. Barney et al. (1988) suggested that higher soil organic matter levels associated with zero-tillage retain carbofuran more readily, and therefore, enhance uptake by the plant. Since pasture sod results in a relatively large amount of organic matter being retained near the soil surface, the effects of seed-placed insecticides on alfalfa establishment may be apparent under sod-seeding.

Grant et al. (1982) found that the application of an insecticide and molluscicide had little apparent effect on alfalfa seedling height. In contrast, McKenna et al. (1991) found that the height of switchgrass and caucasian bluestem treated with carbofuran was three times greater than untreated plants. Barney et al. (1988) reported a 9 cm increase in sod-seeded alfalfa stem height when 2.2 kg a.i. ha^{-1} of carbofuran was foliar applied compared to untreated plants. These researchers proposed that insecticides, such as carbofuran, or their metabolites, function as growth stimulants within the plant resulting in an unknown physiological response (Pless et al. 1971). Therefore, it appears that the establishment of sod-seeded alfalfa may be enhanced in the presence of seed-placed insecticides.

2.3.2.4 Pre-seeding Seed Hydration with Water and Gibberellic Acid

Soaking seeds in water prior to seeding can enhance crop emergence and establishment. For example, Chippindale (1934) observed more rapid germination in tame oat that had been soaked in water prior to seeding. Similarly, Bleak and Keller (1970) found that soaking crested wheatgrass in water prior to seeding enhanced germination and emergence, especially when soil water became limiting. Increased root and shoot development from pre-soaking in water was observed for crested wheatgrass (Keller and Bleak 1969) and *Bromus* and *Agropyron* species (Bleak and Keller 1972). Prior soaking in water of various *gramineae* seeds resulted in more rapid plant development rates (Chippindale 1934). Keller and Bleak (1969) found increased shoot length (approximately 10 mm longer) of crested wheatgrass after the seeds had soaked in water prior to seeding. Thus, pre-soaking seed in water prior to seeding may enhance germination and emergence of sod-seeded alfalfa, especially if soil water is limiting.

The application of growth hormones to seed prior to seeding has also affected seedling establishment. Pauli and Stickler (1961) indicated that seed-applied gibberellic acid enhanced the rate of emergence in grain sorghum. Therefore, the potential exists for using pre-soaking treatments as an effective tool to enhance sod-seeding establishment.

Treating wheat seeds with gibberellic acid prior to seeding resulted in greater leaf development rates (Bhat et al. 1990). This observation was attributed to the growth promoting abilities of gibberellic acid.

The effects of pre-seeding treatments on seeds are usually observed during the germination and emergence period. Aqueous solutions of 100 ppm gibberellic acid increased shoot dry matter production of pinto bean (*Phaseolus vulgaris* L.) 35% above the control (Marth et al. 1956). However, in an experiment where gibberellic acid was seed applied, no effect on sorghum grain yield or yield components was observed (Pauli and Stickler 1961). The effect of gibberellic acid on growth of sod-seeded alfalfa does not appear to have been previously investigated.

Plant height is also influenced by pre-seeding seed treatments and foliar applications of gibberellic acid. Brain and Hemming (1955) indicated that pea seedling height was increased with the application of 200 ppm gibberellic acid to the seed. Similarly, Alder et al. (1959) found that, at certain stages of development, foliar applications of gibberellic acid significantly increased corn plant height. Increased stem elongation continued for more than 30 days when 100 and 300 ppm of gibberellic acid were applied to pinto bean plants (Marth et al. 1956).

It appears that there is a threshold concentration of gibberellic acid. Application of the growth hormone stimulates plant growth to a certain concentration but inhibits growth at further concentrations. Allan et al. (1959) observed growth stimulation in wheat with the application of 100 ppm of gibberellic acid but inhibitory effects with the application of 1000 ppm. Pauli and Stickler (1961) reported that pre-seeding application of gibberellic acid to grain sorghum seed did not influence plant height.

2.3.3 Conclusions

The potential for chemical sod-suppression and various seed treatments (ie. seed-placed phosphorous, insecticides, synthetic growth hormones) to improve sod-seeded alfalfa establishment have been discussed. The suitability of these various treatments to enhance sod-seeded alfalfa establishment and survival will depend on how these treatments influence alfalfa seedling emergence, development and growth.

2.4 Methods and Materials

2.4.1 General

Field experiments were conducted in 1991 and 1992 at two different sites in south-central Manitoba. The first site was at the University of Manitoba Research Station at Portage la Prairie, MB. (50°N, 98°W). The soil type was a Neuhorst clay loam. The existing sward was a relatively productive timothy (cv. Climax) sward seeded with 15 cm row spacing that had never been grazed but was mowed regularly. The second site was located near Gladstone, MB. (50°11'N, 99°1'W) on an overgrazed native pasture (predominant species were bluegrass and smooth bromegrass). The soil type at this site was an Isafold loamy sand.

In 1991 and 1992, in early spring before spraying, both sites were soil tested to obtain a baseline soil fertility level (Table A3.2). No fertilizer was applied except in the seed-placed phosphorous treatments. The experimental design at both sites was a split-plot with sod-suppression (sprayed vs. non-sprayed) as the main plot and seed treatment as the subplot. The subplots were 3 m x 10 m and each treatment was replicated 4 times.

The sprayed main plots were treated with 0.890 kg a.i. ha^{-1} glyphosate approximately seven days prior to seeding. Approximately 30 days after seeding (DAS) in 1991, both sites were sprayed with sethoxydim (0.515 kg a.i. ha^{-1}) to suppress the grass regrowth.

2.4.2 Seed Treatments

Prior to applying the seed treatments, all alfalfa seed was sized using seed sieves (with an opening of 1.25 mm). Only the portion of seed greater than 1.25 mm in size was used in the experiment. This seed had a thousand kernel mass of 1.83 g.

Seed treatments investigated were: 1. 30 kg P_2O_5 ha^{-1} seed-placed, 2. 40 kg P_2O_5 ha^{-1} seed-placed, 3. 100 ppm gibberellic acid (GA_3), 4. 200 ppm gibberellic acid (GA_3), 5. seed-placed terbufos at 0.5 kg a.i. ha^{-1}, 6. seed-placed carbofuran at 0.28 kg a.i. ha^{-1}, 7. distilled water-soaked control, and 8. control. The GA_3 and water-soaked control seed treatments required special treatment before seeding. Different seed lots were used in 1991 and 1992, and therefore, the seed treatments were applied to new seed each year. Therefore, Aqueous solutions containing 100 and 200 ppm GA_3 were formulated using the following procedure. The required amount of granular GA_3 was dissolved in 0.05 L of sodium hydroxide. Once dissolved the mixture was added to 1 L of distilled water. The pH of each solution was then tested. The solution containing 100 ppm GA_3 had a pH of 7.9. The solution containing 200 ppm GA_3 had a pH of 11.2 which was adjusted to 8.3 with the required amount of hydrochloric acid. Prior to soaking, the seed was weighed to determine its original mass. Seed was soaked in each GA_3 solution (including distilled water) for 6 hours. After this time, the seed was removed and dried at 23°C and a relative humidity of 40% in the dark (approximately 12 to 18 hours). After 12 hours, the seed was weighed regularly until it had achieved its original mass. All seed was re-inoculated with *Rhizobium meliloti* prior to seeding.

2.4.3 Crop Management

No tillage operations were performed in this study. In 1991 and 1992 at both sites, certified alfalfa, cv. Rangelander, was seeded directly into the resident sward at a rate of 505 viable seeds m^{-2} (approximately 10 kg ha^{-1}). The Gladstone site was seeded on May 18 in 1991 and May 13 in 1992. The Portage la Prairie site was seeded on May 21 in 1991 and May 15 in 1992. Alfalfa was seeded at an angle to the timothy rows at this location. Both experimental sites were seeded with a Connor Shea Coil Tyne Coulter Drill (Connor Shea., Victoria, Australia) with a 15 cm row space and were packed with a lawn packer immediately after seeding.

2.4.4 Measurements

Stand establishment (emergence) of alfalfa was monitored every seven to ten days until approximately 35 DAS. Plant population density was determined by counting the number of plants in the same randomly chosen 0.5 m^2 area within each subplot. Plant height and plant development stage (as indicated by number of fully emerged trifoliate leaves) were also measured on 10 randomly selected plants within each subplot at the time that plant population density was determined. For the purposes of this study, plant development describes the change in number of fully emerged trifoliate leaves. During the emergence period, the level of solar radiation reaching the soil surface was measured using a Licor Model LI-185B quantum meter with a line quantum sensor (1 m long) at solar noon. Percent light interception was calculated by comparing the quantum flux (uE $M^{-2}s^{-1}$) at the soil surface with that 1 m above the soil surface.

Aerial dry matter (DM) production of alfalfa and the resident sward was determined in one randomly selected 0.25 m^2 areas in each subplot at both sites in 1991 and 1992. Samples were dried for 48 hours at 70°C before weighing. In the non-sprayed area, the resident sward DM was harvested separately from the alfalfa portion. After the second DM harvest in 1991, the plot area was harvested completely at Gladstone and Portage la Prairie. Second year DM measurements were taken when alfalfa was 10% bloom at the sites that were established in 1991. Individual plant DM production was calculated by dividing the alfalfa DM m^{-2} by the number of plants m^{-2} from a $0.5m^2$ sample. In both years, relative growth rates (g $plant^{-1}$ day^{-1}) were calculated for the interval between seeding and the first harvest date (time 1), and between harvest dates (time 2).

Volumetric soil water content between 0 and 10 cm and 10 and 30 cm (1992 only) was determined at both sites in 1991 and 1992. Soil water content was determined at seeding and at intervals during the emergence period in the control treatment in the sprayed and non-sprayed area. The soil water in a soil core approximately 10 cm in diameter was determined after drying for 48 hours at 70°C. Daily maximum, minimum, and mean air temperature and daily precipitation were monitored throughout the growing season at both sites using a Campbell Model CR-10 datalogger (Campbell Scientific Inc., Logan, Utah). Daily maximum and minimum soil temperature for 0, 2, 8, and 20 cm depths was measured in the control plot of one replicate in the sprayed and non-sprayed area at Gladstone in 1991 and 1992 and at Portage la Prairie in 1992 only.

2.4.5 Statistical Analysis

All data gathered were subjected to analysis of variance (Statistical Analysis Systems Institute, 1986). Mean separations were conducted using the Fisher Protected least significant difference (LSD) test at the p=0.05 level, after GLM indicated significant ($p < 0.05$) differences. Significant interaction ($p < 0.05$) mean separations (for two-way interactions) were calculated using the technique described by Gomez and Gomez (1984). Homogeneity of error variances was checked using the maximum F test (Rohlf and Sokal 1969).

2.5 Results and Discussion

Due to lack of homogeneity of error variances, no combined analysis was conducted (ie. the data was not combined over years or sites). Therefore, both the Gladstone and the Portage la Prairie site will be discussed separately with both 1991 and 1992 being discussed individually.

2.5.1 Physical Measurements of the Environment

At Gladstone and Portage la Prairie in 1991, precipitation and air temperature during the growing season were similar to or exceeded the long-term average (Tables 1.1 and 2.1). At Gladstone, precipitation in June and July was considerably higher than the long-term average (Table 2.1). At both sites in 1992, air temperature was below the long-term average from June through September (Tables 1.1 and 2.1). Precipitation was much below normal during the emergence period (May and early June) and similar to the long-term average for the remainder of the growing season (Tables 1.1 and 2.1). Air temperature was above normal in May of both years and this may have exaggerated the effects of below normal precipitation. Therefore, the experiment was conducted under virtually ideal growing conditions in 1991 and under more adverse conditions in 1992.

Table 2.1 Monthly mean air temperature and precipitation at Gladstone, Manitoba, in 1991 and 1992, and the 17-year average (1973-1990)[z]

	temperature (C)				precipitation (mm)		
	1991	1992	Avg.		1991	1992	Avg.
May	13.8	13.4	11.2		45.4	8.6	54.7
June	17.8	15.0	16.7		146.6	64.5	71.7
July	19.0	15.9	19.6		104.4	83.8	62.6
August	17.9	16.4	17.8		15.6	68.1	72.0
Sept.	12.2	10.9	12.1		74.8	71.0	55.7
Avg.	16.9	14.3	15.5	Total	386.8	296.0	316.7

[z]Environment Canada Atmospheric Environment Service, Winnipeg, Manitoba, R3C 3V4. The 17-year average (1973-1990) is the most recent period for which data has been compiled.

2.5.1.1 Volumetric Soil Water Content

Adequate precipitation at both sites throughout the growing season in 1991 (Tables 1.1 and 2.1) prevented any water conserving benefits of sod-suppression from being expressed (Figure 2.1). The only significant sod-suppression

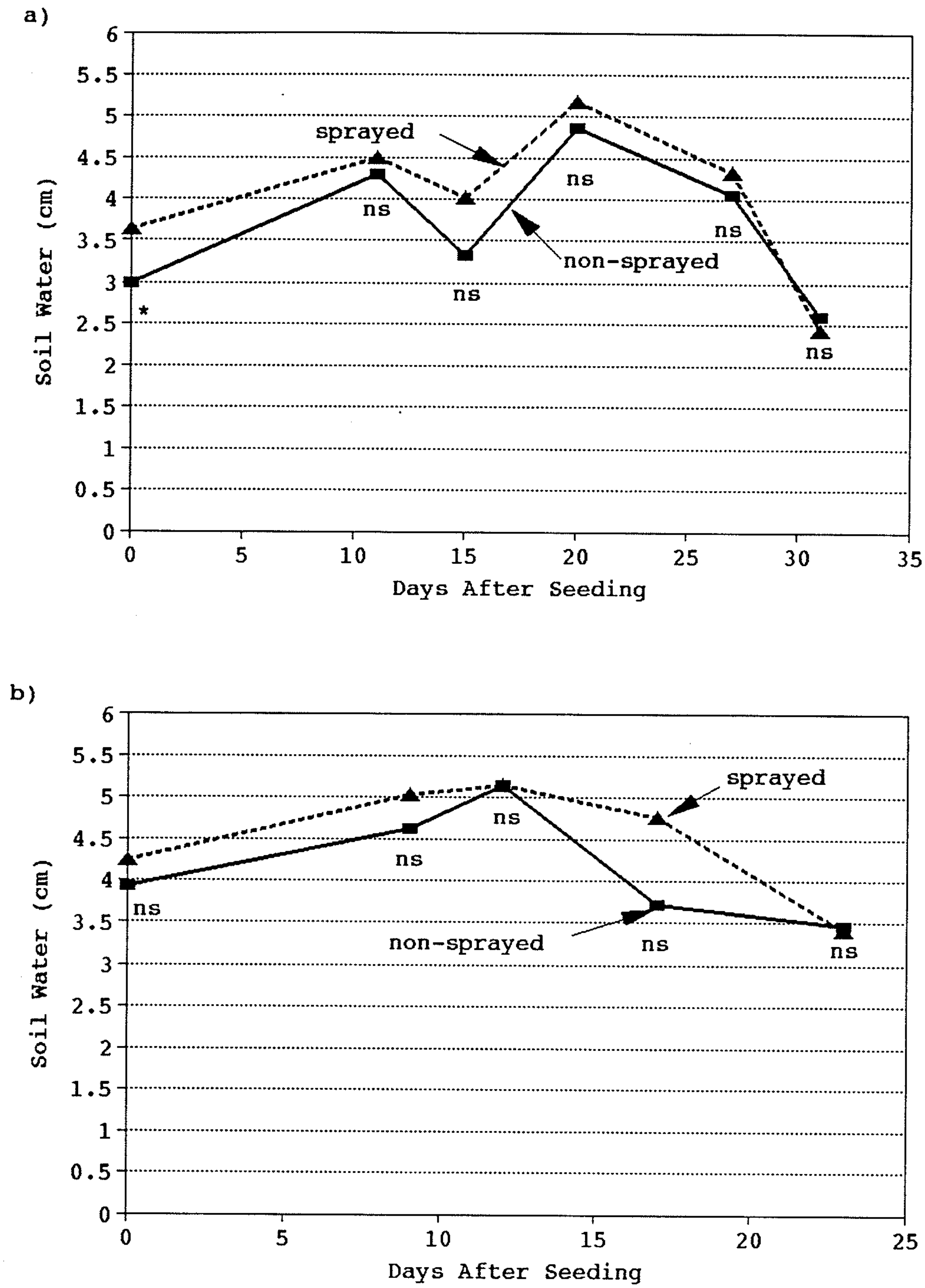


Figure 2.1 Influence of sod-suppression on volumetric soil water content (0 to 10 cm) at a) Gladstone and b) Portage la Prairie in 1991. * Significant at 0.05 probability level; ns=nonsignificant.

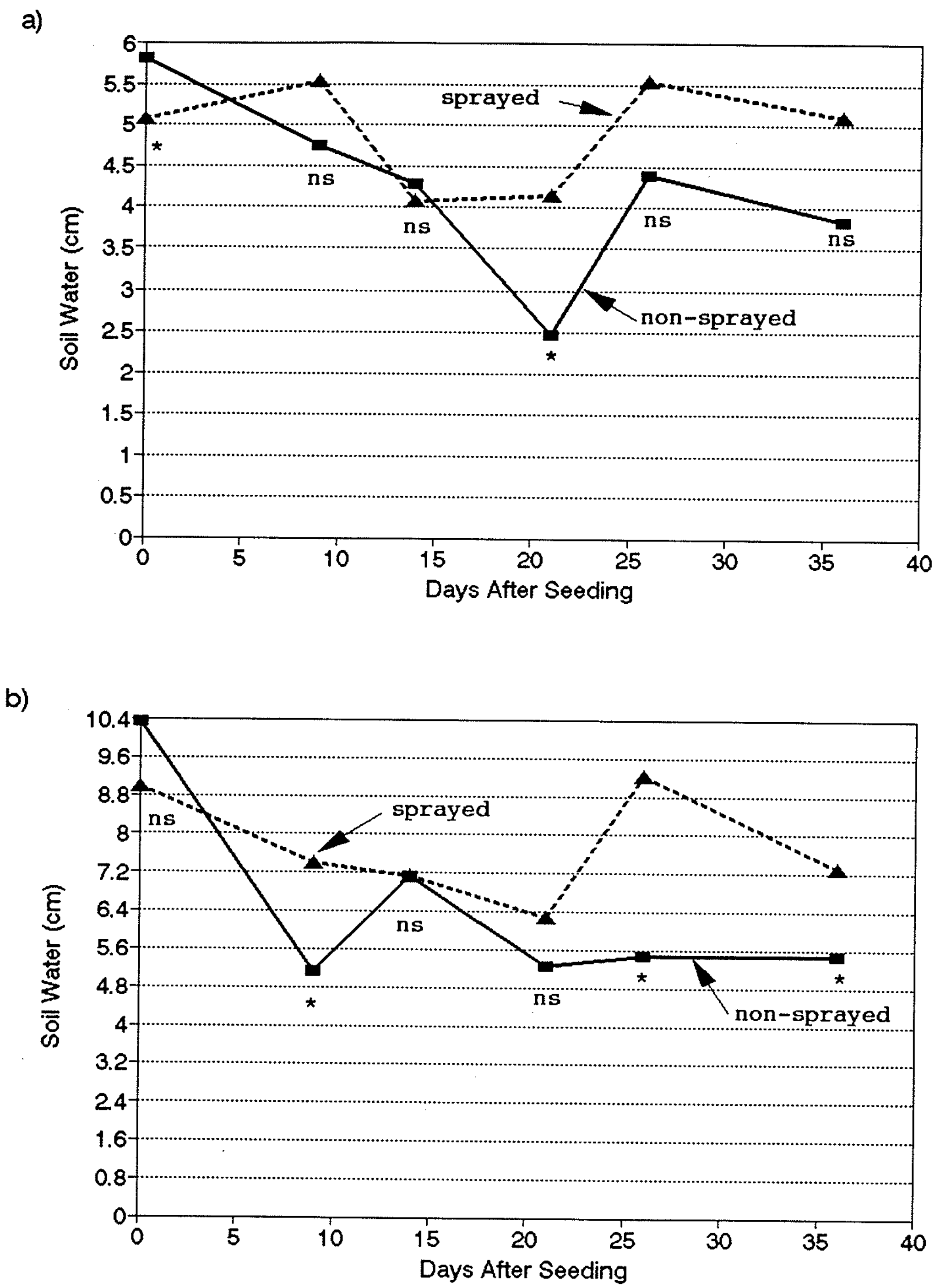
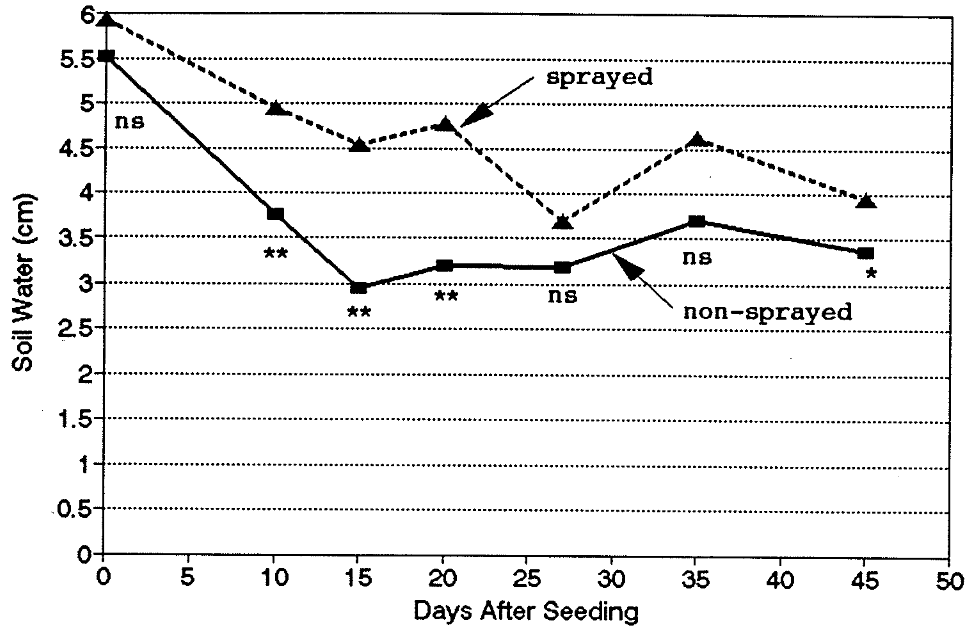


Figure 2.2 Influence of sod-suppression on volumetric soil water content at a) 0 to 10 cm and b) 10 to 30 cm depth at Gladstone in 1992. * Significant at 0.05 probability level; ns=nonsignificant.

a)



b)

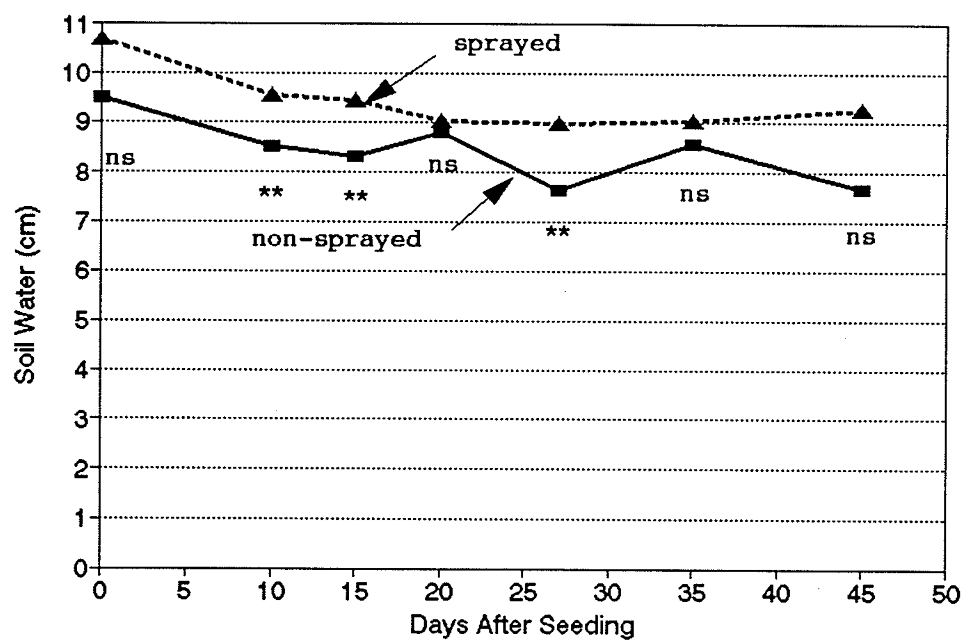


Figure 2.3 Influence of sod-suppression on volumetric soil water content at a) 0 to 10 cm and b) 10 to 30 cm depth at Portage la Prairie in 1992. **, * Significant at 0.01 and 0.05 probability levels, respectively. ns=nonsignificant.

effect on volumetric soil water content from both sites in 1991 was at seeding in Gladstone (Figure 2.1a). At this time, there was significantly more soil water in the 0 to 10 cm depth in the sprayed compared to the non-sprayed area (Figure 2.1a).

At Gladstone in 1992, soil moisture at seeding (0 DAS) in the 0 to 10 cm depth was influenced by sod-suppression. Significantly greater soil water was present in the non-sprayed compared to the sprayed area (Figure 2.2a). This was opposite to what was expected. Since glyphosate was applied only a week prior to seeding, plants in the sprayed treatment may still have been transpiring. At 21 DAS, significantly more soil water was present in the sprayed compared to the non-sprayed area. No significant differences in soil water content in the 0 to 10 cm depth were observed between the sprayed and non-sprayed areas 9, 14, 26, or 36 DAS (Figure 2.2a). In general, available soil water in the top 10 cm was similar regardless of sod-suppression. No significant differences in water content between 10 and 30 cm were detected at seeding (0 DAS), 14 or 21 DAS (Figure 2.2b) at Gladstone in 1992. However 9, 26, and 36 DAS, significantly more soil water was present in the sprayed compared to the non-sprayed area (Figure 2.2b).

At Portage la Prairie in 1992, no significant differences in soil water (0 to 10 cm) were observed at seeding, 27, and 35 DAS (Figure 2.3a). On the 10, 15, 20, and 45 DAS sampling dates, however, significantly more soil water was present between 0 and 10 cm in the sprayed compared to the non-sprayed area (Figure 2.3a). Significant sod-suppression effects on soil water content in the 10 to 30 cm soil zone were detected only on the 10, 15, and 27 DAS sampling dates (Figure 2.3b). On these dates, significantly more soil water was present in the sprayed compared to the non-sprayed area.

In summary, soil water content was increased at both sites in 1992 with the use of sod-suppression. The greatest increase was observed at Gladstone 27 DAS when soil water content in the 10 to 30 cm depth was 3.8 cm greater in the sprayed compared to the non-sprayed treatment. Chemically suppressing the resident vegetation conserved soil water in the present study which is consistent with similar studies in the literature. For example, Trimmer and Linscott (1986) reported increased water content (1.44 cm more in the upper 20 cm) with chemical suppression of a Kentucky bluegrass and orchardgrass sward. Waddington et al. (1992) observed approximately 7% more soil water in the top 20 cm when the resident crested wheatgrass was sprayed with glyphosate compared to the non-sprayed treatment. This increased soil water in the presence of sod-suppression should enhance the establishment and early season growth of sod-seeded alfalfa.

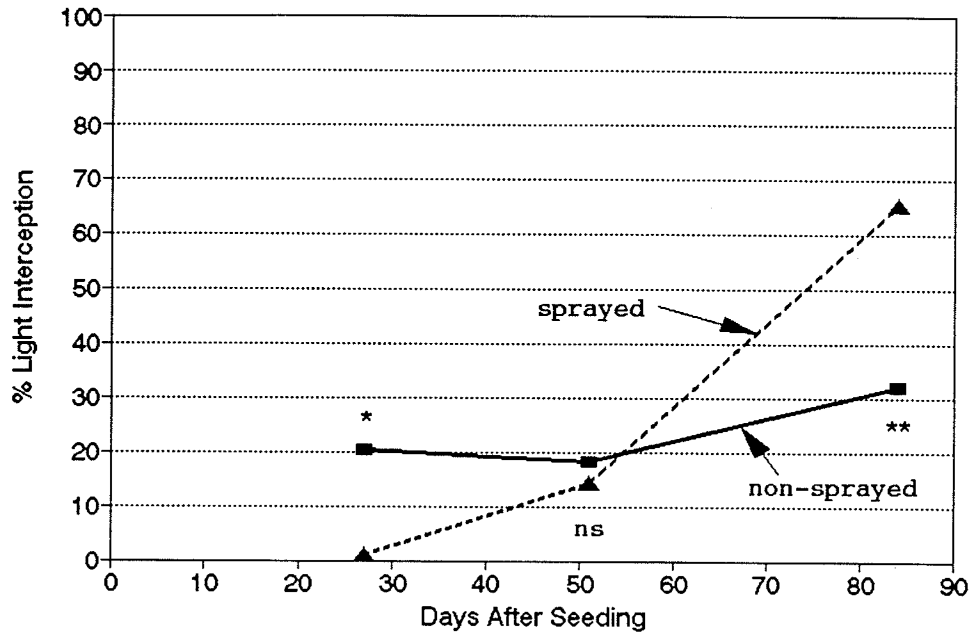
2.5.1.2 Light Interception

No significant sod-suppression X seed treatment interactions were observed on light interception in either site-year. Therefore, sod-suppression and seed treatment effects will be discussed separately.

At Gladstone in 1991, light interception early in the growing season (27 DAS) was significantly greater in the non-sprayed than in the sprayed area (Figure 2.4a). Hence competition for light from the resident vegetation was greater in the non-sprayed plots. The resident bluegrass sward intercepted approximately 20% of the incoming radiation compared to the alfalfa seedlings growing in virtually full sunlight in the sprayed area (Figure 2.4a). No significant difference in light interception between the sprayed and non-sprayed areas was detected 51 DAS. As the growing season progressed in 1991 (to 84 DAS), the alfalfa in the sprayed area intercepted more light than the vegetation in the non-sprayed treatment (Figure 2.4a). In 1992, considerable shading (approximately 25%) of alfalfa seedlings was again observed early in the growing season (21 DAS) (Figure 2.4b). However, by 60 DAS, alfalfa in the sprayed area intercepted significantly more light than in the non-sprayed area (Figure 2.4b). This trend continued throughout the remainder of the growing season.

Sod-suppression effects on light interception at Portage

a)



b)

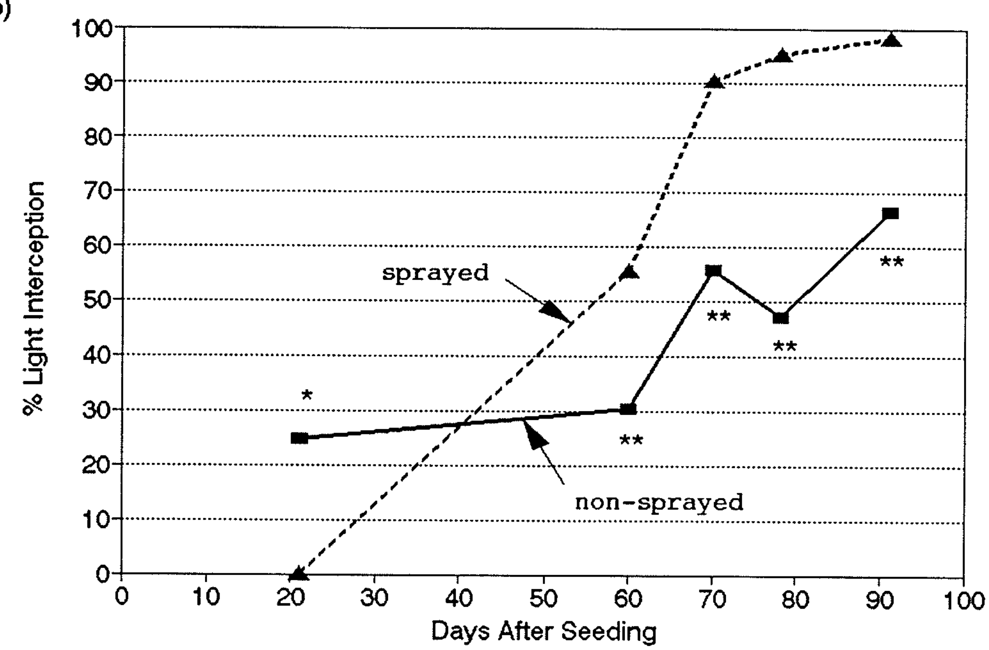
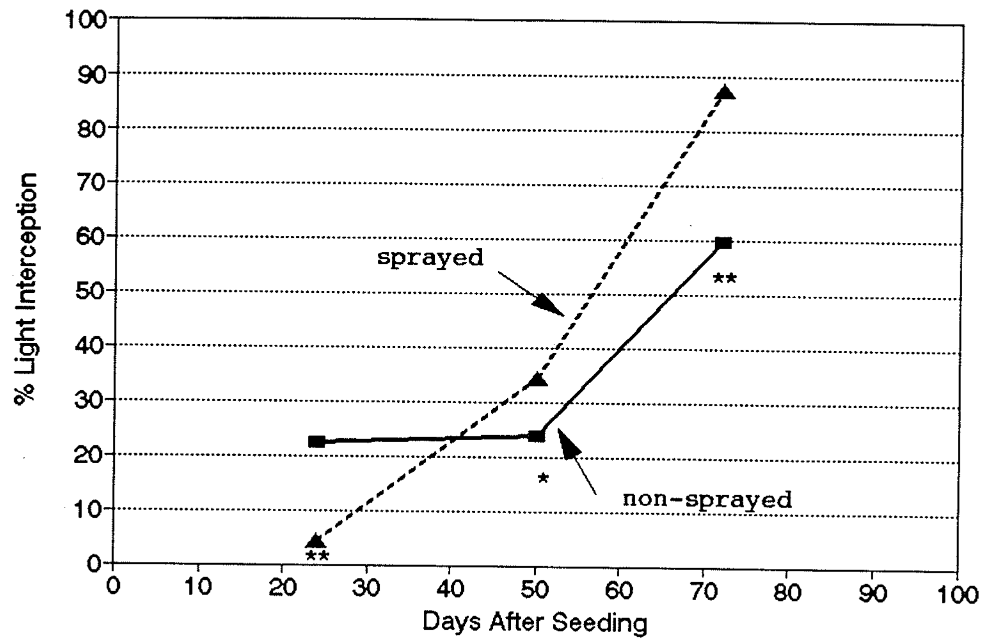


Figure 2.4 Influence of sod-suppression on percent light interception at the soil surface at Gladstone in a) 1991 and b) 1992. **, * Significant at 0.01 and 0.05 probability levels, respectively; ns=nonsignificant.

a)



b)

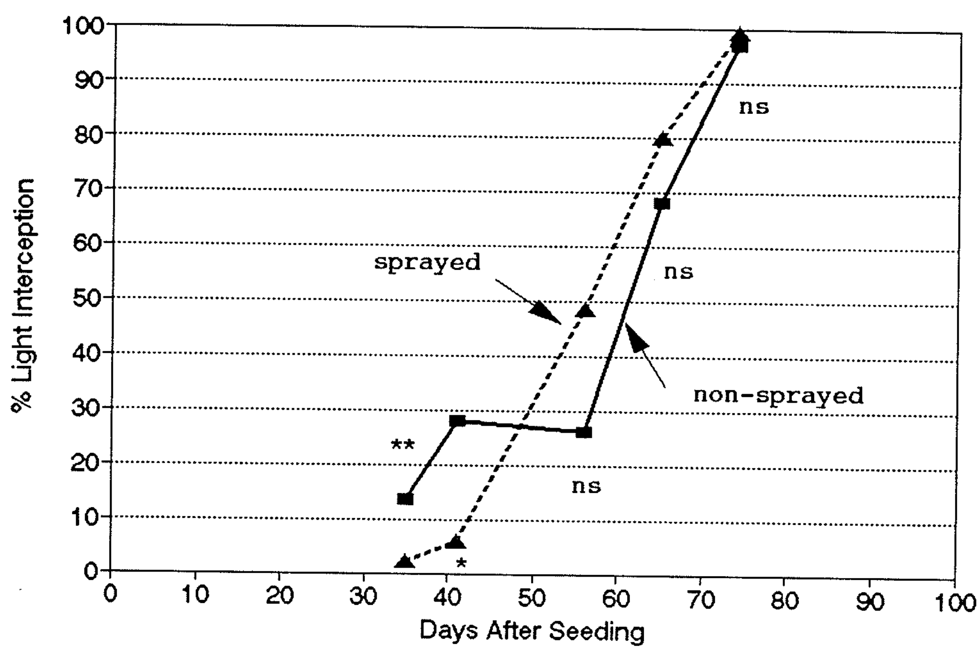


Figure 2.5 Influence of sod-suppression on percent light interception at the soil surface at Portage la Prairie in a) 1991 and b) 1992. **, * Significant at 0.01 and 0.05 probability levels, respectively; ns=nonsignificant.

la Prairie (Figure 2.5) were similar to those at Gladstone (Figure 2.4). In 1991, at 24 DAS, approximately 23% of the incoming light was intercepted by the resident timothy sward in the non-sprayed area (Figure 2.5a) while negligible light interception occurred in the sprayed treatment. For the remainder of the growing season (50 to 72 DAS), light interception in both the sprayed and non-sprayed treatments increased as alfalfa production increased (Figure 2.5a). However, light interception was significantly greater in the sprayed compared to the non-sprayed area. In 1992, light interception 35 and 41 DAS was significantly greater in the non-sprayed treatment as the resident timothy shaded the sod-seeded alfalfa seedlings (Figure 2.5b). Again as the growing season progressed, light interception in sod-suppression treatments increased as alfalfa growth and development increased (Figure 2.5b). No significant differences in light interception between the sprayed and non-sprayed treatments were detected 56, 65, and 74 DAS.

Results in all four field experiments indicated that alfalfa seedlings growing in the non-sprayed plots were subjected to approximately 20% shading early in the growing season. Therefore, in the non-sprayed area in the present study the resident timothy and bluegrass/bromegrass mixture intercepted the same amount of incoming light. Despite the fact that the timothy sward at Portage la Prairie was seeded with a 15 cm row space, similar amounts of incoming light were intercepted at both locations. Sod-seeding research which evaluates the level of shading from different types of resident sods is lacking in the literature. Only Groya and Sheaffer (1981) have reported on such a study. In their 1981 study, they reported greater shading of sod-seeded alfalfa occurred with a bromegrass compared to a Kentucky bluegrass sod. No studies appear to have compared the level of shading (percent light interception) when alfalfa was seeded into a bunch type vs. a rhizomatous sod. Results from the present study suggest that the percent light interception between the two swards would be similar.

Gist and Mott (1957) indicated that root growth rather than shoot growth was more severely affected by shading. Therefore, shading and soil water content are related because inhibited root development and root growth in the presence of shade, interferes with a plant's ability to seek out soil water (Gist and Mott 1957). Therefore, alfalfa seedlings growing in association with resident sod may be more susceptible to soil water deficits.

Significant seed treatment effects on percent light interception were detected at both sites in 1991 only (Table 2.2 and 2.3). No significant seed treatment effect was detected during the emergence period (27 DAS) at Gladstone (Table 2.2). However, 51 DAS the greatest light interception at the soil surface occurred in the 40 kg P_2O_5 ha^{-1} treatment which was significantly different than only the carbofuran and water-soaked treatments. A significant seed treatment effect detected 84 DAS indicated that the greatest light interception again occurred in the 40 kg P_2O_5 ha^{-1} treatment which was significantly different than that in the 100 ppm and 200 ppm GA_3, carbofuran, and water-soaked treatments (Table 2.2).

Table 2.2 Influence of sod-suppression and seed treatments on percent light interception at Gladstone in 1991.

Treatment	Light interception		
	27 DAS	51 DAS	84 DAS
	------% interception-----		
Non-sprayed	21 a	18 a	32 b
Sprayed	1 b	14 a	65 a
L.S.D.[z]	11	NS	14
30 kg P_2O_5 ha^{-1}	9 a	19 ab	59 a
40 kg P_2O_5 ha^{-1}	10 a	21 a	60 a
100 ppm GA_3	12 a	16 abc	45 b
200 ppm GA_3	8 a	18 ab	44 b
Terbufos	10 a	17 ab	50 ab
Carbofuran	13 a	11 c	39 b
Water-soaked	12 a	14 bc	40 b
Control	11 a	16 abc	51 ab
L.S.D.[y]	NS	5	12

[z]L.S.D. applies to main plot effect.
[y]L.S.D. applies to subplot effect.

At Portage la Prairie, significant seed treatment effects were detected on all sampling dates in 1991 (Table 2.3). Early in the emergence period (24 DAS), the 40 kg P_2O_5 ha^{-1} seed treatment intercepted the greatest amount of incoming light which was significantly different than that in the terbufos and 100 ppm GA_3 treatment. Since this sampling date is early in the growing season, the greatest influence on light interception would be the resident vegetation in the non-sprayed area. Therefore, at Portage la Prairie the application of 40 kg P_2O_5 ha^{-1} affected resident timothy growth which resulted in increased light interception. Similarly, Malik and Waddington (1990) concluded that the addition of 60 kg ha^{-1} P_2O_5 did not improve alfalfa establishment into a bluegrass/bromegrass sod. The researchers suggested that the addition of phosphorous increased grass competition (light interception was not measured) and masked any positive responses of the sod-seeded alfalfa. The lack of a seed treatment effect at Gladstone early in the growing season suggests that the addition of P_2O_5 did not influence the bluegrass/bromegrass sod's ability to intercept incoming light.

Fifty days after seeding at Portage la Prairie in 1991, the 40 kg P_2O_5 ha^{-1} again intercepted the greatest amount of light which was significantly different than that in the terbufos, carbofuran and both GA_3 treatments (Table 2.3). At 72 DAS, the greatest amount of light was intercepted in the 30 and 40 kg P_2O_5 ha^{-1} treatments which was significantly different than light interception in the 100 ppm and 200 ppm GA_3, terbufos and carbofuran treatments (Table 2.3).

Table 2.3 Influence of sod-suppression and seed treatments on percent light interception at Portage la Prairie in 1991.

Treatment	Light interception		
	24 DAS	50 DAS	72 DAS
	--------% interception--------		
Non-sprayed	23 a	34 a	87 a
Sprayed	4 b	24 b	60 b
L.S.D.[z]	4	9	4
30 kg P_2O_5 ha^{-1}	13 abc	35 ab	81 a
40 kg P_2O_5 ha^{-1}	18 a	37 a	81 a
100 ppm GA_3	10 bc	27 bc	64 d
200 ppm GA_3	15 abc	26 bc	71 bcd
Terbufos	10 bc	25 c	66 cd
Carbofuran	14 abc	22 c	68 cd
Water-soaked	13 abc	34 ab	75 abc
Control	16 ab	28 abc	78 ab
L.S.D.[y]	5	9	9

[z]L.S.D. applies to main plot effect.
[y]L.S.D. applies to subplot effect.

Later in the growing season at Portage la Prairie and Gladstone, seed placed P_2O_5 and the insecticides resulted in increased and decreased light interception at the soil surface, respectively. At this time, alfalfa and the resident vegetation were present, and therefore, the addition of phosphorous and insecticides influenced the ability of both plants to intercept light. No studies in the past have investigated the effect of seed-placed P_2O_5 or insecticides on the light interception of sod-seeded alfalfa and the resident sod.

2.5.1.3 Soil Temperature

Soil temperature was monitored in only one replicate. Therefore, no statistical comparisons for temperature between sprayed and non-sprayed areas could be conducted. Any differences in soil temperature will, therefore, be discussed as relative differences.

At Gladstone in 1991, mean soil temperatures at all depths were slightly higher in the sprayed treatment compared to the non-sprayed treatment early in the growing season (until early June) (Figure A4.1 and A4.2). Early in the season at Gladstone in 1992, soil temperatures at the soil surface were similar between the sod-suppression treatments (Figures A4.3a) Soil temperatures in the sprayed treatment at the 8 and 20 cm depth were slightly higher than those in the non-sprayed treatment during the emergence period (Figure A4.4). At Portage la Prairie in 1992, soil temperature during the emergence period in the sprayed treatment was slightly higher than that in the non-sprayed treatment (Figure A4.5 and A4.6) at all soil depths. Over the three field experiments where soil temperature was measured, daily mean soil temperatures were approximately 1 to 2°C higher in the sprayed area.

Results of this study indicate that chemically suppressing sod altered the microclimate. Higher soil temperatures in the sprayed treatment early in the growing season were attributed to greater radiant energy at the soil surface (Figure 2.4 and 2.5). This warmer microclimate would be expected to enhance alfalfa growth, and especially alfalfa development. Higher soil temperatures should accelerate the rate of germination and plant development, and therefore, potentially increase speed of emergence. Evenson and Rumbaugh (1972) observed a 17% increase in alfalfa growth rate when soil temperatures were approximately 5°C higher under unmulched wheat plots. Olusuyi and Raguse (1968) observed higher percent emergence of Ladino clover when air temperature was 20°C compared to 15°C. Similarly, Wolf and Blaser (1971) reported that alfalfa leaf development was enhanced significantly when grown at 32°C compared to 10°C.

Sod-seeded alfalfa growth and development would be stimulated provided that the soil heat flow did not increase evaporation significantly. Welty et al. (1981) found that sod-suppression increased light penetration to the soil surface which indirectly increased evaporation and dried out the seedbed. In the present study, greater soil water in the sprayed areas (Figure 2.2 and 2.3) suggests that evaporation was not increased from elevated soil temperatures or that transpiration in the non-sprayed area was greater than evaporation in the sprayed area.

2.5.2 Agronomic Responses

2.5.2.1 Crop Establishment

Since no significant sod-suppression X seed treatment interactions were observed for alfalfa establishment at any site year, effects of sod-suppression and seed treatment on alfalfa establishment will be discussed separately.

At Gladstone in 1991, no significant differences in emergence were detected 11 and 15 DAS (Table 2.4). A significant sod-suppression effect was observed 20, 27, and 48 DAS at Gladstone in 1991 (Table 2.4). At these sampling dates significantly more alfalfa seedlings had emerged in the sprayed area compared to the non-sprayed area (Table 2.4). On each sampling date at Gladstone in 1992, greater alfalfa emergence was observed in the sprayed area compared to the non-sprayed area (Table 2.5). This difference was approximately three-fold 21 DAS.

No sod-suppression effects were observed for alfalfa emergence on any of the sampling dates at Portage la Prairie in 1991 (Table 2.6). One explanation for the different responses in sod-suppression at the different sites in 1991 may be explained by the amount of precipitation that was

Table 2.4 Influence of sod-suppression and seed treatments on plant population of sod-seeded alfalfa at Gladstone in 1991.

	Plant population				
Treatment	11 DAS	15 DAS	20 DAS	27 DAS	48 DAS
	plants m^{-2}				
Non-sprayed	16 a	17 a	117 b	203 b	185 b
Sprayed	42 a	37 a	275 a	310 a	284 a
L.S.D.[z]	NS	NS	33	67	78
$30\ kg\ P_2O_5\ ha^{-1}$	13 a	16 a	161 b	279 ab	249 abc
$40\ kg\ P_2O_5\ ha^{-1}$	25 a	22 a	171 b	218 bc	205 bc
100 ppm GA_3	23 a	22 a	156 b	209 bc	190 c
200 ppm GA_3	33 a	27 a	168 b	238 bc	207 bc
Terbufos	13 a	16 a	222 ab	269 ab	259 ab
Carbofuran	21 a	24 a	143 b	192 c	189 c
Water-soaked	30 a	30 a	196 ab	265 abc	236 abc
Control	51 a	43 a	274 a	318 a	289 a
L.S.D.[Y]	NS	NS	92	75	63

[z]L.S.D. applies to main plot effect.
[Y]L.S.D. applies to subplot effect.

Table 2.5 Influence of sod-suppression and seed treatments on plant population density of sod-seeded alfalfa at Gladstone in 1992.

Treatment	Plant population				
	9 DAS	14 DAS	21 DAS	26 DAS	36 DAS
	plants m^{-2}				
Non-sprayed	82 b	153 b	88 b	122 b	105 b
Sprayed	168 a	222 a	222 a	238 a	224 a
L.S.D.[z]	54	45	58	19	50
30 kg P_2O_5 ha^{-1}	103 b	170 bc	157 a	177 a	190 a
40 kg P_2O_5 ha^{-1}	73 b	123 c	103 a	123 a	117 a
100 ppm GA_3	170 a	231 ab	160 a	194 a	181 a
200 ppm GA_3	171 a	228 ab	188 a	225 a	192 a
Terbufos	98 b	170 bc	150 a	167 a	154 a
Carbofuran	86 b	162 c	165 a	178 a	154 a
Water-soaked	201 a	262 a	188 a	222 a	167 a
Control	112 b	171 bc	141 a	167 a	161 a
L.S.D.[y]	55	65	NS	NS	NS

[z]L.S.D. applies to main plot effect.
[y]L.S.D. applies to subplot effect.

obtained. Precipitation obtained at Gladstone in May was below the long-term average (83% of long-term average) while it was above the long-term average (109% of long-term average) at Portage la Prairie. Therefore, soil water was more limiting at Gladstone, and therefore, sod-suppression resulted in increased soil water conservation (Figure 1a). Thus, sod-suppression influenced alfalfa emergence more strongly at Gladstone than at Portage la Prairie in 1991. This is similar to the findings of Taylor et al. (1969) who concluded that the amount and distribution of precipitation immediately following seeding alfalfa into a Kentucky bluegrass sod affected emergence more than soil and air temperature.

Significant sod-suppression effects for establishment were detected 10, 15 and 20 DAS at Portage la Prairie in 1992 (Table 2.7). On each of the dates, a greater number of alfalfa seedlings had emerged in the sprayed compared to the non-sprayed treatment (Table 2.7). Similar to Gladstone in 1992, the difference was approximately three-fold 15 DAS. In 1992, precipitation was limiting at Portage la Prairie early in the growing season (44% of long-term average in May and June) and it appeared that the water conserving benefits of sod-suppression were expressed (Figure 2.3). No significant sod-suppression effect was found later in the emerging period, 27 and 36 DAS, in 1992 (Table 2.7), and this was attributed to wetter conditions later in the emerging period (Table 1.1).

Similar to the results of Waddington et al. (1990),

Table 2.6 Influence of sod-suppression and seed treatments on plant population density of sod-seeded alfalfa at Portage la Prairie in 1991.

Treatment	Plant population			
	9 DAS	12 DAS	17 DAS	23 DAS
	---------------plants m^{-2}-------------			
Non-sprayed	106 a	161 a	325 a	262 a
Sprayed	161 a	207 a	301 a	239 a
L.S.D.^{z}	NS	NS	NS	NS
30 kg P_2O_5 ha^{-1}	161 a	213 a	315 ab	263 a
40 kg P_2O_5 ha^{-1}	142 a	205 a	359 a	296 a
100 ppm GA_3	97 a	143 a	288 ab	236 a
200 ppm GA_3	121 a	172 a	304 ab	227 a
Terbufos	99 a	143 a	243 b	201 a
Carbofuran	125 a	164 a	256 b	233 a
Water-soaked	118 a	167 a	322 ab	249 a
Control	168 a	226 a	365 a	275 a
L.S.D.^{y}	NS	NS	96	NS

^{z}L.S.D. applies to main plot effect.
^{y}L.S.D. applies to subplot effect.

Table 2.7 Influence of sod-suppression and seed treatments on plant population density of sod-seeded alfalfa at Portage la Prairie in 1992.

Treatment	Plant population				
	10 DAS	15 DAS	20 DAS	27 DAS	35 DAS
	plants m^{-2}				
Non-sprayed	40 b	60 b	71 b	113 b	140 b
Sprayed	87 a	165 a	192 a	217 a	228 a
L.S.D.[z]	31	62	77	NS	NS
30 kg P_2O_5 ha^{-1}	72 a	124 a	137 a	165 a	179 a
40 kg P_2O_5 ha^{-1}	53 a	112 a	130 a	158 a	170 a
100 ppm GA_3	78 a	122 a	135 a	158 a	151 a
200 ppm GA_3	72 a	108 a	136 a	145 a	211 a
Terbufos	52 a	103 a	136 a	166 a	170 a
Carbofuran	53 a	104 a	131 a	185 a	181 a
Water-soaked	58 a	107 a	109 a	156 a	154 a
Control	68 a	115 a	135 a	174 a	190 a
L.S.D.[y]	NS	NS	NS	NS	NS

[z]L.S.D. applies to main plot effect.
[y]L.S.D. applies to subplot effect.

alfalfa emergence at Gladstone in 1991 and 1992 and Portage la Prairie in 1992 was enhanced significantly (three-fold) when the resident sward was suppressed. Waddington et al. (1990) attributed increased sod-seeded alfalfa emergence to greater soil water content when the resident crested wheatgrass sod was chemically suppressed. The authors concluded that surface soil water in the non-sprayed treatments was well below the permanent wilting point, and was close to the permanent wilting point at all depths where the resident vegetation had not been suppressed. A similar explanation may apply in the present study since soil water content was increased with sod-suppression on a number of sampling dates at all site-years (Figure 2.1; 2.2; 2.3).

No significant correlations between plant emergence and soil water content were detected in 1991. However, in 1992 a positive correlation was observed between alfalfa emergence and soil water content (0 to 10 cm depth) 20 DAS (r=0.66*) and (10 to 30 cm depth) 27 DAS (r=0.65*) at Portage la Prairie. Trimmer and Linscott (1986) found that sod-seeded red clover plant density was strongly correlated (r=0.86) with soil water content. Enhanced red clover establishment was attributed to the higher soil water content in the sod-suppressed treatment.

Significant seed treatment effects (alfalfa plant population density averaged over sod-suppression treatments) for plant emergence were detected 20, 27 and 48 DAS at Gladstone in 1991 (Table 2.4). At 20 DAS, the greatest number of alfalfa seedlings had emerged in the control treatment which was significantly greater than the number of alfalfa seedlings in the 30 kg P_2O_5 ha^{-1}, 40 kg P_2O_5 ha^{-1}, carbofuran, 100 ppm GA_3, or 200 ppm GA_3 treatments. At 27 and 48 DAS, the greatest number of alfalfa seedlings had emerged in the control treatment which was significantly greater than the number of alfalfa seedlings in the 40 kg P_2O_5 ha^{-1}, 100 ppm GA_3 and 200 ppm GA_3, and carbofuran treatments (Table 2.4).

At Gladstone in 1992, significant seed treatment effects were detected 9 and 14 DAS (Table 2.5). At 9 DAS, the greatest number of alfalfa seedlings had emerged in the water-soaked treatment which was not significantly greater than the 100 ppm GA_3 or 200 ppm GA_3 treatments (Table 2.5). However, these treatments were significantly greater than all others. At 14 DAS, the greatest number of seedlings had emerged in the water-soaked treatment which was not significantly greater than the 100 ppm GA_3 or 200 ppm GA_3 treatments. However, these three treatments were significantly greater than the number of alfalfa seedlings that had emerged in the carbofuran and 40 kg P_2O_5 ha^{-1} treatments.

At Gladstone, it appears that 40 kg P_2O_5 ha^{-1} seed-placed negatively affected sod-seeded alfalfa emergence. The higher rate of seed-placed P_2O_5 may have resulted in phytotoxic effects due to the amount of fertilizer contacting the seed directly. In a similar study, Williams et al. (1985) observed decreased white clover seedling emergence when 50 and 100 kg

P_2O_5 ha^{-1} was seed placed, however, no negative effects were observed when the fertilizer was banded beneath the seed row. The authors attributed the reduced seedling emergence to harmful effects on the seed due to locally high nutrient concentrations. A similar explanation may apply in the present study.

Precipitation was more limiting in 1992 (Table 2.1) and this may explain why the pre-soaked seed treatments resulted in the greatest alfalfa emergence at Gladstone that year. Keller and Bleak (1969) observed a 1 to 2 day advantage in root length 6 days after planting crested wheatgrass seeds that were pre-soaked in tap water for 10 hours. In an earlier study, Keller and Bleak (1968) found that pre-soaking crested wheatgrass for 60 hours resulted in more rapid emergence (40 hour difference) than un-soaked seeds. The researchers suggested that pre-soaking of seed would contribute towards greater success of sod-seeding plants.

The only significant effect on alfalfa seedling emergence at Portage la Prairie in both years was a significant seed treatment effect 17 DAS in 1991 (Table 2.6 and 2.7). At this time, the greatest number of alfalfa seedlings had emerged in the control treatment which was significantly greater than the number of alfalfa seedlings in the terbufos and carbofuran treatments (Table 2.6). It appears that seed-placed carbofuran, and to a lesser degree terbufos, reduced sod-seeded alfalfa establishment at Gladstone in both years and at

Portage la Prairie in 1991. No studies in the literature have reported reduced seedling establishment with seed-placed insecticides. In fact, carbofuran is recommended for alfalfa establishment in the United States (Wolf 1988). Dowling and Linscott (1983) found a 20% increase in sod-seeded alfalfa emergence when 1.1 kg a.i. ha^{-1} carbofuran was broadcast over the plot area at seeding. In the present study, the close proximity of the insecticides and the alfalfa seed could have been the reason for the phytotoxic effect.

Despite significant differences in emergence, all seed treatments in non-sprayed areas achieved an optimum plant population density of 100 plants m^{-2} required for establishment year alfalfa hay production (Meyer 1985). Mueller-Warrant and Koch (1980) reported that 90 to 100 plants m^{-2} of alfalfa was sufficient for optimal yield.

2.5.2.2 Alfalfa Dry Matter Production

At Portage la Prairie in 1991, a significant sod-suppression X seed treatment interaction on alfalfa DM was detected 50 DAS (Table 2.8). The basis for this interaction was that alfalfa DM in all seed treatments in the non-sprayed area was similar, however, in the sprayed area, alfalfa DM in the 30 kg P_2O_5 ha^{-1} treatment was greatest and significantly different than that in the 200 ppm GA_3, terbufos, carbofuran, and H_2O-soaked control treatments. A significant sod-

Table 2.8 Influence of sod-suppression and seed treatments on dry matter production of sod-seeded alfalfa at Portage la Prairie in 1991 and 1992.

		1991		1992	
Spray Trt	Seed Trt	50 DAS	77 DAS	65 DAS	82 DAS
		$kg\ ha^{-1}$			
Non-sprayed	30 kg P_2O_5 ha^{-1}	359	2563	904	2745
Non-sprayed	40 kg P_2O_5 ha^{-1}	349	2612	689	3278
Non-sprayed	100 ppm GA_3	302	2495	1026	4692
Non-sprayed	200 ppm GA_3	335	2380	762	2748
Non-sprayed	Terbufos	288	2143	519	1920
Non-sprayed	Carbofuran	330	2061	623	2435
Non-sprayed	Water-soaked	526	2892	938	2701
Non-sprayed	Control	346	3073	942	2265
Sprayed	30 kg P_2O_5 ha^{-1}	1259	5758	3853	7732
Sprayed	40 kg P_2O_5 ha^{-1}	1106	5844	3870	8400
Sprayed	100 ppm GA_3	1047	5934	2757	4802
Sprayed	200 ppm GA_3	857	5368	3018	5543
Sprayed	Terbufos	787	5380	2189	7098
Sprayed	Carbofuran	611	4653	2188	7696
Sprayed	Water-soaked	942	4785	1390	6577
Sprayed	Control	1207	6396	3077	7191
L.S.D.[z]		318	NS	NS	2171

[z]L.S.D. applies to the two-interaction only.

suppression X seed treatment interaction was also detected 82 DAS at Portage la Prairie in 1992. The basis for this interaction was that in the non-sprayed area, DM in the 100 ppm GA_3 seed treatment was greatest and significantly greater than that in the terbufos, carbofuran, and control treatments. However, in the sprayed area alfalfa DM was greatest in the 40 kg P_2O_5 ha^{-1} treatment which was significantly greater than DM produced in the 100 ppm GA_3 and 200 ppm GA_3 seed treatments (Table 2.8). One explanation for the lack of increased alfalfa DM production in the presence of phosphorous in the non-sprayed area may be that the resident timothy sward was competing strongly and was able to utilize the additional phosphorous earlier than the alfalfa seedlings. Others (Elgabaly and Wiklander 1949; Mouat and Walker 1959; Williams et al. 1985) have found that legumes are poor competitors for certain soil nutrients, such as phosphorous, when growing in association with grass species.

A significant sod-suppression effect on alfalfa dry matter production was detected in all site years except 65 DAS at Portage la Prairie in 1992. Alfalfa DM production (averaged over seed treatments) was consistently greater in the sprayed than the non-sprayed area (Table 2.8 and 2.9). The greatest increase in dry matter production attributed to sod-suppression occurred 64 DAS at Gladstone in 1992 (Table 2.9). Dry matter production on this sampling date was approximately 100-fold greater in the sprayed compared to the

Table 2.9 Influence of sod-suppression and seed treatments on dry matter production of sod-seeded alfalfa at Gladstone in 1991 and 1992.

Treatment	1991		1992	
	48 DAS	82 DAS	64 DAS	96 DAS
	$kg\ ha^{-1}$			
Non-sprayed	55 b	360 b	20 b	254 b
Sprayed	426 a	3232 a	2428 a	4971 a
L.S.D.[z]	130	610	410	2120
30 kg P_2O_5 ha^{-1}	369 a	2553 a	1167 ab	3478 a
40 kg P_2O_5 ha^{-1}	349 a	2728 a	984 b	2710 a
100 ppm GA_3	216 b	1620 b	1524 a	2538 a
200 ppm GA_3	219 b	1431 b	1481 a	2075 a
Terbufos	188 b	1510 b	1029 b	2337 a
Carbofuran	205 b	1414 b	1335 ab	2013 a
Water-soaked	212 b	1415 b	1153 ab	2705 a
Control	205 b	1746 b	1172 ab	2173 a
L.S.D.[y]	117	628	404	NS

[z]L.S.D. applies to main plot effect.
[y]L.S.D. applies to subplot effect.

non-sprayed area. In general, sod-suppression increased dry matter less dramatically at Portage la Prairie (approximately three-fold increase with sod-suppression) (Table 2.8). The resident sward at Portage la Prairie was a bunch type grass (as compared to rhizomatous type at Gladstone) and this may have allowed the alfalfa to overcome the effects of grass competition more readily at Portage la Prairie than at Gladstone. Eltun et al. (1985) observed a 17% increase in alfalfa DM production when sod-seeded into a timothy compared to a Kentucky bluegrass sward. Belanger and Winch (1985) observed a two- to three-fold increase in dry matter production of sod-seeded alfalfa by suppressing the Canada bluegrass (*Poa compressa* L) dominant sward with 2.1 kg a.i. ha^{-1} glyphosate. In the present study, alfalfa DM production in the sprayed area was similar to establishment year hay yields obtained by Mueller and Chamblee (1984).

A significant seed treatment effect for DM production was detected 48 and 82 DAS at Gladstone in 1991 and 64 DAS in 1992 (Table 2.9). On both the 48 and 82 DAS sampling dates, alfalfa DM production was greatest in the P_2O_5 treatments which were significantly greater than all other treatments (Table 2.9). Soil tests indicated that soil phosphorous levels were low (Table A3.2). Therefore, it appears that increased alfalfa DM was due to the correction of phosphorous deficiencies. Increased sod-seeded white clover DM production with the application of phosphorous has also been reported by

Williams (1986). Sheard (1980) indicated that banding phosphorous for forage species is of singular importance for seedling vigour, even on soils testing high in phosphorous for forage production. At 64 DAS in 1992 at Gladstone, DM was greatest in the 100 ppm GA_3 treatment which was significantly greater than the terbufos and 40 kg P_2O_5 ha^{-1} seed treatments (Table 2.9). However, no significant seed treatment effects were detected 96 DAS in 1992. Therefore, although 40 kg P_2O_5 ha^{-1} reduced emergence and DM earlier in the growing season, no negative effects were observed 96 DAS.

At Portage la Prairie, the only significant seed treatment effect on alfalfa DM production was detected 50 DAS in 1991 (Table 2.8). On this date, alfalfa DM production was greatest in the control treatment which was significantly different than that in the terbufos and carbofuran treatments (Table 2.8). The seed-placed insecticides appeared to negatively affect alfalfa DM production on this one sampling date. Lin et al. (1972) observed a 50% decrease in alfalfa seedling weight when the seed was mixed with 50 ppm carbofuran. However, the majority of research in the literature reports increased alfalfa DM production with the use of carbofuran (Barney et al. 1988; Sheaffer et al. 1982; Dowling and Linscott 1983). Sheaffer et al. (1982) attributed the increased DM production to the ability of carbofuran to significantly reduce root lesion nematode insects. Carbofuran controlled various arthropods, and therefore, indirectly increased alfalfa DM production in the study by Dowling and Linscott (1983). No stimulation effects on plant DM production with the use of insecticides were observed in the present study. Insect populations were not monitored in the present study, and therefore, the efficiency of insecticides on pest control could not be measured.

2.5.2.3 Resident Sward Dry Matter Production

Only the living vegetation was harvested and considered in this study, and therefore, no resident sward DM was harvested from the sprayed areas. The lack of a seed treatment effect in both years at Gladstone indicated that DM production of the resident sward was similar across all seed treatments on both dates (Table 2.10).

A significant seed treatment effect for resident sod DM production was observed 50 and 77 DAS in 1991 and 65 DAS in 1992 at Portage la Prairie. In 1991, timothy DM production was greatest in the 40 kg P_2O_5 ha^{-1} treatment 50 DAS but was not significantly greater than that produced in the 30 kg P_2O_5 ha^{-1} treatment (Table 2.11). However, DM production in the 40 kg P_2O_5 ha^{-1} was significantly greater than all other seed treatments. At 77 DAS, timothy DM production was greatest in the 40 kg P_2O_5 ha^{-1} treatment which was significantly different from only the water-soaked treatment. Similar to 1991, timothy DM production in the 40 kg P_2O_5 ha^{-1} treatment 65 DAS

Table 2.10 Influence of seed treatments on dry matter production of resident bluegrass/bromegrass sward at Gladstone in 1991 and 1992.

Seed Treatment[z]	1991 48 DAS	1991 82 DAS	1992 64 DAS	1992 96 DAS
	-----	----- $kg\ ha^{-1}$ -----	-----	-----
30 kg P_2O_5 ha^{-1}	1148 a	1628 a	2406 a	2906 a
40 kg P_2O_5 ha^{-1}	1003 a	1839 a	2301 a	2610 a
100 ppm GA_3	838 a	1639 a	1871 a	2216 a
200 ppm GA_3	875 a	1274 a	1884 a	1781 a
Terbufos	718 a	1344 a	2158 a	2850 a
Carbofuran	935 a	1144 a	2197 a	2194 a
Water-soaked	772 a	1423 a	2724 a	2638 a
Control	823 a	1299 a	2306 a	2841 a
L.S.D.	NS	NS	NS	NS

[z]Resident sod dry matter production was measured in non-sprayed area only.

Table 2.11 Influence of seed treatments on dry matter production of resident timothy sward at Portage la Prairie in 1991 and 1992.

Seed Treatment[z]	1991 50 DAS	1991 77 DAS	1992 65 DAS	1992 82 DAS
	----------	----------kg ha^{-1}	----------	----------
30 kg P_2O_5 ha^{-1}	1362 ab	1498 ab	2032 b	1891 a
40 kg P_2O_5 ha^{-1}	1583 a	1854 a	2358 a	1989 a
100 ppm GA_3	1239 bc	1291 bc	1797 bc	1512 a
200 ppm GA_3	970 c	1392 bc	1589 cd	1749 a
Terbufos	1056 bc	1296 bc	1585 cd	1862 a
Carbofuran	1248 bc	1463 bc	1119 de	1554 a
Water-soaked	1017 c	1120 c	1476 de	1938 a
Control	1198 bc	1266 bc	1293 e	1734 a
L.S.D.	259	671	262	NS

[z]Resident sod dry matter production was measured in non-sprayed area only.

in 1992 was significantly greater than that in the other seed treatments (Table 2.11).

The results at Portage la Prairie indicate that the addition of seed-placed phosphorous increased DM production of the resident timothy sward. In 1991, the timothy sod intercepted more light in the presence of seed-placed phosphorous early in the growing season (Table 2.3). It appears that fibrous-rooted timothy had the ability to out-compete tap-rooted alfalfa for soil phosphorous. Therefore, the addition of phosphorous can increase resident sward DM production which will consume more soil water and nutrients, thereby creating more shade for sod-seeded alfalfa (Table 2.3). However, in the present study alfalfa seedlings at Portage la Prairie were not negatively affected by the increased resident timothy competition.

At both sites in 1991 and 1992, alfalfa DM production was inversely correlated with resident sward DM production (Table 2.12). As resident sod dry matter decreased, alfalfa DM production increased. Therefore, the increased alfalfa DM production, in the presence of sod-suppression, can be attributed to reduced competition for light and soil water from the resident sward. Taylor et al. (1972) attributed increased white clover and alfalfa DM production in the presence of Kentucky bluegrass sward suppression to increased soil moisture and reduced shading.

Table 2.12 Correlation coefficients between alfalfa dry matter production and resident sod dry matter production at Gladstone and Portage la Prairie in 1991 and 1992.

Site	Year	Days after seeding	Correlation coefficient
Gladstone	1991	48	-0.76***
Gladstone	1991	82	-0.82***
Gladstone	1992	64	-0.89***
Gladstone	1992	96	-0.79***
Portage	1991	50	-0.79***
Portage	1991	77	-0.77***
Portage	1992	65	-0.76***
Portage	1992	82	-0.83***

*** indicates significance at $P < 0.001$.

2.5.2.4 Year After Establishment Alfalfa Dry Matter Production

A significant sod-suppression effect was observed for year after establishment alfalfa DM production at the Gladstone site only (Table 2.13). Alfalfa DM in the sprayed area was significantly greater (approximately two-fold) compared to the non-sprayed area (Table 2.13) although the difference was not as dramatic as in the establishment year (Table 2.9). No seed treatment differences were observed for year after establishment DM production at either site (Table 2.13). The lack of sod-suppression effects in year after

Table 2.13 Influence of sod-suppression and seed treatments on dry matter production of sod-seeded alfalfa in the year after establishment at Portage la Prairie and Gladstone in 1992.

Treatment	Gladstone	Portage
	---------------kg ha^{-1}---------------	
Non-sprayed	945	6922
Sprayed	1977	8363
L.S.D.[z]	633	NS
30 kg P_2O_5 ha^{-1}	2142	8310
40 kg P_2O_5 ha^{-1}	1684	7113
100 ppm GA_3	1903	7385
200 ppm GA_3	1218	7960
Terbufos	1461	7730
Carbofuran	1272	7695
Water-soaked	1174	7295
Control	1237	7649
L.S.D.[y]	NS	NS

[z]L.S.D. applies to the main plot effect.
[y]L.S.D. applies to the subplot effect.

establishment alfalfa DM production at Portage la Prairie once again was attributed to the less competitive nature of the resident bunch-type timothy sward at this site. Despite the establishment-year increased timothy sod DM production in 30 and 40 kg P_2O_5 ha^{-1} seed treatments and increased light interception in 1991 (Table 2.3), alfalfa DM production the year after establishment at Portage la Prairie was not negatively affected. Again, the timothy sod represented little competition with the sod-seeded alfalfa. Smoliak

(1981) indicated that bunch type grasses were more desirable in alfalfa/grass mixtures because they are not as competitive.

Total forage yield (alfalfa and resident sod DM combined) obtained during the establishment year is shown in Table A1.1 (Gladstone) and Table A1.2 (Portage la Prairie). At each site, the greatest first year total yields were obtained in the sprayed areas which consisted of 100% alfalfa. Forage productivity was reduced in the non-sprayed area which represents an alfalfa/resident grass mixture. In the non-sprayed area, alfalfa represented approximately 50% of the total forage yield at Portage la Prairie while the percent alfalfa was approximately 15% at Gladstone. Again, the rhizomatous sod at Gladstone competed strongly for soil resources (water, nutrients, physical space) and the alfalfa component suffered. The alfalfa/grass mixture obtained in the non-sprayed area at Portage la Prairie would represent a desirable pasture mixture for maximum productivity (Smoliak 1981).

2.5.3 Physiological Responses

Results of this study indicate that the main factor affecting establishment and production of sod-seeded alfalfa is removal of competition of the resident vegetation. This supports the results of many previous studies (Mueller-Warrant and Koch 1980; Olsen et al. 1981; Mueller and Chamblee 1984; Byers and Templeton, Jr. 1988; Waddington et al. 1992). While the positive effect of sod-suppression on performance of sod-seeded alfalfa has been well documented, little previous research has attempted to describe, in detail, the physiological response of alfalfa growing in sprayed vs. non-sprayed areas. In the following section, an attempt will be made to explain some of the mechanisms contributing to successful sod-seeded alfalfa establishment. In this section, only sod-suppression treatment differences will be discussed.

2.5.3.1 Crop Development

Results of this study indicated that alfalfa development, as indicated by leaf number, was usually increased by sod-suppression (Figure 2.6 and 2.7). In 1991, significant sod-suppression effects on alfalfa development were observed 48 and 82 DAS at Gladstone (Figure 2.6a), and 50 DAS at Portage la Prairie (Figure 2.7a). On all sampling dates, alfalfa development was greater in the sprayed area compared to the

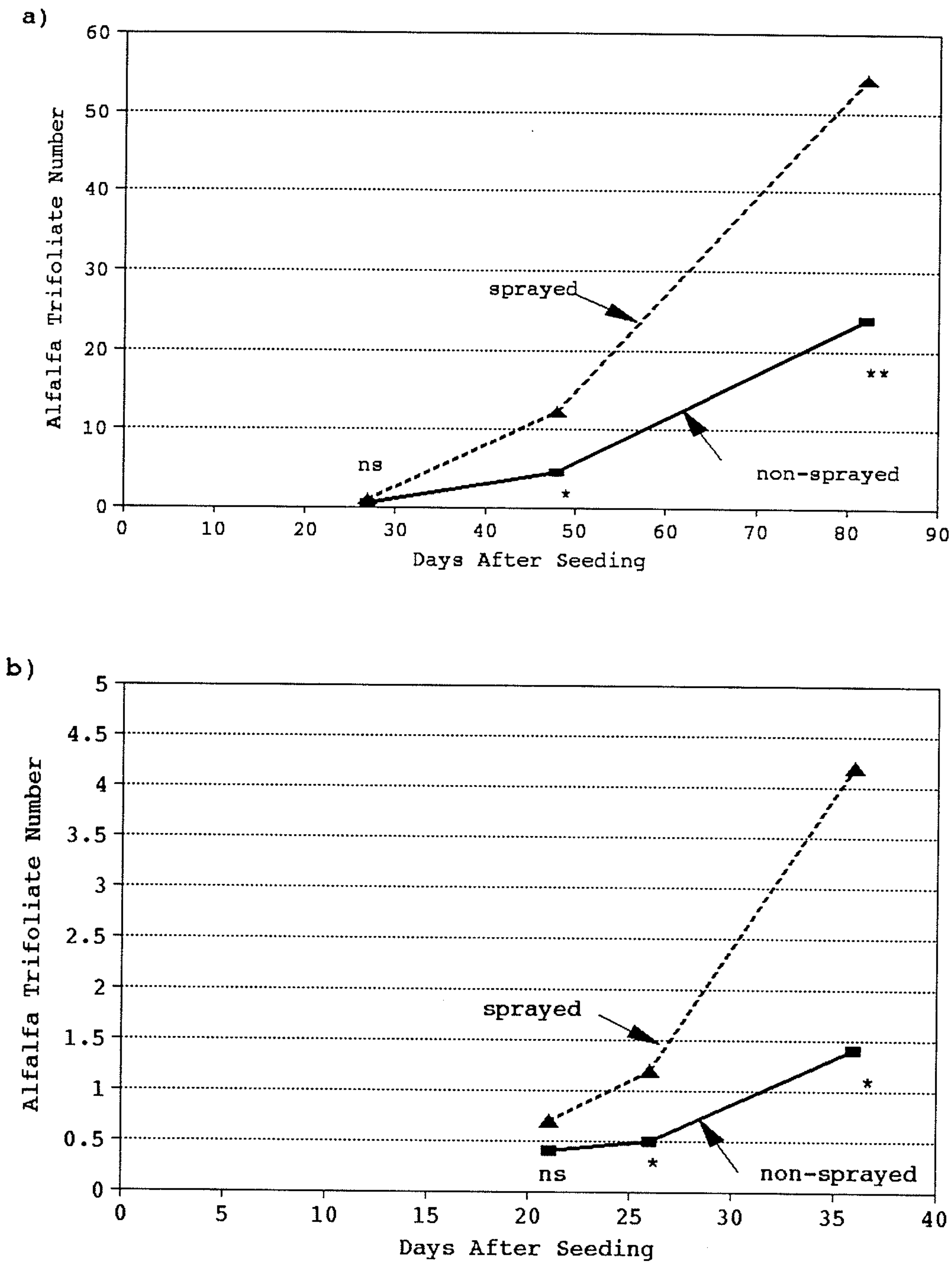


Figure 2.6 Influence of sod-suppression on alfalfa plant development (as indicated by trifoliate leaf number) at Gladstone in a) 1991 and b) 1992. **, * Significant at 0.01 and 0.05 probability levels, respectively; ns=nonsignificant.

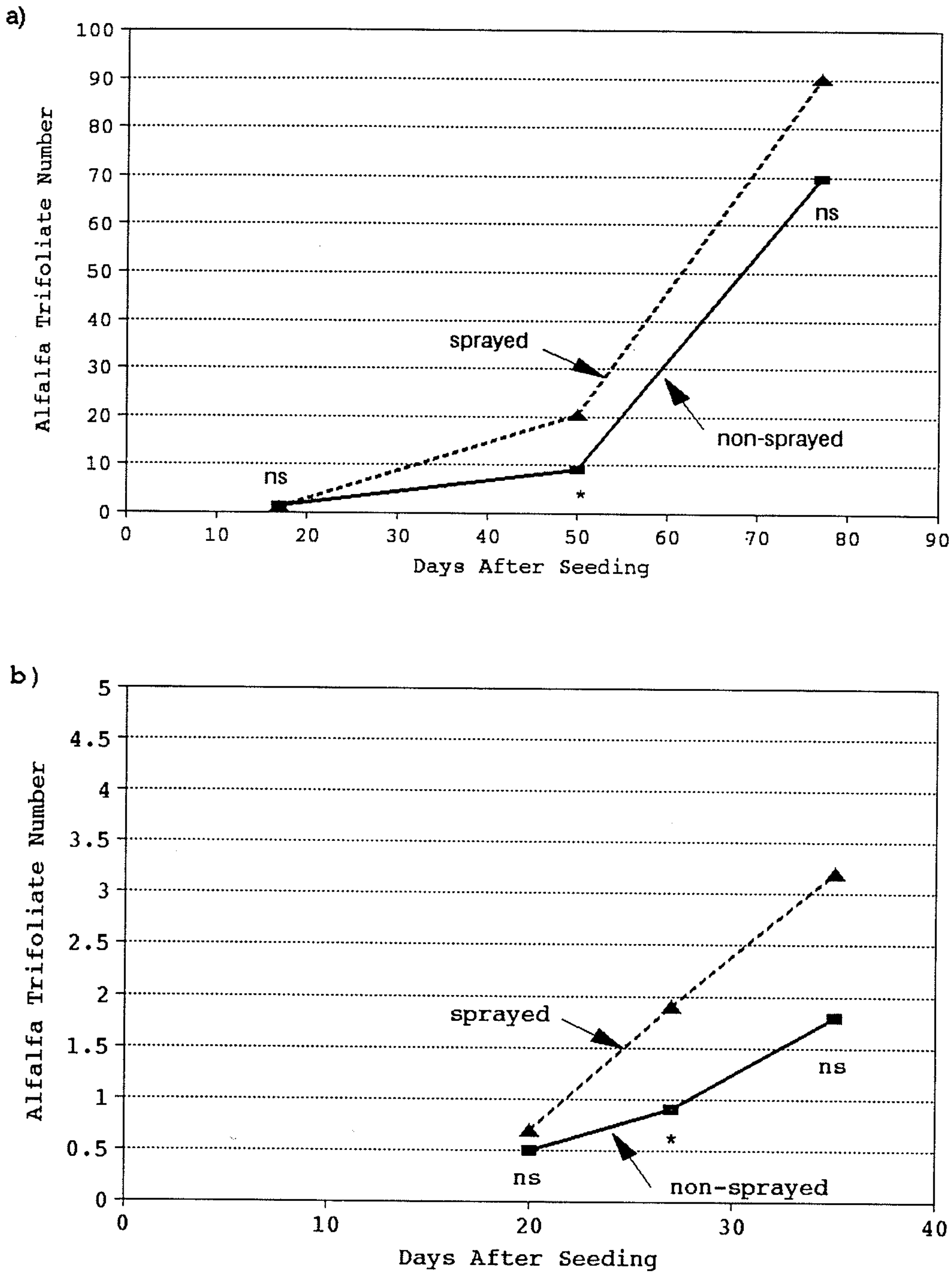


Figure 2.7 Influence of sod-suppression on alfalfa plant development (as indicated by trifoliate leaf number) at Portage la Prairie in a) 1991 and b) 1992. * Significant at 0.05 probability level; ns=nonsignificant.

non-sprayed area. In 1992, a significant sod-suppression effect on alfalfa development was observed 26 and 36 DAS at Gladstone (Figure 2.6b), and 27 DAS at Portage la Prairie (Figure 2.7b). Similar to 1991, alfalfa plant development in the sprayed area was greater than plant development in the non-sprayed area.

In both 1991 and 1992, alfalfa development was more affected by sod-suppression at Gladstone than Portage la Prairie. In 1991 for example, alfalfa plants 82 DAS at Gladstone had 23 and 55 trifoliate leaves in the non-sprayed and sprayed areas, respectively, however, alfalfa plants 77 DAS at Portage la Prairie had 70 and 90 leaves in the non-sprayed and sprayed areas, respectively (Figure 2.6 and 2.7). Temporary differences in alfalfa development between treatments were detected once during the emergence period at Portage la Prairie, while at Gladstone, differences were sustained throughout the growing season. Similar to the results reported by Eltun et al. (1985) sod-seeded alfalfa plants in the present study were more developed in the sod-suppressed treatments.

The absence of significant differences in alfalfa plant development due to sod-suppression later in the growing season at the Portage la Prairie site suggests that alfalfa plants growing amongst the resident timothy plants were able to overcome the effects of competition. The bunch grass at Portage la Prairie was less productive (Table 2.10 and 2.11), and therefore, alfalfa development in the non-sprayed area was less adversely affected (Figure 2.6 and 2.7).

Early in the growing season at Gladstone in 1991 and 1992 and at Portage la Prairie in 1992, alfalfa development was negatively correlated with percent light interception (Table 2.14).

Table 2.14 Correlation coefficients between percent light interception and alfalfa plant development at Gladstone and Portage la Prairie in 1991 and 1992.

Site	Year	Days after seeding	Correlation coefficient
Gladstone	1991	27	-0.66**
Gladstone	1991	51	NS
Gladstone	1991	84	0.91***
Gladstone	1992	21	-0.92***
Portage	1991	24	NS
Portage	1991	50	0.68**
Portage	1991	72	0.72**
Portage	1992	35	-0.66**

,* Significant at 0.01 and 0.001 probability levels, respectively.

Therefore, the greater the amount of light intercepted the slower the rate of alfalfa development. No correlation was observed at Portage la Prairie in 1991. Therefore, it appears that the resident rhizomatous vegetation at Gladstone influenced alfalfa development more strongly than at Portage la Prairie. At both sites in 1991, positive correlations between percent light interception and plant development were observed (Table 2.14).

Suppressing the rhizomatous sod at Gladstone resulted in dramatic changes in the microclimate surrounding the alfalfa seedlings (Figure 2.1; 2.2; 2.4; A4.1; A4.2, A4.3; A4.4). Taylor et al. (1972) attributed increased white clover and alfalfa plant development, sod-seeded into a chemically suppressed Kentucky bluegrass sward, to increased soil moisture and reduced shading effects. A similar explanation may apply in the present study since suppressing the resident vegetation at both sites significantly increased the amount of light reaching the soil surface (Figure 2.4) and the soil water content (Figure 2.1, 2.2 and 2.3). Increased soil temperatures arising from increased light penetration resulted in enhanced plant development in the sprayed area. Similarly, Evenson and Rumbaugh (1972) observed increased alfalfa development in the presence of increased (5°C higher) soil temperatures.

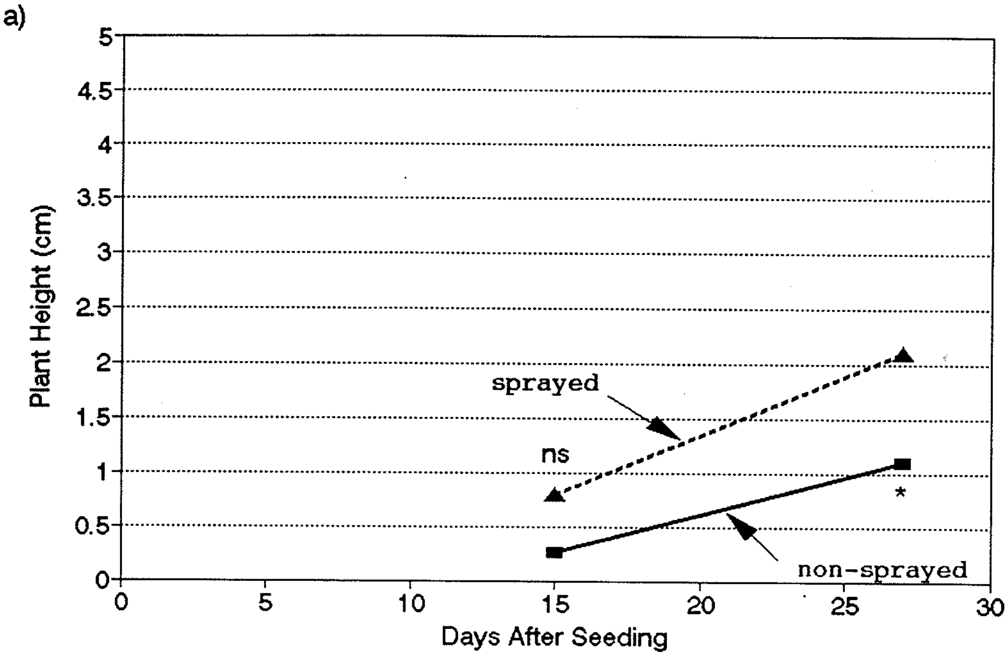
2.5.3.2 Crop Height

Crop growth is frequently characterized by measuring crop height, since crop height can integrate a number of parameters (rate of development, DM production, etc.). Under sod-seeded conditions, crop height may be increased due to shading effects stimulating stem elongation (Evers 1989). However, in the present study, alfalfa plant height was consistently greater in the sprayed compared to the non-sprayed areas (Figure 2.8 and 2.9). At Gladstone, a significant sod-suppression effect on alfalfa plant height was detected 27 DAS in 1991, and on all sampling dates in 1992 (Figure 2.8). No significant differences in alfalfa plant height were observed at Portage la Prairie in 1991 (Figure 2.9a), while in 1992 significant sod-suppression effects were observed 27, 35, and 82 DAS (Figure 2.9b).

Alfalfa plant height in the sprayed area was similar to that in the non-sprayed area at both sites in 1991. Precipitation was not limiting alfalfa height in 1991, and therefore, virtually ideal growing conditions prevailed (Table 1.1 and 2.1). As a result, volumetric soil water content at both sites in 1991 was similar in the sprayed and non-sprayed area (Figure 2.1). Soil water was not limiting alfalfa growth in 1991, and therefore, alfalfa height was not influenced by sod-suppression.

In 1992, increased alfalfa plant height was observed in the presence of sod-suppression with glyphosate. Since plant height was reduced in the non-sprayed area, shading effects of the resident vegetation did not stimulate stem elongation as was found by Evers (1989). Rather, increased plant height in the sprayed area can be attributed to increased soil water content in the presence of sod-suppression that was available

a)



b)

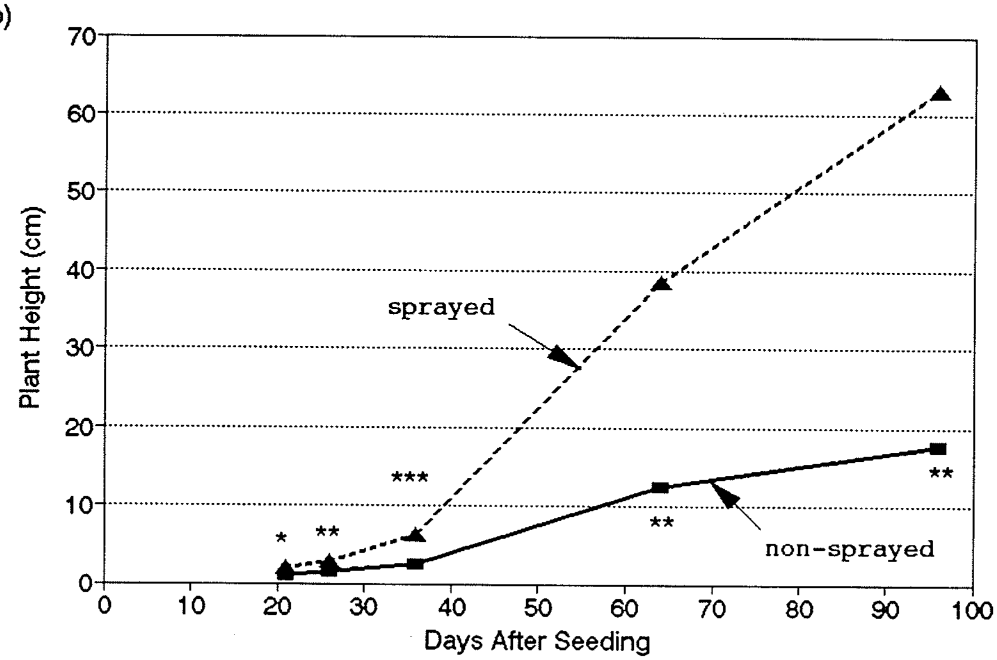
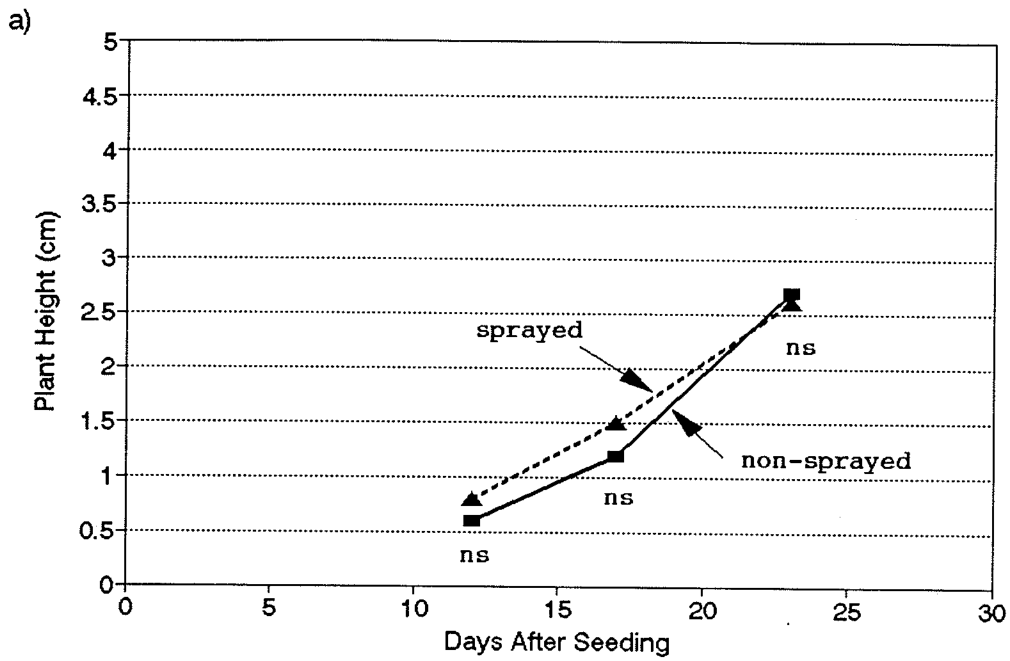


Figure 2.8 Influence of sod-suppression on alfalfa height at Gladstone in a) 1991 and b) 1992. ***, **, * Significant at 0.001, 0.01, and 0.05 probability levels, respectively; ns=nonsignificant.



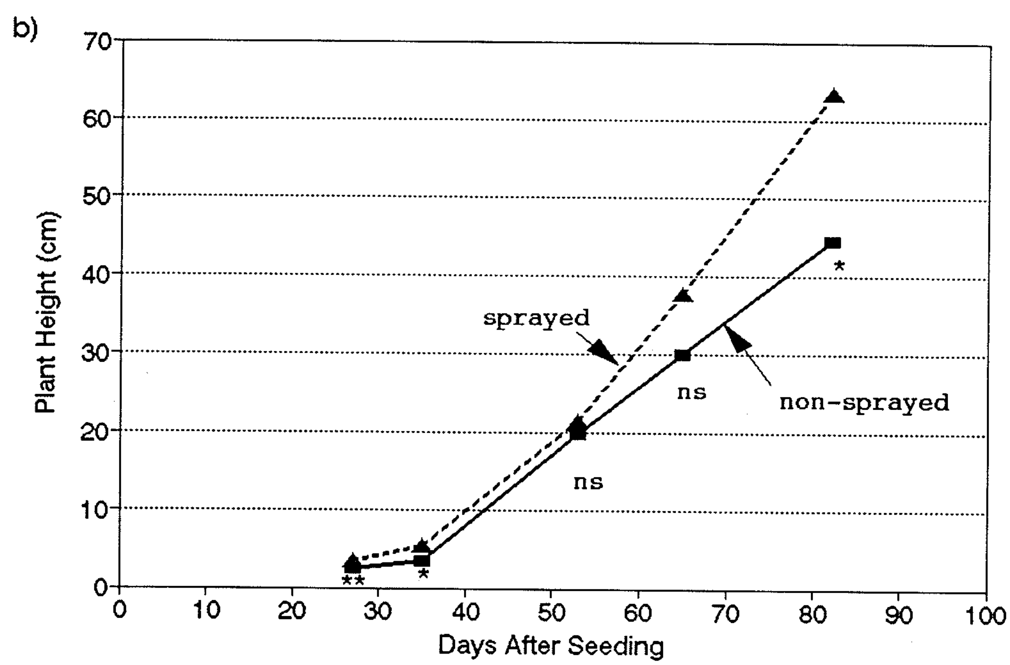


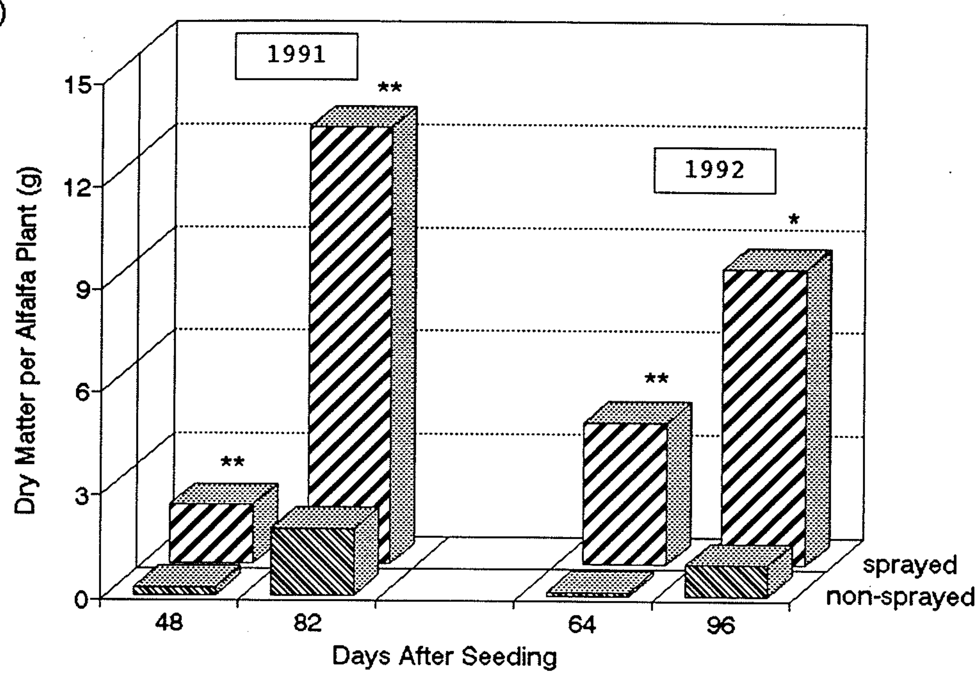
Figure 2.9 Influence of sod-suppression on alfalfa height at Portage la Prairie in a) 1991 and b) 1992. **, * Significant at 0.01, and 0.05 probability levels, respectively; ns=nonsignificant.

at both sites in 1992 (Figure 2.2 and 2.3). This is similar to the results reported by Moshier and Penner (1978), who observed increased sod-seeded alfalfa height when the resident Kentucky bluegrass sward was suppressed with glyphosate.

2.5.3.3 Individual Plant Dry Matter Production

The DM production per alfalfa plant was calculated for each of the DM harvest dates in 1991 and 1992 at both sites. At Gladstone in 1991 and 1992, DM production per alfalfa plant was significantly greater in the sprayed compared to the non-sprayed area for both sampling dates (Figure 2.10a). At Portage la Prairie in 1991, DM production per alfalfa plant was again greater in the sprayed compared to the non-sprayed area on both sampling dates (Figure 2.10b). In 1992, DM production per alfalfa plant was significantly greater in the sprayed compared to the non-sprayed area 65 DAS (Figure 2.10b), however, no significant difference was observed 82 DAS. Increased light penetration to the soil surface (Figure 2.4 and 2.5) and increased soil water content (Figure 2.2 and 2.3) in the presence of sod-suppression was the likely reason for enhanced DM production per alfalfa plant. Similarly, Taylor et al. (1969) attributed increased DM production per plant of white clover and alfalfa to less shading and greater levels of soil water when the resident Kentucky bluegrass sod was chemically suppressed.

a)



b)

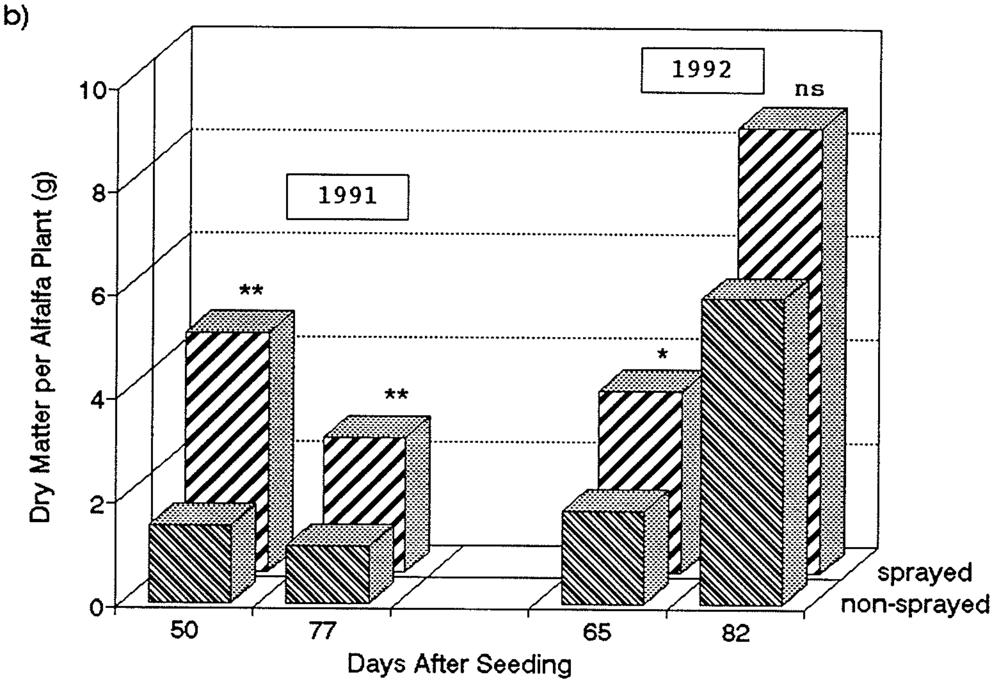


Figure 2.10 Influence of sod-suppression on dry matter production per alfalfa plant in 1991 and 1992 at a) Gladstone and b) Portage la Prairie. **, * Significant at 0.01, and 0.05 probability levels, respectively; ns=nonsignificant.

High DM production in alfalfa seedlings is critical to maintenance of plant vigour. Larger plants should be better able to withstand stresses such as low temperatures, grazing and drought. Belanger and Winch (1985) considered a treatment successful if alfalfa plants growing in that treatment achieved approximately 1.1 g per alfalfa plant 12 weeks after planting. At Gladstone, alfalfa plants in the non-sprayed area did not achieve this critical dry weight per plant within 84 DAS in 1992 (Figure 2.10a). As a result, the alfalfa seedlings growing amongst the resident sod at Gladstone in 1992 were small, weak plants that may not be able to survive stressful conditions (ie. over wintering).

2.5.3.4 Relative Growth Rate

The relative growth rates (RGR's) of individual sod-seeded alfalfa plants at Gladstone are shown in Table 2.15.

Table 2.15 Influence of sod-suppression on the relative growth rate of alfalfa plants at Gladstone in 1991 and 1992.

	1991		1992	
Trt	Time 1	Time 2	Time 1	Time 2
	----------------g plant^{-1} day^{-1}----------------			
Non-sprayed	0.00147	0.01415	0.000244	0.0051
Sprayed	0.00844	0.0887	0.0602	0.1753
L.S.D.	1.4×10^{-17}	1.1×10^{-16}	0.0002	2.2×10^{-16}

In 1991 and 1992, during time 1 (from seeding to the first DM harvest), the RGR of alfalfa plants in the sprayed treatment was greater compared to plants in the non-sprayed treatment. This trend was also observed during time 2 (between harvest sampling dates). It appears that competition from the resident vegetation throughout the growing season in the non-sprayed treatment resulted in a lower rate of alfalfa growth, and therefore, lower DM production (Figure 2.10). The largest difference between RGR's in the sprayed compared to the non-sprayed area at Gladstone was observed for time 1 in 1992. At this time, the RGR of plants in the sprayed area was approximately 246-fold greater than plants in the non-sprayed area. In 1992, the RGR in the non-sprayed area at time 2 was approximately 20-fold greater than that in the non-sprayed area at time 1. However, in 1991, the RGR in the non-sprayed area at time 2 was only 10-fold greater than the RGR at time 1. Therefore, although competition from the resident vegetation was more severe in 1992 (Table 2.15) the alfalfa plants were able to tolerate the effects better than plants in the non-sprayed area in 1991.

The relative growth rates (RGR's) of individual sod-seeded alfalfa plants at Portage la Prairie are shown in Table 2.16. At time 2 in 1991, negative RGR's were obtained. Dry matter per alfalfa plant declined between sampling dates, especially in the sprayed treatment (Figure 2.10). One explanation for the decline may be that at the later sampling date (77 DAS) some of the alfalfa leaves had senesced naturally. Leaf senescence was more pronounced in the sprayed treatment because intracrop competition for light, nutrients, and soil water intensified as the season progressed. In both years at time 1, sod-suppression resulted in a significantly greater RGR (Table 2.16) which resulted in increased DM production (Figure 2.10). However, similar RGR's were obtained between the sprayed and non-sprayed areas at time 2 in 1992. Sod-suppression did not influence the rate of alfalfa growth at Portage la Prairie in 1992. Therefore, competition from the resident vegetation in the non-sprayed area did not adversely affect sod-seeded alfalfa performance. In general, alfalfa seedlings were more tolerant of the competition from the resident vegetation at Portage la Prairie (Table 2.16) compared to Gladstone (Table 2.15).

Table 2.16 Influence of sod-suppression on the relative growth rate of alfalfa plants at Portage la Prairie in 1991 and 1992.

Trt	1991		1992	
	Time 1	Time 2	Time 1	Time 2
	$g\ plant^{-1}\ day^{-1}$			
Non-sprayed	0.0094	-0.0559	0.0073	0.1830
Sprayed	0.0224	-0.1659	0.0226	0.2000
L.S.D.	2.1×10^{-17}	5.5×10^{-17}	4.2×10^{-17}	NS

Results from this study indicate that sod-suppression is essential for establishing sod-seeded alfalfa when the resident sod is a competitive, rhizomatous stand. However, establishment into a bunch type resident vegetation may not require sod-suppression.

2.5.4 Conclusions

Alfalfa emergence, development, height, and DM production at both sites were significantly greater in the sprayed compared to the non-sprayed area. By spraying, the resident sward was killed and no longer competed with the sod-seeded alfalfa seedlings for water, nutrients and light.

Alfalfa establishment and production (relative growth rate, DM production, etc.) were increased more dramatically by sod-suppression at Gladstone than at Portage la Prairie. The timothy sward at Portage la Prairie was less competitive with the sod-seeded alfalfa seedlings than the Kentucky bluegrass/bromegrass sward at Gladstone. Sod-suppression did not affect year after establishment DM at Portage la Prairie. Therefore, sod-suppression was not essential for successful establishment at this site.

Sod-seeded alfalfa plants growing in the non-sprayed area at Gladstone were unable to achieve the critical DM production per plant in 1992. These alfalfa plants would be less able to survive stressful conditions (ie. low temperature stress, or grazing pressure). Sod-suppression was necessary to obtain establishment of strong, vigorous seedlings at Gladstone.

Potential phytotoxic effects of seed-placed insecticides and temporary effects of 40 kg P_2O_5 ha^{-1} resulted in reduced emergence and DM production of sod-seeded alfalfa at both sites. When precipitation was limiting at Gladstone in 1992, pre-soaking seed treatments enhanced alfalfa emergence. Meyer (1985) indicated that approximately 100 plants m^{-2} was the minimum density required for successful alfalfa establishment for hay production. Therefore, despite the adverse effects of some seed treatments on alfalfa emergence, all seed treatments in both the sprayed and non-sprayed areas (at both sites and years) resulted in a sufficient plant population to form a productive stand.

The application of both rates of P_2O_5 resulted in increased alfalfa DM late in the growing season at both locations. The phytotoxic effects observed earlier in the presence of 40 kg P_2O_5 ha^{-1} alleviated as the growing season progressed. Soil tests indicated that soil phosphorous was lacking, especially at Gladstone, and alfalfa DM was enhanced when seed-placed.

3.0 General Discussion

The first study investigated the feasibility of establishing forages under ZT into arable land following wheat, canola and field pea. Where previous residues were high (>7500 kg ha^{-1}), establishment year emergence, development and DM production of meadow bromegrass was more negatively affected than that of alfalfa. In contrast, Hart and Dean (1986) found no effect of tillage (CT vs. ZT) system on date of emergence or stand density of western wheatgrass or alfalfa when barley was the previous crop. In their study, the barley was harvested at the soft dough stage and all harvested material was removed from the land (eg. silage). One possible explanation for the reduced establishment observed in the present study was that soil temperatures may have been reduced in the presence of heavy residues as has been reported in other ZT studies (Gauer et al. 1982). Alfalfa and meadow bromegrass may differ in response to lower soil temperatures. Another possible explanation was that the heavy residue may have physically impeded the emerging crop (Cochran et al. 1977). The presence of so much residue may have prevented the seedlings from reaching the surface. However, when the wheat residue was managed carefully (removed from the land), successful establishment of alfalfa and meadow bromegrass was achieved.

The ability to establish forages into arable lands under

ZT is important economically and environmentally. Conventional tillage production has a greater labour requirement than ZT because more passes are made across the field. Zero-tillage crop production is often more cost effective than conventional techniques because of the savings on labour and liquid fuel (Berardi 1978). Since extensive tillage is required for weed control or pre-plant herbicide incorporation (Dodds et al. 1984) with clear seeding forage establishment, successful ZT production would result in significant cost-saving in the establishment year.

The most common method of forage establishment involves the use of a companion crop (Mupondwa et al. 1993). However, Waddington and Bittman (1983) observed a 20% decrease in yield the year after establishment when alfalfa and bromegrass were established with a canola companion crop compared to being seeded alone. Under ZT forage establishment, the previous crop residue acts as an "inert" companion crop because it does not compete for resources (light, nutrients, soil water). Therefore, ZT establishment provides all the benefits of a companion crop (eg. protects the seedlings from sand-blasting and desiccation by wind (Koch 1992)), yet does not cause a reduction in forage production.

Seedbed preparation for clear seeding forage establishment often results in a soil surface susceptible to erosion prior to canopy closure (Sturgul et al. 1990). Again, under ZT the previous crop residue protects the soil from wind and water erosion. Therefore, forage production under ZT is feasible even on lands susceptible to erosion.

Under ZT there appears to be less risk of forage establishment failure due to soil water deficits (Sheaffer 1989). The water conserving benefits of ZT (Mueller-Warrant and Koch 1980) were expressed in the present study and resulted in enhanced forage emergence. In areas where post-seeding precipitation is unpredictable, there may be an advantage to ZT forage establishment. Therefore, the promising results of this study should encourage more producers to include forages in crop rotations.

Including more perennial forages in the crop rotation will reverse the trend of soil degradation that has been occurring over time. Much of this degradation can be attributed to excess tillage. Perennial forages improve soil structure and soil fertility (Heichel 1978), increase soil organic matter (Campbell et al. 1990), and reduce soil erosion (Stinner and House 1989). Demonstrating that forage establishment is feasible under ZT should encourage current growers to shorten stand length and spread the soil improving benefits of forages around a land base more readily.

Significant improvements to pasture dry matter production can be obtained when legumes are introduced into low production pastures (Bryan 1985). However, pasture land is often marginal land (eg. presence of stones, adverse topography, etc.) and conventional pasture renovation with tillage is not feasible. Therefore, the second study, described, in detail, the agronomic and physiological responses of sod-seeded alfalfa to different seed treatments in a system where indigenous pasture vegetation was suppressed or left unsuppressed.

Alfalfa emergence, development and DM production were significantly greater in the sprayed compared with the non-sprayed treatments at both locations. Similar results have been reported by others (Vogel et al. 1983; Belanger and Winch 1985; and Zarnstorff et al. 1990). Chemical suppression of the resident vegetation prior to seeding, resulted in increased light penetration to the soil surface and increased soil water content. Similar results were obtained by Trimmer and Linscott (1986) who found that the use of sod-suppression increased soil water content by 1.44 cm in the upper 20 cm during the first ten days after treatment. Sheaffer (1989) concluded that grass sods compete with legume seedlings for water, and therefore, suppression of resident vegetation is important for successful alfalfa establishment. Increased water conservation and increased light penetration to the soil surface with sod-suppression both played a role in enhancing alfalfa emergence and subsequent establishment.

Chemical suppression of a rhizomatous sod increased alfalfa establishment and DM production approximately 10-fold, while suppression of a bunch type sod resulted in a three-fold increase. In addition, the relative growth rate of sod-seeded alfalfa plants was influenced more by sod-suppression at Gladstone (rhizomatous sward) compared to Portage la Prairie (bunch sward). Both resident swards resulted in similar light interception, and therefore, the plants must differ in their level of competition for soil resources (eg. nutrients, water, space, etc.). Williams et al. (1985) attributed the inability to establish sod-seeded alfalfa in a meadow foxtail (*Alopecurus pratensis* L.) sward to severe competition for nutrients from the grass component. In the present study, the alfalfa seedlings were able to withstand the competition of the bunch type sod more readily than that of the rhizomatous sod. Therefore, sod-suppression of the bunch type grass was not as critical. Sod-suppression significantly affected year after establishment DM production at Gladstone only. However, the increase was much less dramatic than had been observed in the establishment year.

Belanger and Winch (1985) determined that a sod-seeding treatment could be considered successful if alfalfa plants growing in that treatment achieved approximately 1.1 g per plant 12 weeks after planting. In the present study, individual alfalfa seedlings growing in the non-sprayed area at Gladstone in 1992 were unable to achieve this critical DM production in the establishment year. As a result, these seedlings would be considered less able to withstand future stresses such as grazing or drought. Therefore, it was concluded that sod-suppression was essential for successful establishment into the relatively productive, rhizomatous sod at Gladstone.

Since sod-seeded alfalfa seedlings are continuously competing with the resident vegetation for resources (light, water, and nutrients), it is important to use management techniques that favour rapid alfalfa emergence and early season growth. Seed-placing phosphorous is one such technique since pastures often lack soil phosphorous. However, in the present study the addition of seed-placed phosphorous at 40 kg ha^{-1} P_2O_5 sometimes resulted in adverse effects. However, seed-placing 30 kg ha^{-1} P_2O_5 increased alfalfa production without any apparent phytotoxic effects. This is consistent with findings of Sheard et al. (1971).

Seed-placing insecticides has successfully protected seedlings from slugs and nematodes in other sod-seeding studies (Sheaffer et al. 1982; Dowling and Linscott 1983). However, past research has investigated foliar or broadcast (immediately prior or following seeding) applications of insecticides. In the present study, the insecticides were seed-placed and the proximity of the amendments to the seed caused a phytotoxic effect.

Dry conditions during the emergence period in 1992 may explain why the pre-soaked seed treatments resulted in the greatest alfalfa emergence at Gladstone. Keller and Bleak (1968) suggested that pre-soaking of seed would contribute towards greater success of sod-seeding plants.

Regardless of the adverse effects observed with some seed treatments (eg. 40 kg ha^{-1} P_2O_5, insecticides), all seed treatments in both the sprayed and non-sprayed areas resulted in a sufficient plant population (> 100 plants m^{-2}) to form a productive hay stand (Meyer 1985).

Both studies determined that forage establishment under conservation tillage is feasible in both arable and pasture situations in prairie Canada. The encouraging results of this research should encourage producers to adopt the practice of forage establishment under conservation tillage. The short and long-term benefits would include: soil and water conservation, lower machinery expense, and fewer passes across the field.

4.0 Recommendations

To achieve successful establishment of forages under ZT into arable lands heavy wheat residue needs to be managed carefully (> 7500 kg ha^{-1} may need to be removed). Chaff spreaders should be used to facilitate uniform residue return. Chaff collection wagons could also be used to remove the majority of chaff.

Since forages are often planted in alfalfa/grass mixtures, further research should investigate the feasibility of establishment of such mixtures under ZT. Also, the potential to include forages in crop rotations should warrant research evaluating ZT forage establishment after lower residue crops, such as lentils and after other cereal crops, such as oats and barley.

When renovating a pasture through sod-seeding, if the resident vegetation is a relatively productive, rhizomatous stand, it appears that sod-suppression is essential to achieve strong, vigorous seedlings that will be able to withstand various stresses (eg. grazing pressure, low temperature and drought stress, etc.). Suppressing the resident vegetation with 0.89 kg ha^{-1} glyphosate prior to seeding, results in increased light penetration to the soil surface and increased soil water content.

For producers concerned with the hazard of bloat or wanting to maintain some vegetation in the event of an establishment failure, it would be feasible to only suppress strips of vegetation. Therefore, some grass will be maintained to obtain a grass legume/mixture and to ensure the pasture remains productive.

Seed-placing 30 kg ha^{-1} P_2O_5 will result in increased alfalfa DM production without causing any phytotoxic effects.

Seed-placed insecticides sometimes reduced alfalfa emergence in this study. The nearness of the insecticides with the seed may have caused seedling damage, and therefore, reduced emergence. Future research should examine, in detail, the interaction of carbofuran and terbufos with alfalfa seedlings when the insecticides are seed-placed. This problem may be alleviated if sod-seeding drills were designed to place (band) seed amendments, such as P_2O_5 and insecticides, away from (below or beside) the seed.

Finally, alfalfa seedlings established under sod-seeding in the non-sprayed areas constantly compete with the resident vegetation for light, nutrients, and soil water. When establishing alfalfa without sod-suppression (eg. into bunch type sod), avoiding grazing the sod-seeded alfalfa during the establishment year would alleviate placing another stress on the developing seedlings. Long-term survival of the seedlings would be enhanced if the seedlings were allowed to grow and develop without being grazed in the year of establishment.

5.0 Literature Cited

Aase, J.K. and Siddoway, F.H. 1980. Stubble heights on seasonal microclimate, water balance, and plant development of no-till winter wheat. Agric. Meteor. 21:1-20.

Aguiler, R., Kelly, E.F., and Hill, R.D. 1988. Effects of cultivation on soils in northern Great Plains rangeland. Soil Sci. Soc. Am. J. 52:1081-1085.

Alder, E.F., Leben, C., and Chichuk, A. 1959. Effects of gibberellic acid on corn, Agron. J. 51:307-308.

Allan, R.E., Vogel, O.A., and Craddock, Jr., J.C. 1959. Comparative response to gibberellic acid of dwarf, semidwarf, and standard short and tall winter wheat varieties. Agron. J. 51:737-740.

Allmaras, R.R., Burrows, W.C., and Larson, W.E. 1964. Early growth of corn as affected by soil temperature. Soil Sci. Soc. Am. Proc. 28:271-275.

Anonymous, 1987. Value of forage production. p. 1-11. In: Forages '87, Manitoba Agriculture, Winnipeg, MB.

Bahler, C.C., Byers, R.A., and Stout, W.L. 1987. The effect of weed and invertebrate pest management on alfalfa establishment in oat stubble. p. 76-77. In: J.F. Power (ed.), The Role of Legumes in Conservation Tillage Systems., Proc. Soil Conserv. Soc. Am., Athens, GA.

Barker, G.M. 1990. Pasture renovation: interactions of vegetation control with slug and insect infestations. J. Agric. Sci. 115:195-202.

Barnes, R.F. and Gordon, C.H. 1972. Feeding and on-farm feeding. In: C.H. Hanson (ed.), Alfalfa Science and Technology. Agronomy 15:601-630. Am. Soc. Agron., Madison, WI.

Barney, R. J. and Pass, B.C. 1987. Influence of no-tillage planting on foliage-inhabiting arthropods of alfalfa in Kentucky. J. Econ. Entomol. 80:1288-1290.

Barney, R.J., Parr, J.C., and Pass, B.C. 1988. Carbofuran effect on alfalfa establishment under no-tillage conditions. Transactions Kentucky Academy Sciences. 49:80-84.

Belanger, G. and Winch, J.E. 1985. Herbicides for sod-seeding legumes on shallow soil pastures. Can. J. Plant Sci. 65: 1049-1055.

Berardi, G.M. 1978. Organic and conventional wheat production: Examination of energy and economics. Agro-Ecosystems. 4:367-376

Beveridge, J.L. and Wilsie, C.P. 1959. Influence of depth of planting, seed size, and variety on emergence and seeding vigour in alfalfa. Agron. J. 51:731-734.

Bhat, M.L., Sen, A. and Misra, N.M. 1990. Rainfed wheat as affected by cycocel, absorbic acid, and gibberellic acid seed treatments. Rachis. 9: 17-20.

Black, A.L. and Wright, J.R. 1972. Nitrogen and phosphorous availability in a fertilized rangeland ecosystem of the northern Great Plains. J. Range Manage. 25:456-460.

Bleak, A.T. and Keller, W. 1970. Field emergence and growth of crested wheatgrass from pretreated vs nontreated seeds. Crop Sci. 10:85-87.

Bleak, A.T. and Keller, W. 1972. Germination and emergence of selected forage species following preplanting seed treatment. Crop Sci. 12:9-13.

Blevins, R.L., Cook, D., Phillips, S.H., and Phillips, R.E. 1971. Influence of no-tillage on soil moisture. Agron. J. 63:593-596.

Blevins, R.L., Thomas, G.W., Smith, M.S., Frye, W.W., and Cornelius, P.L. 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. Soil Till. Res. 3:135-146.

Bowes, G.G., and Zentner, R.P. 1992. Effect of vegetation suppression on the establishment of sod-seeded alfalfa in the Aspen Parkland. Can. J. Plant Sci. 72:1349-1358.

Brian, P.W. and Hemming, H.G. 1955. The effect of gibberellic acid on shoot growth of pea seedlings. Physiologia Plantarum 8:669-681.

Brown, C.S. and Stafford, R.E. 1970. Get top yields from alfalfa seedings. Better Crops Plant Food. 54:16-18.

Bryan, W.B. 1985. Effect of sod-seeding legumes on hill land pasture productivity and composition. Agron. J. 77:901-905.

Byers, R.A., Mangan, R.L., and Templeton, Jr., W.C. 1983. Insect and slug pests in forage legume seedlings. J. Soil Water Conserv. 38:224-226.

Byers, R.A., Templeton, Jr., W.C., Mangan, R.L., Bierlein, D.L., Campbell, W.F., and Donley, H.J. 1985. Establishment of legumes in grass swards: effects of pesticides on slugs, insects, legume seedling numbers and forage yield and quality. Grass and Forage Sci. 40: 41-48.

Byers, R.A. and Templeton, Jr., W.C. 1988. Effects of sowing date, placement of seed, vegetation suppression, slugs, and insects upon establishment of no-till alfalfa in orchardgrass sod. Grass and Forage Sci. 43: 279-289.

Campbell, C.A., Zentner, R.P., Janzen, H.H., and Bowren, K.E. 1990. Crop rotation studies on the Canadian prairies. Agric. Can. Publ. 1841/E. Supply and Services Canada., Ottawa. ON.

Cardwell, V.B. 1984. Germination and crop production. p. 53-92. In: M.B. Tesar (ed.) Physiological basis of crop growth and development. ASA, Madison, WI.

Carter, M.R. and Rennie, D.A. 1985. Soil temperature under zero tillage systems for wheat in Saskatchewan. Can. J. Soil. Sci. 65:329-338.

Chippindale, H.G. 1934. The effect of soaking in water on the "seeds" of some *gramineae*. Annals Appl. Biol. 21:225-232.

Cochran, V.L., Elliott, L.F., and Papendick, R.I. 1977. The production of phytotoxins from surface crop residues. Soil Sci. Soc. Am. J. 41:903-908.

Cochran, V.L., Elliott, L.F., and Papendick, R.I. 1982. Effect of crop residue management and tillage on water use efficiency and yield of winter wheat. Agron. J. 74:929-932.

Cooper, C.S. 1966. Response of bird'sfoot trefoil and alfalfa to various levels of shade. Crop Sci. 6:63-66.

Cooper, C.S. 1967. Relative growth of alfalfa and bird'sfoot trefoil seedlings under low light intensity. Crop Sci. 7:17-178.

Cowett, E.R. and Sprague, M.A. 1963. Effect of stand density and light intensity on the microenvironment and stem production of alfalfa. Agron. J. 55:432-434.

Decker, A.M., Taylor, T.H., and Willard, C.J. 1973. Establishment of new seedlings, (ed. M.E. Heath), In: Forages - The Science of Grassland Agriculture. Iowa State University Press, Ames, IA.

Diebert, E.J. and Utter, R.A. 1989. Sunflower growth and nutrient uptake: Response to tillage system, hybrid maturity and weed control method. Soil Sci. Soc. Am. J. 53:133-138.

Dodds, D.L., Meyer, D., and Van Der Puy, D. 1984. Hay in 10 weeks direct seeding alfalfa. North Dakota State University Bulletin R-841. Fargo, ND.

Dowling, P.M. and Linscott, D.L. 1983. Use of pesticides to determine relative importance of pest and disease factors limiting establishment of sod-seeded lucerne. Grass Forage Sci. 38:179-185.

Drake, M., Vengris, J., and Colby, W.G. 1951. Cation-exchange capacity and plant roots. Soil Sci. 72: 139-147.

Dumanski, J. 1986. Towards a soil conservation strategy for Canada. p. 1-10. In D.W. Anderson (ed.) In Search of Soil Conservation Strategies in Canada. Conference Proceedings. April 1-3, 1986.

Eck, H.V., Martinez, T., And Wilson, G.C. 1977. Alfalfa production on a profile-modified slowly permeable soil. Soil Sci. Soc. Am. J. 41:1181-1186.

Elgabaly, M.M. and Wiklander, L. 1949. Effect of exchange capacity of clay mineral and acidoid content of plant on uptake of sodium and calcium by excised barley and pea roots. Soil Sci. 67:419-424.

Eltun, R., Wakefield, R.C., and Sullivan, W.M. 1985. Effect of spray/planting intervals and various grass sods on no-till establishment of alfalfa. Agron. J.77:5-8.

Evenson, P.D., and Rumbaugh, M.D. 1972. Influence of mulch on postharvest soil temperatures and subsequent regrowth of alfalfa (*Medicago sativa* L.). Agron. J. 64:154-157.

Evers, G.W. 1989. Light competition simulation technique for sod-seeded crops. Agron. J. 81:991-992.

Fick, G.W., Holt, D.A., and Lugg, D.G. 1988. Environmental physiology and crop growth. p. 163-189. In A.A. Hanson, D.K. Barnes, and R.R. Hill, Jr. (ed.) Alfalfa and Alfalfa Improvement. Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am., Madison, WI.

Forney, D.R., Foy, C.L., and Wolf, D.D. 1985. Weed suppression in no-till alfalfa (*Medicago sativa* L.) by prior cropping of summer-annual forage grasses. Weed Sci. 33:490-497.

Gauer, E., Shaykewich, C.F., and Stobbe, E.H. 1982. Soil temperature and soil water under zero tillage in Manitoba. Can. J. Plant Sci. 62:311-325.

Gist, G.R. and Mott, G.O. 1957. Some effects of light intensity, temperature, and soil moisture on the growth of alfalfa, red clover and birdsfoot trefoil. Agron. J. 49:33-36.

Godfrey, L.D., Legg, D.E., and Yeargan, K.V. 1986. Effects of soil-borne organisms on spring alfalfa establishment in an alfalfa rotation system. J. Econ. Entomol. 79:1055-1063.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research, John Wiley and Sons, Toronto, ON.

Grant, J.F., Yeargan, K.V., Pass, B.C., and Parr, J.C. 1982. Invertebrate organisms associated with alfalfa seedling loss in complete-tillage and no-tillage plantings. J. Econ. Entomol. 75:822-826.

Gray, B., Drake, M. and Colby, W.G. 1953. Potassium competition in grass-legume associations as a function of root cation exchange capacity. Soil Sci. Soc. Am. Proc. 17:235-239.

Groya, F.L. and Sheaffer, C.C. 1981. Establishment of sod-seeded alfalfa at various levels of soil moisture and grass competition. Agron. J. 73:560-565.

Hanson, C.H. and Barnes, D.K. 1973. Alfalfa. p. 136-147. In: M.E. Heath (ed.) Forages / The Science of Grassland Agriculture, 3rd. edition., Iowa State University Press, Ames, IO.

Hart, R.H. and Dean, J.G. 1986. Forage establishment: weather effects of stubble vs. fallow and fall vs. spring seeding. J. Range Management. 39:228-230.

Haun, J.R. 1973. Visual quanitification of wheat development. Agron. J. 65:116-119.

Haynes, R.J. 1980. Ion exchange properties of roots and ionic interactions within the root apoplasm: their role in ion accumulation by plants. Botan. Rev. 46:75-99.

Heichel, G.H. 1978. Stabilizing agriculture energy needs: Roles of forages, rotations, and nitrogen fixation. J. Soil Water Conserv. 33:279-282.

Hicks, S.K., Wendt, C.W., Gannaway, J.R., and Baker, R.B. 1989. Allelopathic effects of wheat straw on cotton germination, emergence, and yield. Crop Sci. 1057-1061.

Higgs, R.L., Peterson, A.E., and Paulson, W.H. 1990. Crop rotations sustainable and profitable. J. Soil Water Conserv. 45:68-70.

Huggins, D.R. and Pan, W.L. 1991. Wheat stubble management affects growth, survival, and yield of winter grain legumes. Soil Sci. Soc. Am. J. 55:823-829.

Ives, R.M. and Shaykewich, C.F. 1987. Effect of simulated soil erosion on wheat yields on the humid Canadian prairie. J. Soil Water Conserv. 42:205-208.

Jackobs, J.A. 1963. A measurement of the contribution of ten species to pasture mixtures. Agron. J. 55:127-131.

Kehr, W.R., Manglitz, G.R., Ogden, R.L. 1982. Insect control on seedling alfalfa by cultivars and soil and foliar insecticides. Agron. J. 74:407-411.

Keller, W. and Bleak, A.T. 1969. Root and shoot growth following preplanting treatment of grass seed. J. Range Manage. 22:43-46.

Keller, W. and Bleak, A.T. 1972. Preplanting treatment to hasten germination and emergence of grass seed. J. Range Manage. 21:213-216.

Kendall, W.A. and Stringer, W.C. 1985. Physiological aspects of clovers. _In_ N.L. Taylor (ed.) Clover science and technology. Agronomy 25: 111-159.

Ketcheson, J.W. 1980. Long-range effects of intensive cultivation and monoculture on the quality of southern Ontario soils. Can. J. Soil Sci. 60:403-410.

Koch, D.W. 1991. Introducing alfalfa into meadows without tillage. Proc. 3rd Intermountain Meadow Symposium, July 1-3, 1991. Steamboat Springs, CO.

Koch, D.W. 1992. Establishing no-till alfalfa in Wyoming. p. 96-99. In: H.E. White (ed.), Proc. 22nd Annual National Alfalfa Symposium, March 5-6, 1992. Roanoke, VI.

Kreuger, C.R. and Vigil, F.R. 1979. Interseeding alfalfa for grassland improvement in the Northern Great Plains. In: Proc. 26th Alfalfa Impr. Conf., Agriculture Reviews and Manuals, Science and Education Administration, USDA.

Kulkarni, J.H., Sardeshpande, J.S., and Bagyaraj, D. 1974. Effect of four soil-applied insecticides on symbiosis of *rhizobium spp*. with *Arachis hypogaea* Linn. Plant Soil. 40:169-172.

Kunelius, H.T., Campbell, A.J., Mcrae, K.B., and Ivany, J.A. 1982. Effects of vegetation suppression and drilling techniques on the establishment and growth of sod-seeded alfalfa and bird'sfoot trefoil in grass dominant swards. Can. J. Plant Sci. 62:667-675.

Lafond, G.P., and Loeppky, H. 1988. Crop management study, 1988, Indian Head: Progress Report. Indian Head Experimental Farm, Agriculture Canada, Indian Head, SK.

Lafond, G.P., Loeppky, H., and Derksen, D.A. 1992. The effects of tillage systems and crop rotations on soil water conservation, seedling establishment, and crop yield. Can. J. Plant Sci. 72:103-115.

Lal, R. 1989. Conservation tillage for sustainable agriculture: tropics versus temperate environments. Adv. Agron. 42:85-197.

Lee, T.T. 1976. Insecticide-plant interaction: Carbofuran effect on indole-3-acetic acid metabolism and plant growth. Life Sci. 18:205-210.

Lin, S.C., Funke, B.R., and Shultz, J.T. 1972. Effects of organophosphate and carbamate insecticides on nitrification and legume growth. Plant and Soil. 37: 489-496.

Lindstrom, M.J. and Onstad, C.A. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. Soil Water Conserv. 39:149-152.

Lodge, G.M. and Gleeson, A.C. 1984. A comparison of methods of estimating lucerne population for monitoring persistence. Aust. J. Exp. Agric. Anim. Husban. 24:174-177.

Manitoba Agriculture. 1994. Guide to Crop Protection 1994. 193 pp.

Malik, N. and Waddington, J. 1990. No-till pasture renovation after sward suppression by herbicides. Can. J. Plant Sci. 70:261-267.

Marth, P.C., Audia, W.V., and Mitchell, J.W. 1956. Effects of gibberellic acid on growth and development of plants of various genera and species. Botan. Gaz. 118:106-111.

Martin, N.P., Sheaffer, C.C., Wyse, D.L., and Schriever, D.A. 1983. Herbicide and planting date influence establishment of sod-seeded alfalfa. Agron. J. 75:951-955.

Mattson, S. 1926. Electrodialysis of the colloidal soil material and the exchangeable bases. J. Agric. Res. 33:553-567.

McConnaughay, K.D.M., and Bazzaz, F.A. 1987. The relationship between gap size and performance of several colonizing annuals. Ecology. 68:411-416.

McKee, G.W. 1962. Effects of shading and plant competition on seedling growth and nodulation of bird'sfoot trefoil. Pennsylvania Agric. Exp. Stn. Bull. 689.

McKenna, J.R., Wolf, D.D., and Lentner, M. 1991. No-till warm season grass establishment as affected by atrazine and carbofuran. Agron. J. 83:311-316.

Metcalfe, D.S. 1973a. Forages Statistics. p. 64-79. <u>In</u>: M.E. Heath (ed.) Forages / The Science of Grassland Agriculture, 3rd. edition., Iowa State University Press, Ames, IO.

Metcalfe, D.S. 1973b. The botany of grasses and legumes. p. 80-97. <u>In</u>: M.E. Heath (ed.) Forages / The Science of Grassland Agriculture, 3rd. edition., Iowa State University Press, Ames, IO.

Meyer, D.W. 1985. Plant density effects on alfalfa forage yield and quality. p. 101. Agron. Abstr., Am. Soc. Agron., Madison, WI.

Mitchell, K. J. 1953. Influence of light and temperature on the growth of ryegrass *Lolium* spp. I. Pattern of vegetative development. Physiol. Plant. 6:21-46.

Moshier, L. and Penner, D. 1978. Use of glyphosate in sod seeding alfalfa (*Medicago sativa*) establishment. Weed Sci. 26:163-166.

Mouat, M.C.H. and Walker, T.W. 1959. Competition for nutrients between grasses and white clover. II. Effect of root cation-exchange capacity and rate of emergence of associated species. Plant Soil. 9:41-52.

Mueller, J.P. and Chamblee, D.S. 1984. Sod-seeding of ladino clover and alfalfa as influenced by seed placement, seeding date, and grass suppression. Agron. J. 76:284-289.

Mueller-Warrant, G.W. and Koch, D.W. 1980. Establishment of alfalfa by conventional and minimum-tillage seeding techniques in a quackgrass-dominant sward. Agron. J. 72:884-889.

Mupondwa, K.F., Bullied, J., and Entz, M.H. 1993. A survey of forage crop production practices and the role of forages in crop rotations in Manitoba and eastern Saskatchewan. p. 143-149. In: Proc. Manitoba Agriforum, 5-1767 Portage Ave., Winnipeg, MB., R3J 0E7.

Nyborg, M. and Mahli, S.S. 1989. Effect of zero and conventional tillage on barley yield and nitrate nitrogen content, moisture and temperature of soil in north-central Alberta. Soil Till. Res. 15:1-9.

Olsen, F.J., Jones, J.H., and Patterson, J.J. 1981. Sod-seeding forage legumes in a tall fescue sward. Agron. J. 73: 1032-1036.

Olusuyi, S.A. and Raguse, C.A. 1968. Effect of temperature on germination and seedling development of Ladino clover (*Trifolium repens* L.) and Salina strawberry clover (*Trifolium fragiferum* L). Crop Sci. 8:543-544.

Pauli, A.W. and Stickler, F.C. 1961. Effects of seed treatment and foliar spray applications of gibberellic acid on grain sorghum. Agron. J. 53:137-139.

Perfect, E., Kay, B.D., van Loon, W.K.P., Sheard, R.W., and Pojasok, T. 1990. Rates of change in soil structural stability under forages and corn. Soil Sci. Soc. Am. J. 54:179-186.

Phillips, R.E. 1981. Soil Moisture. In: R.E. Phillips, G.W. Thomas, and R.C. Blevins (eds.), No-tillage Research: Research Reports and Reviews. College of Agriculture and Agricultural Experiment Station, Lexington, KY.

Phillips, R.E., Blevins, R.L., Thomas, G.W., Frye, W.W., and Phillips, S.H. 1980. No-tillage agriculture. Science. 208:1108-1113.

Pless, C.D., Cherry, E.T., Morgan, Jr., H. 1971. Growth and yield of burley tobacco as affected by two systemic insecticides. J. Econ. Entomol. 64:172-175.

Poppe, S. 1991. Comparative response of canola, field pea and wheat to zero-tillage., M.Sc. Thesis, Dept. of Plant Science, University of Manitoba, Winnipeg, MB., R3T 2N2.

Potter, K.N., Cruse, R.M., and Horton, R. 1985. Tillage effects on soil thermal properties. Soil Sci. Soc. Am. J. 49:968-973.

Prairie Farm Rehabilitation Administration Soil and Water Conservation Service. 1989. Prairie Soils: The Case for Conservation., Ag. Can. Publ., Ottawa, ON.

Pritchett, W.L. and Nelson, L.B. 1951. The effect of light intensity on the growth characteristics of alfalfa and bromegrass. Agron. J. 43:172-177.

Rhem, G.W. 1984. Yield and quality of a warm-season grass mixture treated with N, P, and atrazine. Agron. J. 76:731-734.

Ritchie, J.T. and NeSmith, D.S. 1991. Temperature and crop development. p. 5-29. In: Modeling Plant and Soil Systems, Agronomy Monograph no. 31. Am. Soc. Agron., Madison, WI.

Rodell, S., Funke, B.R., Schultz, J.T. 1977. Effects of insecticide on acetylene reduction by *Azotobacter vinelandii* and soybean nodules. Plant Soil. 47:375-381.

Rogers, D.D., Chamblee, D.S., Mueller, J.P., and Campbell, W.V. 1983. Fall sod-seeding of ladino clover into tall fescue as influenced by time of seeding, and grass and insect suppression. Agron. J. 75:1041-1046.

Rogers, D.D., Chamblee, D.S., Mueller, J.P., and Campbell, W.V. 1985. Conventional and no-till establishment of ladino clover as influenced by time of seeding and insect and grass suppression. Agron. J. 531-538.

Rohlf, F.J. and Sokal, R.R. 1969. Statistical tables. W.H. Freeman, San Fransico, CA. pp. 235.

Roth, G.W., Wolf, D.D., Hagood, Jr., E.S. 1985. Alfalfa establishment without tillage as influenced by insecticide and vegetation suppression. Grass Forage Sci. 40:473-478.

Russel, J.C. 1939. The effect of surface cover on soil moisture losses by evaporation. Soil Sci. Soc. Am. Proc. 4:65-70.

Shaner, D.L. 1978. Effects of glyphosate on transpiration. Weed Sci. 26:513-516.

Shanholtz, V.O. and Lillard, J.H. 1969. Tillage system effects on water use efficiency. J. Soil Water Conserv. 24:186-189.

Sheaffer, C.C. 1989. Legume establishment and harvest management in the U.S.A. p. 277-289. In: G.C. Marten (ed.) Persistence of forage legumes, Proc. Trilateral Workshop Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Agron., July 18-24, 1989., Honolulu, HI.

Sheaffer, C.C., Rabas, D.L., Frosheiser, F.I., and Nelson, D.L. 1982. Nematicides and fungicides improve legume establishment. Agron. J. 74:536-538.

Sheard, R.W., Bradshaw, G.J., Massey, D.L. 1971. Phosphorous placement for the establishment of alfalfa and bromegrass. Agron. J. 63:922-927.

Sheard, R.W. 1980. Nitrogen in the P band for forage establishment. Agron. J. 72:89-97.

Shiflet, T.N. and Darby, G.M. 1985. Forages and Soil Conservation. p. 21-32. In: Forages: The Science of Grassland Agriculture, 4th ed., Iowa State University Press., Ames, IO.

Sloneker, L.L. and Moldenhauer, W.C. 1977 Measuring the amounts of crop residue remaining after tillage. J. Soil Water Conserv. 32:231-236.

Smoliak, S. 1981. Hay and pasture crops. p. 28-29. In: Alberta Forage Manual, Print Media Branch Alberta Agriculture. Edmonton, AB.

Statistical Analysis Systems Institute. 1986. SAS User's Guide (6.04): Statistics. SAS Institute, Cary, NC.

Stewart, B.A. and Steiner, J.L. 1990. Water-use efficiency. Adv. Soil Sci. 13:151-174.

Stinner, B.R. and House, G.J. 1989. The search for sustainable agroecosystems. J. Soil Water Conserv. 44:111-116.

Stout, W.I., Byers, R.A., Bahler, C.C., and Hoffman, L.D. 1990. Effect of tillage on soil water and alfalfa establishment in corn stubble. Appl. Agric. Res. 5:176-180.

Sturgul, S.J., Daniel, T.C., and Mueller, D.H. 1990. Tillage and canopy cover effects on interill erosion from first-year alfalfa. Soil Sci. Soc. Am. J. 54:1733-1739.

Taylor, T.H., Smith, E.M., and Templeton, Jr., W.C. 1969. Use of minimum tillage and herbicide for establishing legumes in Kentucky bluegrass (*Poa pratensis* L.) swards. Agron. J. 61:761-766.

Taylor, T.H., Foote, J.S., Snyder, J.H., Smith, E.M., and Templeton, Jr., W.C. 1972. Legume seedling stands resulting from winter and spring sowings in Kentucky bluegrass (*Poa pratensis* L.) sod. Agron. J. 64:535-538.

Taylor, T.H. and Allinson, D.W. 1983. Legume establishment in grass sods using minimum-tillage seeding techniques without herbicide application: forage yield and quality. Agron. J. 75:167-172.

Tesar, M.B. and Marble, V.L. 1988. Alfalfa establishment, p. 303-333. <u>In</u>: A.A. Hanson, D.K. Barnes, and R.R. Hill, Jr. (ed.) Alfalfa and Alfalfa Improvement - Agronomy Monograph no. 29., Madison, WI.

Thiagalingam, K., McNamara, T., and Gould, N.S. 1991. No-till technology and legume rotation for sustainable crop production in the Douglas Daly Region of the Northern Territory, Australia. Soil Till Res. 20:285-292.

Townsend, C.E. and McGinnies, W.J. 1972. Temperature requirements for seed germination of several forage legumes. Agron. J. 64:809-812.

Trimmer, M.C. and Linscott, D.L. 1986. Herbicide effects on water use by grass sod and red clover (*Trifolium pratense*) establishment. Weed Science. 34:48-51.

Unger, P.W., Allen, R.R., and Wiese, A.F. 1971. Tillage and herbicides for surface residue maintenance, weed control, and water conservation. J. Soil Water Conserv. 26:147-150.

Unger, P.W. 1990. Conservation tillage systems. Adv. Soil Sci. 13:27-68.

Van Riper, G.E. 1964. Influence of soil moisture on the herbage of two legumes and three grass as related to dry matter yields, crude protein, and botanical composition. Agron. J. 56:45-50.

Vogel, K.P., Kehr, W.R., and Anderson, B.E. 1983. Sod-seeding alfalfa into cool-season grasses and grass-alfalfa mixtures using glyphosate or paraquat. J. Range Manage. 36:700-702.

Vough, L.R., Decker, A.M., and Dudley, R.F. 1981. Influence of pesticide, fertilizers, row spacings, and seeding rates on no-tillage establishment of alfalfa. p. 547-550. In: J.A. Smith and V.W. Hays (eds.), Proc. 14th International Grassland Congress, 15-24 June, 1981., Lexington, KY.

Waddington, J. and Bittman, S. 1983. Bromegrass and alfalfa establishment with a wheat companion crop in northeastern Saskatchewan. Can. J. Plant Sci. 63:659-668.

Waddington, J, and Bittman, S. 1984. Establishment and subsequent productivity of bromegrass and alfalfa seeded with an argentine rapeseed companion crop in northeastern Saskatchewan. Can. J. Plant Sci. 64: 303-308.

Waddington, J., Schellenberg, M.P., and King, J.R. 1992. Direct seeding of alfalfa into northern pasture and rangeland. In: Proc. Symp. Ecol. Reveg. Range. Infest. Ann. Weeds, Boise, ID.

Wall, D.A. and Stobbe, E.H. 1984. The effect of tillage on soil temperature and corn (Zea mays L.) growth in Manitoba. Can. J. Plant Sci. 63:753-757.

Welty, L.E., Barker, K.R., and Lindsay, D.L. 1980. Effects of *Meloidogyne hapla* and *M. incognita* on *Phytophthora* root rot of alfalfa. Plant Dis. 64:1097-1099.

Welty, L.E., Anderson, R.L., Delaney, R.H., and Hensleigh, P.F. 1981. Glyphosate timing effects on establishment of sod-seeded legumes and grasses. Agron. J. 73:813-817.

White, P.F. and Robson, A.D. 1989. Emergence of lupins from a hard setting soil compared with peas, wheat and medic. Aust. J. Agric. Res. 40:529-537.

Wilkinson, S.R. and Gross, C.F. 1964. Competition for light, soil moisture, and nutrients during ladino clover establishment in orchardgrass sod. Agron J. 56:389-392.

Willard, C.J. and Lewis, R.D. 1947. Reduction of stands and yields of clover and alfalfa after combined wheat. Ohio Agric. Exp. Stn. Farm Home Res. 32:64-70.

Williams, E.D. 1986. Further studies on the effect of phosphate fertilizer and propyzamide on the growth of white clover slot-seeded into permanent pasture. Grass Forage Sci. 41:179-182.

Williams, E.D., Hayes, M.J., and Haggar, R.J. 1985. Slot-seeding investigations. 4. Effect of phosphate fertilizer and grass suppressant on the establishment and growth of white clover in permanent pasture. Grass Forage Sci. 40:437-447.

Willis, C.B. and Thompson, L.S. 1969. Effect of root-lesion nematode on yield of four forage legumes under greenhouse conditions. Can. J. Plant Sci. 49:505-509.

Willis, C.B. and Thompson, L.S. 1975. Influence of carbofuran and benomyl on yield and persistence of birdsfoot trefoil. Can. J. Plant Sci. 55:95-99.

Wolf, D.D. and Blaser, R.E. 1971. Leaf development of alfalfa at several temperatures. Agron. J. 11:479-482.

Wolf, D.D., Hagood, Jr., E.S., and Lentner, M. 1985. No-till alfalfa establishment as influenced by previous cover crop. Can. J. Plant Sci. 65: 609-613.

Wolf, D.D. 1988. Carbofuran for forage establishment: An update. p. 48-50. In: Proc. Southern Pasture Forage Crop Improvement Conf., December 3-8, 1988, New Orleans, LA.

Wolf, D.D. and Edmisten, K.L. 1989. Late season alfalfa plantings: Conventional vs. no-till methods. Crop Sci. 29:170-175.

Wolf, D.D., Edmisten, K.L., and White, H.E. 1989. No-till alfalfa planting in late winter following fall vegetation suppression with herbicides. Crop Sci. 29:396-399.

Wolf, D.D. and White, H.E. 1992. Establishing no-till alfalfa in Virginia. p. 87-90. In: Proc. 22nd National Alfalfa Symp., March 5-6, 1992., Roanoke, VI.

Woodhouse, W.W. and Griffith, W.K. 1973. Soil fertility and fertilization of forages. In: Forages - The Science of Grassland Agriculture. Iowa State University Press, Ames, IA.

Zarnstorff, M.E., D.S. Chamblee, J.P. Mueller, and Campbell, W.V. 1990. Late-Winter no-till seeding of alfalfa into autumn suppressed tall fescue. Agron. J. 82:255-261.

Zentner, R.P. and Campbell, C.A. 1988. First 18 years of a long-term crop rotation study in southwestern saskatchewan - yields, grain protein, and economic performance. Can. J. Plant Sci. 68:1-21.

Appendix 1

Total Forage Yield in Establishment Year

Table A1.1 Influence of sod-suppression and seed treatments on total forage yield and botanical composition in year of establishment at Gladstone in 1991 and 1992.

		1991		1992	
Spray Trt	Seed Trt	Total	% Alfalfa[z]	Total	% Alfalfa
		-- kg ha^{-1}--		-- kg ha^{-1}--	
Non-sprayed	30 kg P_2O_5 ha^{-1}	3671	24	5671	6
Non-sprayed	40 kg P_2O_5 ha^{-1}	3590	21	5222	6
Non-sprayed	100 ppm GA_3	2675	7	4334	6
Non-sprayed	200 ppm GA_3	2463	13	3961	7
Non-sprayed	Terbufos	2451	16	5255	5
Non-sprayed	Carbofuran	2354	12	4691	6
Non-sprayed	Water-soaked	2422	9	5642	5
Non-sprayed	Control	2465	14	5370	4
Sprayed	30 kg P_2O_5 ha^{-1}	4946	100	8145	100
Sprayed	40 kg P_2O_5 ha^{-1}	5403	100	7075	100
Sprayed	100 ppm GA_3	3472	100	8645	100
Sprayed	200 ppm GA_3	2984	100	7415	100
Sprayed	Terbufos	3007	100	7191	100
Sprayed	Carbofuran	2962	100	6977	100
Sprayed	Water-soaked	3025	100	7434	100
Sprayed	Control	3557	100	6745	100

[z]Refers to percent alfalfa in total forage yield.

Table A1.2 Influence of sod-suppression and seed treatments on total forage yield and botanical composition in year of establishment at Portage la Prairie in 1991 and 1992.

		1991		1992	
Spray Trt	Seed Trt	Total	% Alfalfa[z]	Total	% Alfalfa
		-- kg ha^{-1}--		-- kg ha^{-1}--	
Non-sprayed	30 kg P_2O_5 ha^{-1}	5782	51	7572	48
Non-sprayed	40 kg P_2O_5 ha^{-1}	6398	46	8314	48
Non-sprayed	100 ppm GA_3	5327	53	9027	63
Non-sprayed	200 ppm GA_3	5077	54	6848	51
Non-sprayed	Terbufos	4783	51	5886	41
Non-sprayed	Carbofuran	5102	47	5731	53
Non-sprayed	Water-soaked	5555	62	7053	52
Non-sprayed	Control	5883	58	6234	51
Sprayed	30 kg P_2O_5 ha^{-1}	7017	100	11585	100
Sprayed	40 kg P_2O_5 ha^{-1}	6950	100	12270	100
Sprayed	100 ppm GA_3	6981	100	7559	100
Sprayed	200 ppm GA_3	6225	100	8561	100
Sprayed	Terbufos	6167	100	9287	100
Sprayed	Carbofuran	5264	100	9884	100
Sprayed	Water-soaked	5727	100	7967	100
Sprayed	Control	7603	100	10268	100

[z]Refers to percent alfalfa in total forage yield.

Appendix 2

Pesticides Applied

Table A2.1 Post-emergent herbicides applied to alfalfa and meadow bromegrass at Portage la Prairie in 1991 and 1992.

Year	Date	Crop	Herbicide	Rate (kg a.i. ha^{-1})
1991	June 14	Alfalfa	imazethapyr	0.050
			sethoxydim	0.809
	June 14	Meadow bromegrass	diclofop methyl	0.807
			bromoxynil	0.281
1992	June 19	Alfalfa & Meadow bromegrass	2,4-DB	1.405
	June 30	Alfalfa	imazethapyr	0.050
			sethoxydim	0.809
	June 30	Meadow bromegrass	diclofop methyl	0.966
			bromoxynil	0.336

Table A2.2 Post-emergent herbicides and insecticides applied at Gladstone and Portage la Prairie in 1991 and 1992.

Location	Year	Date	Pesticide	Rate (kg a.i. ha^{-1})
Gladstone	1991	May 28	cygon	0.488
Gladstone	1991	June 03	carbaryl	1.200
Gladstone	1991	June 16	carbaryl	1.200
Gladstone	1992	June 30	imazethapyr	0.050
Gladstone	1992	July 16	carbaryl	1.200
Portage	1992	June 21	sethoxydim	0.514

Appendix 3

Soil Test Results

Table A3.1 Soil test results (Norwest Lab) for zero-tillage experiment at Portage la Prairie in 1991 and 1992.

Year	Texture	Depth (cm)	Available nutrients (kg ha^{-1})				
			NO_3-N	P	K	SO_4-S	pH
1991	Clay	0-15	2.3	11.1	597.0	36.0+	7.7
	Clay	15-60	6.7			126.0+	
1992	Clay	0-15	25.0	34.0	657.0	36.0+	8.1
	Clay	15-60	69.0			126.0+	

Table A3.2 Soil test results (Norwest Lab) for Gladstone and Portage la Prairie in 1991 and 1992.

Year	Location	Depth (cm)	Soil type[z]	Available nutrients ($kg\ ha^{-1}$)				
				NO_3-N	P	K	SO_4-S	pH
1991	Gladstone	0-15	clay	11.6	2.4	938.3	36.0+	7.7
1991	Gladstone	15-60	clay	22.9			126.0+	
1992	Gladstone	0-15	VFSCL	15.0	8.8	117.0	16.0	7.7
1992	Gladstone	15-60	VFSC	21.0			42.0	
1991	Portage	0-15	clay	2.3	11.1	597.0	36.0+	7.7
1991	Portage	15-60	clay	6.7			126.0+	
1992	Portage	0-15	clay	7.9	20.0	783.0	36.0+	7.9
1992	Portage	15-60	clay	19.0			126.0+	

[z]VFSCL indicates very fine sandy clay loam; VFSC indicates very fine sandy clay.

Appendix 4

Climatic Data

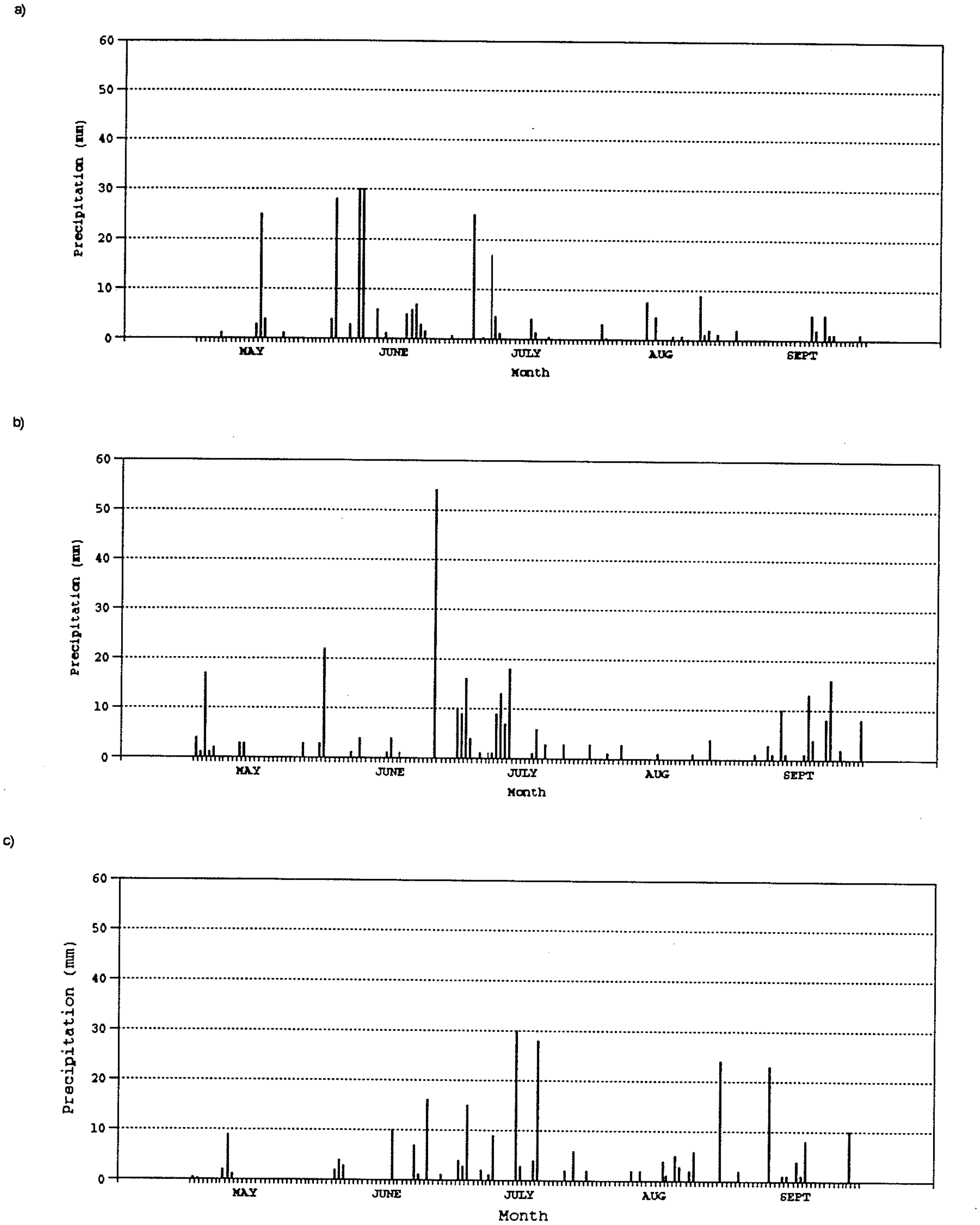
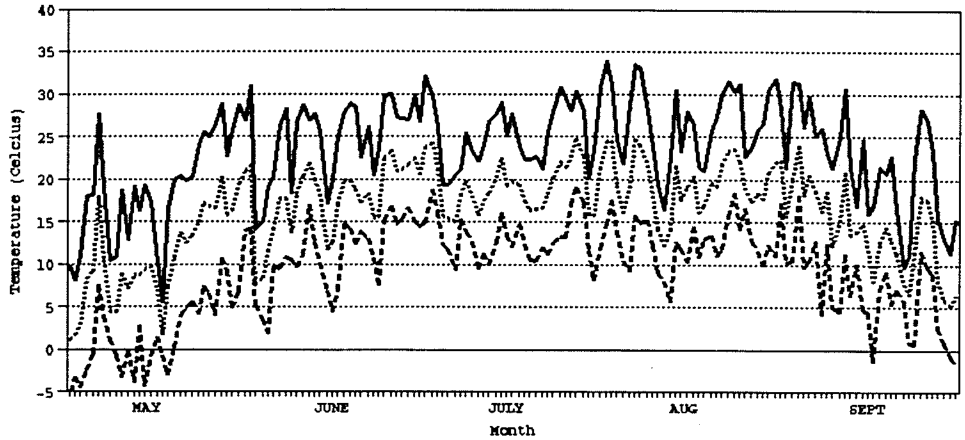
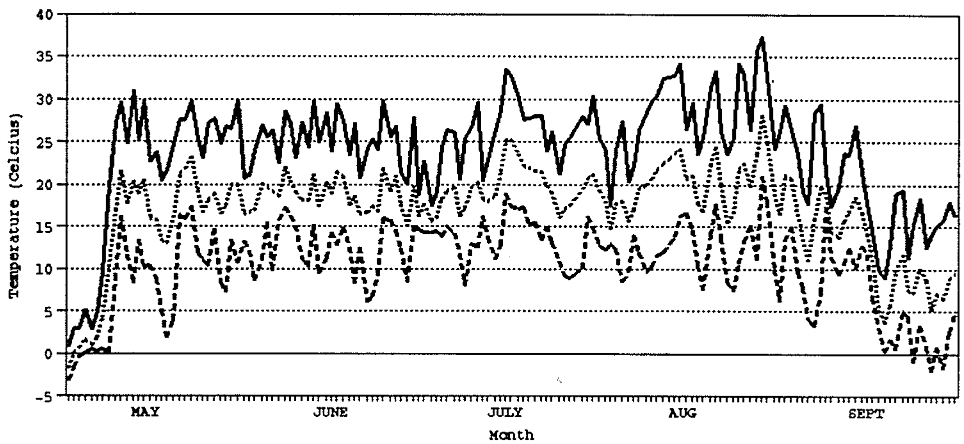


Figure A3.1 Daily precipitation received at Portage la Prairie in a) 1990, b) 1991, and c) 1992.

a)



b)



c)

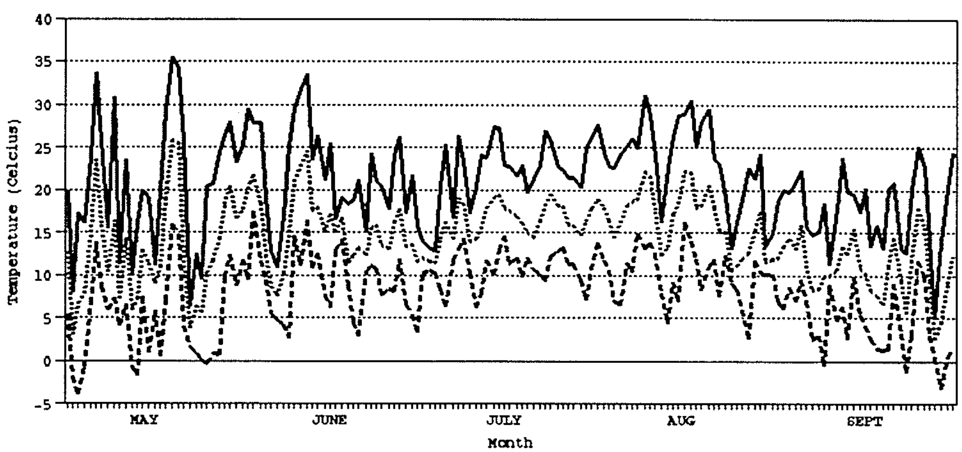
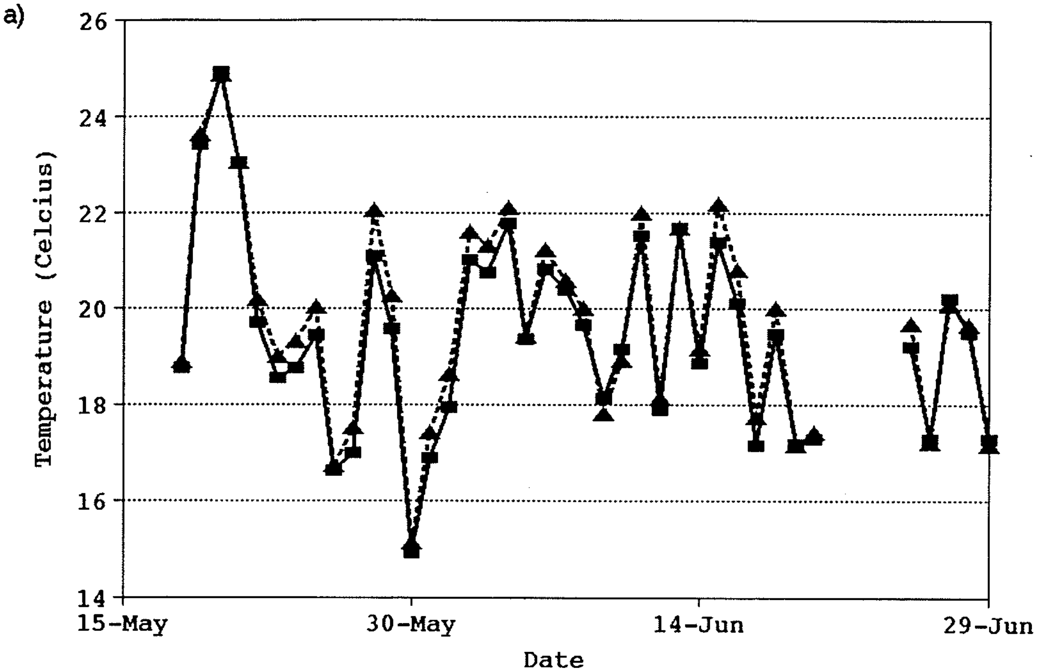


Figure A3.2 Daily maximum, minimum, and mean air temperature at Portage la Prairie in a) 1990, b) 1991, and c) 1992.

Appendix 5

Soil Temperature Data

a)



b)

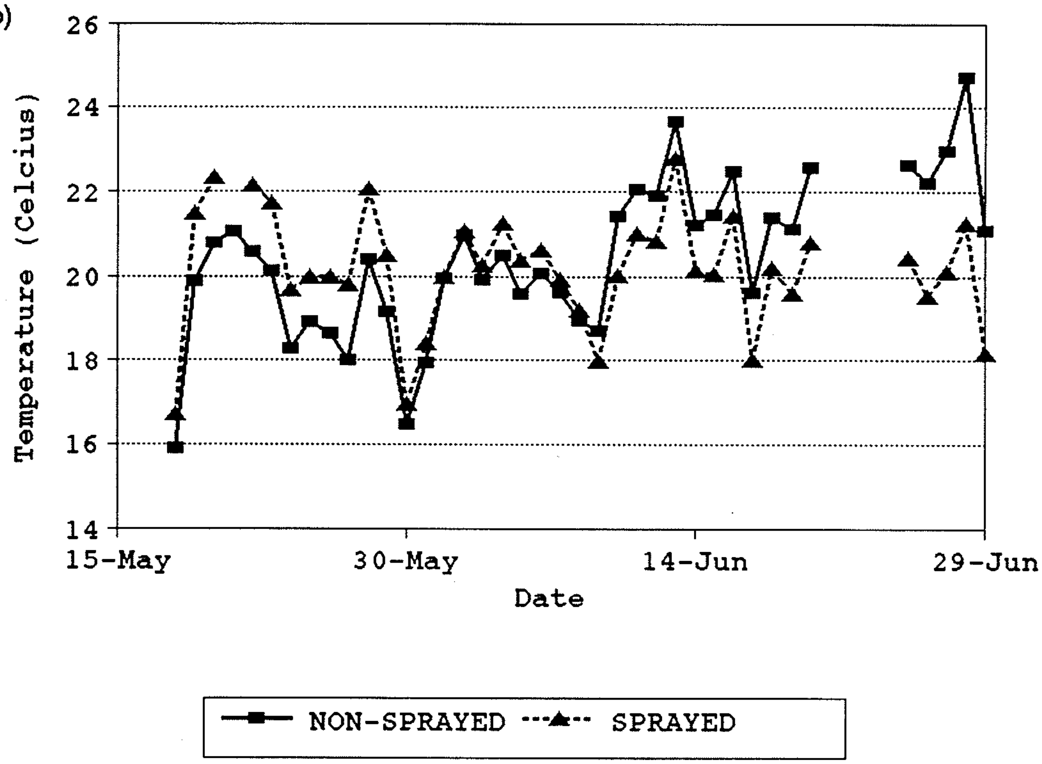


Figure A4.1 Influence of sod-suppression on daily mean soil temperature at Gladstone in 1991 at a) soil surface and b) 2 cm depth.

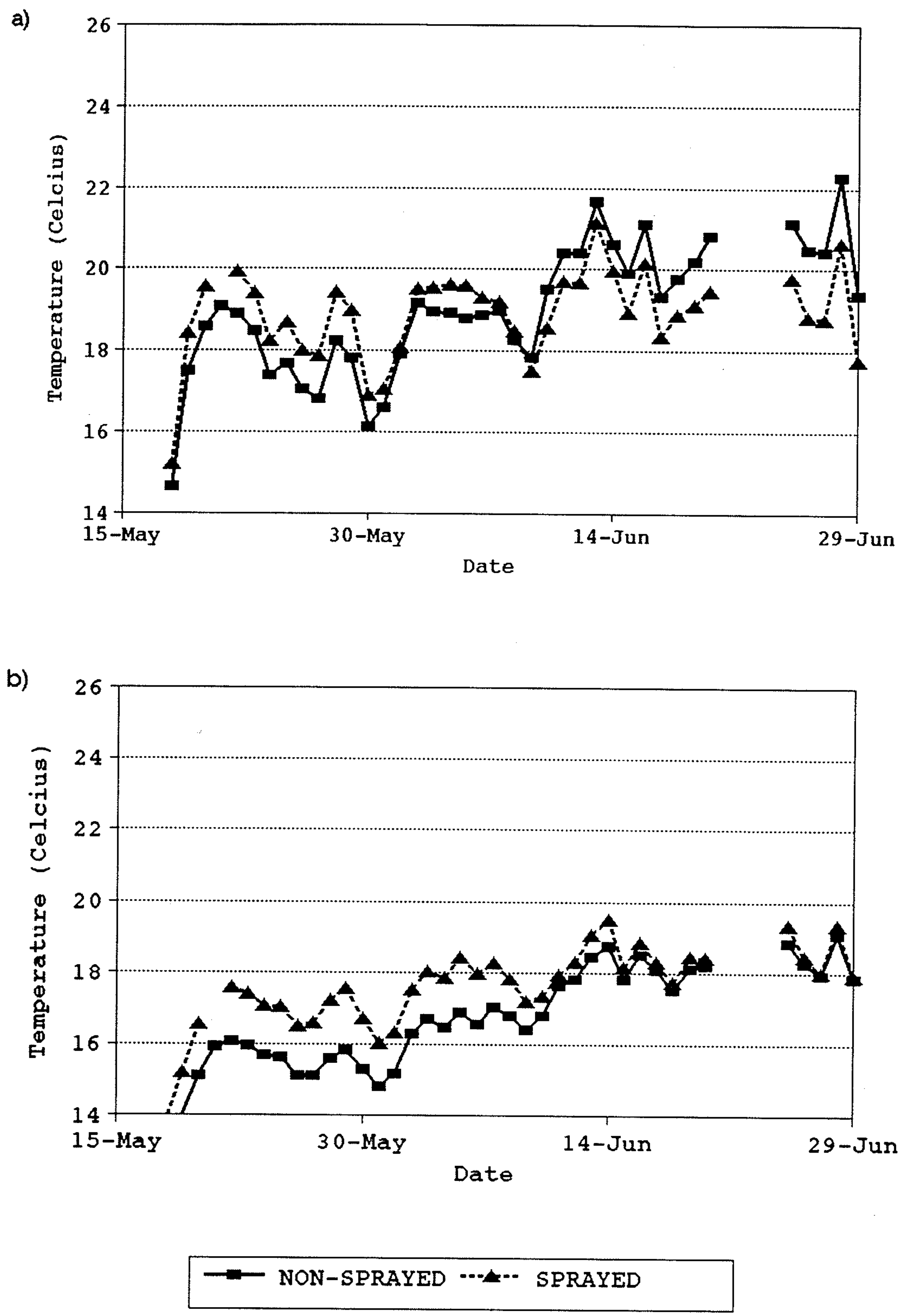
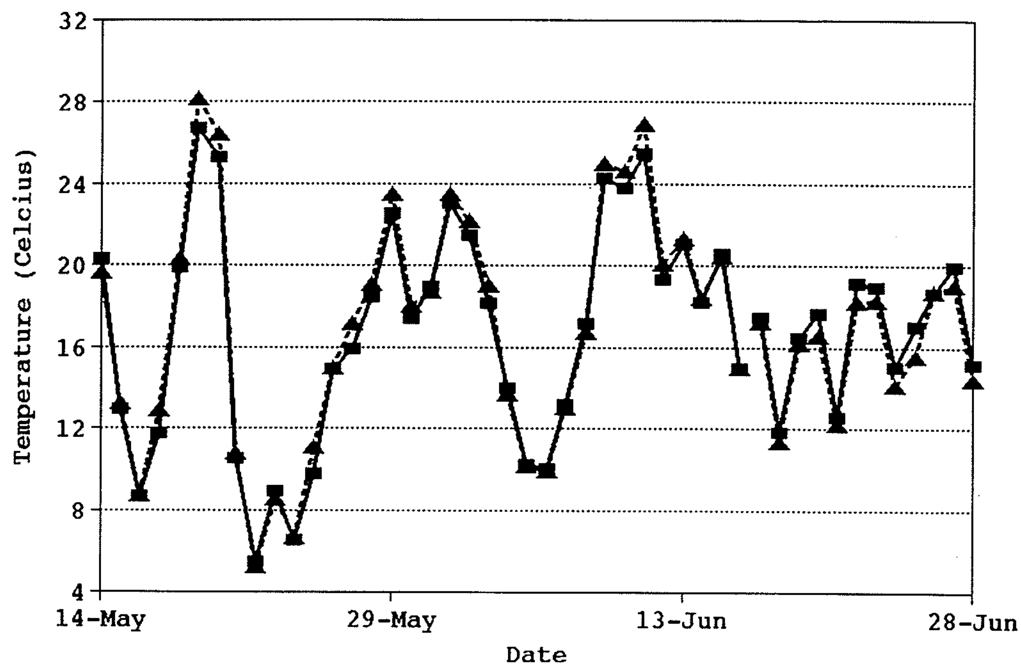


Figure A4.2 Influence of sod-suppression on daily mean soil temperature at Gladstone in 1991 at a) 8 cm and b) 20 cm depths.

a)



b)

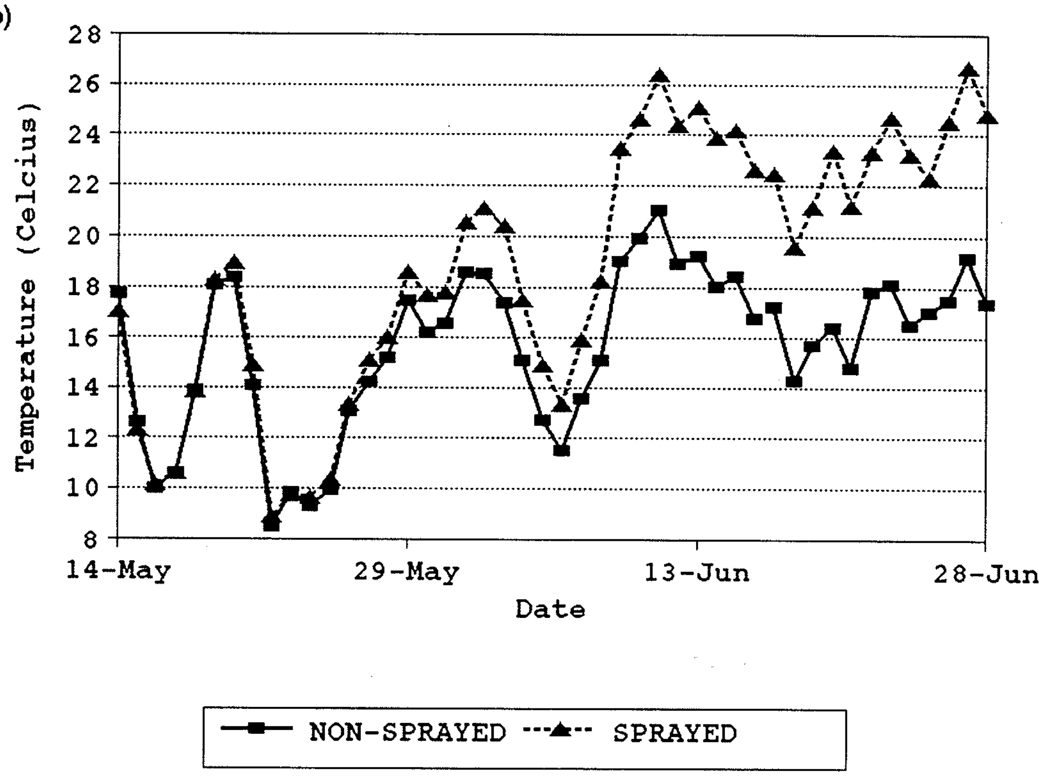


Figure A4.3 Influence of sod-suppression on daily mean soil temperature at Gladstone in 1992 at a) soil surface and b) 2 cm depth.

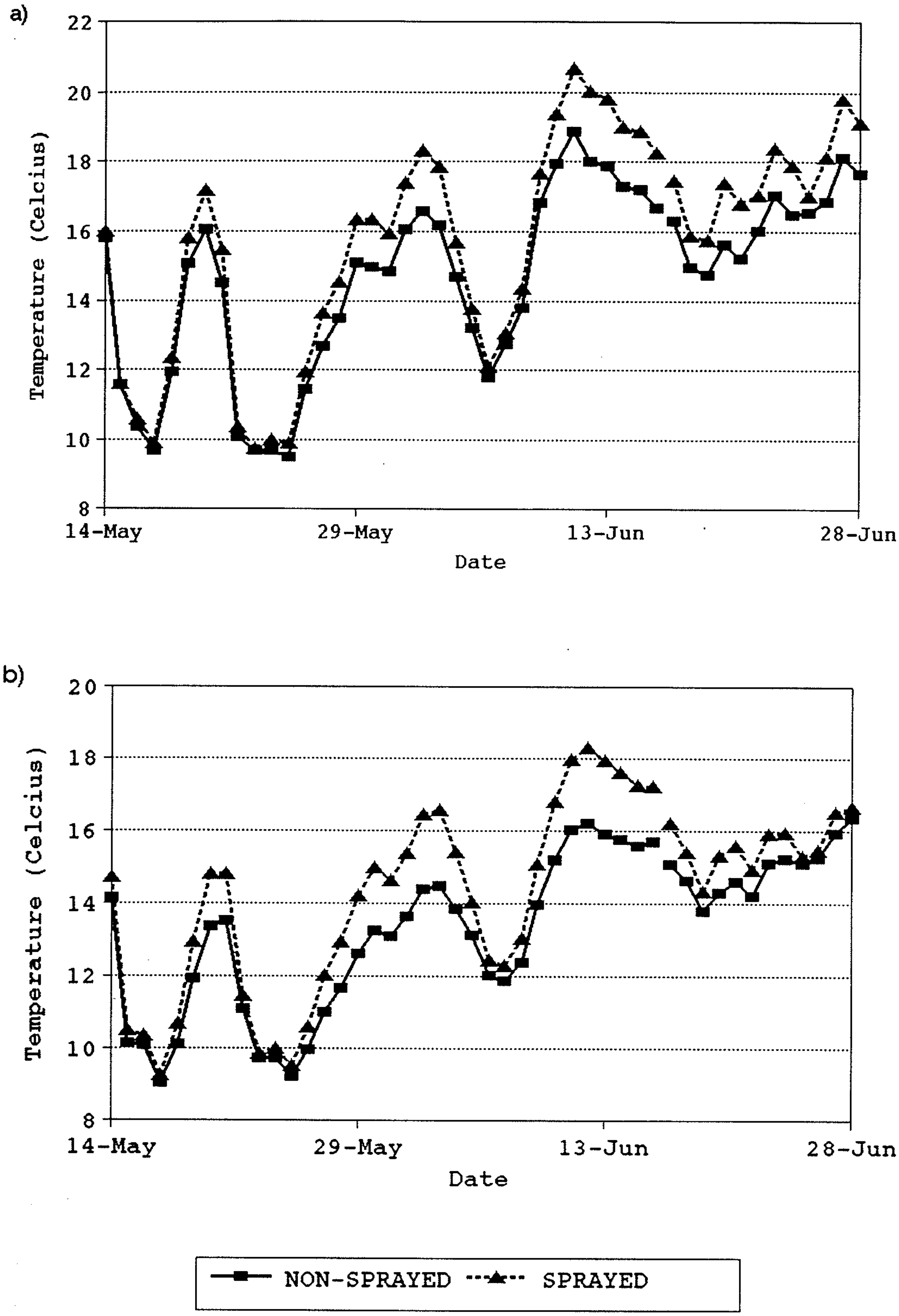
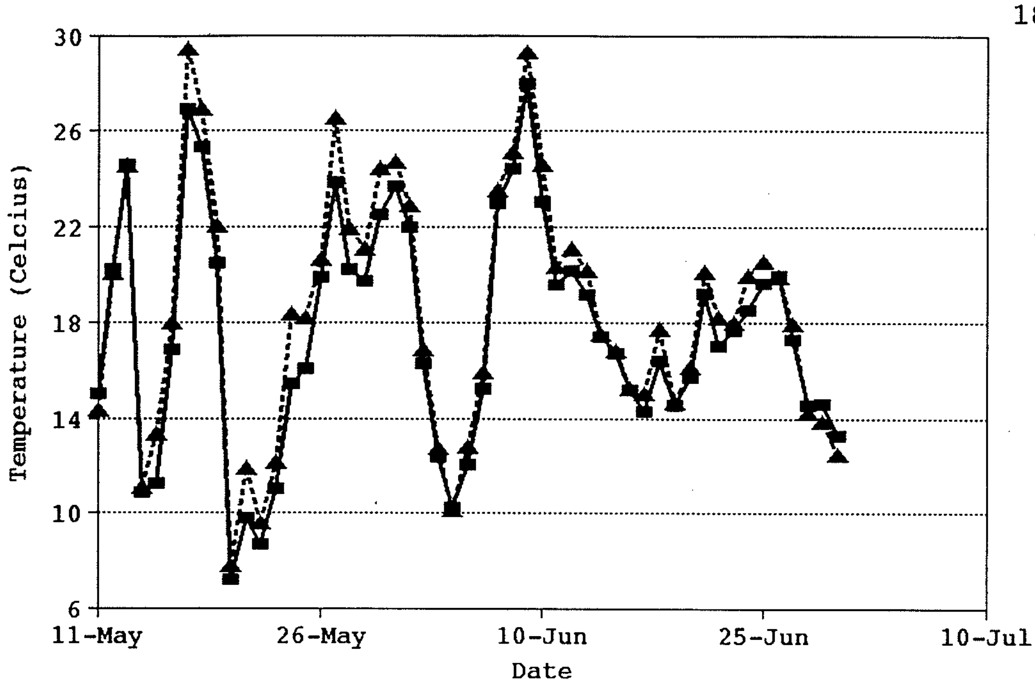


Figure A4.4 Influence of sod-suppression on daily mean soil temperature at Gladstone in 1992 at a) 8 cm and b) 20 cm depths.

a)



b)

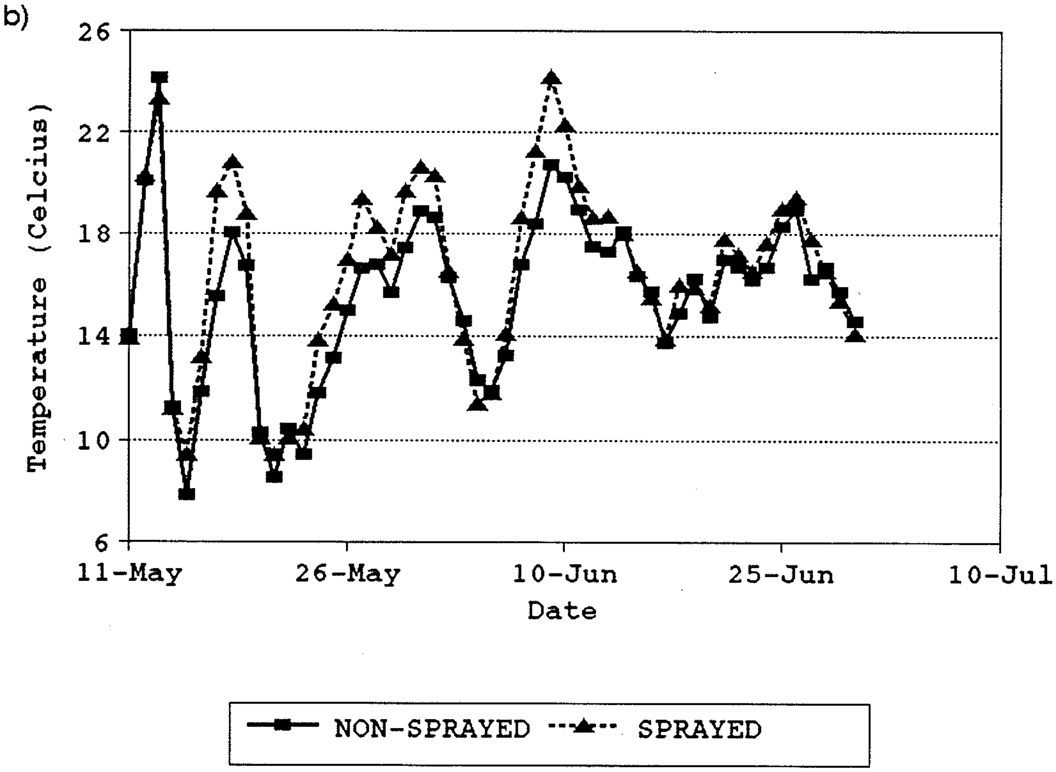


Figure A4.5 Influence of sod-suppression on daily mean soil temperature at Portage la Prairie in 1992 at a) soil surface and b) 2 cm depth.

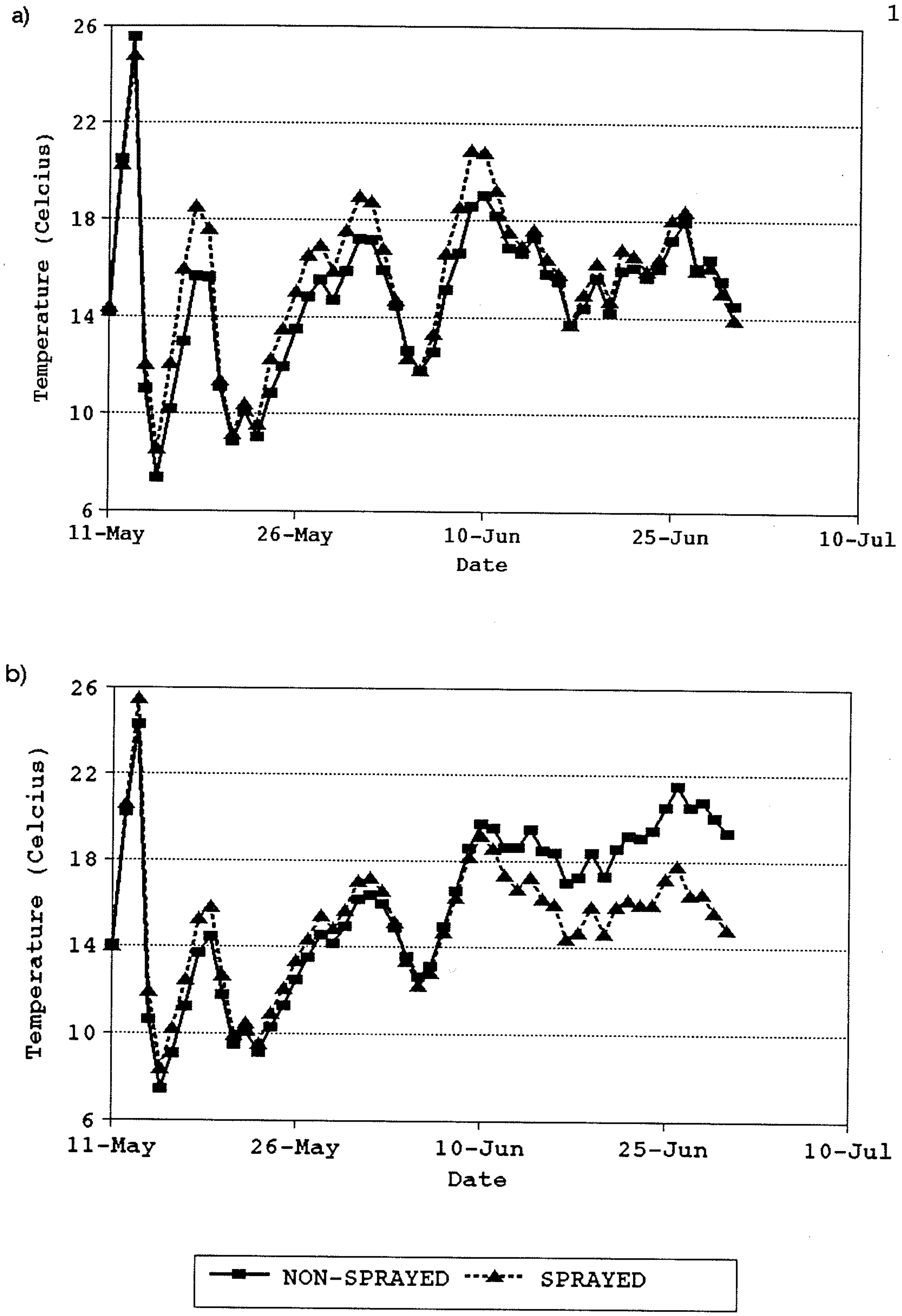


Figure A4.6 Influence of sod-suppression on daily mean soil temperature at Portage la Prairie in 1992 at a) 8 cm and b) 20 cm depths.