EVALUATION OF GRASS ESTABLISHMENT, DEVELOPMENT AND SURVIVAL UNDER SOD-SEEDING CONDITIONS IN THE DRY SUBHUMID PRAIRIES

by

Suzanne M. Gobin

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

MASTER OF SCIENCE

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Abstract

Evaluation of Grass Establishment, Development and Survival Under Sod-Seeding Conditions in the Dry Subhumid Prairies

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In order to increase the nesting potential of pastures and rangelands, increases in the proportion of high quality dense nesting cover (DNC) grasses in the sward are required. Sod-seeding is a system where seeds are placed into an undisturbed pasture or rangeland sod, and this system may be an effective way to establish DNC grasses, especially on fragile soils where pre-seeding tillage is not desirable. Different management practises will affect the degree of success achieved with sod-seeded grass stands. It is not known at the present time if all candidate DNC grass species respond similarly to sod-seeding.

The objectives of this study were 1) to evaluate different sod-suppression techniques for the establishment of tall wheatgrass [Thinopyrum ponticum (Podp.) Barkw. & D.R. Dewey] under two types of resident vegetation and 2) to compare the relative response of switchgrass (Panicum virgatum L.), green needlegrass (Stipa viridula Trin.), tall wheatgrass, and northern wheatgrass [Elymus lanceolatus (Scribner & J.G. Smith) Gould] to seedbed preparation techniques. Field studies were conducted in 1991 and 1992 at

Portage La Prairie and Gladstone, MB and a controlled environment study was conducted in 1992. Grass seedling emergence, development and survival were monitored throughout the growing season, and in some cases, the following season as well. Environmental measurements and competition from the resident vegetation were measured.

Results of the first experiment indicated that under conditions of intense competition from rhizomatous resident vegetation, such as with bromegrass (Bromus inermis L.) and Poa species at Gladstone, chemical suppression of the resident vegetation was critical for successful establishment, development and survival of tall wheatgrass plants. At Portage, satisfactory population establishment and survival were achieved without any suppression of the resident vegetation; however, greater morphological development of the plants, both in the first and second season, occurred when chemical suppression was used.

Results of the second experiment indicated that suppression of the resident vegetation increased plant density, development and survival of all four sod-seeded grasses over the untreated control. The tall and northern wheatgrasses were the most conducive to sod-seeding, and the switchgrass and green needlegrass the most difficult grasses to establish successfully.

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1.0 INTRODUCTION

Many practises used in agriculture over the years have resulted in declines in waterfowl populations. Wetlands, sloughs and potholes have been drained to increase land available for crops. For many waterfowl species, upland nesting sites are as important as wetlands. However, upland areas have been seeded to annual crops, which, for the most part, do not provide high quality nesting cover (Prairie Habitat Joint Venture, 1989). The loss of original habitat suitable for nesting waterfowl has been implicated as a major cause for declining waterfowl populations in the Prairies between 1970 and 1990, from approximately 20 million to 10 million ducks (Prairie Habitat Joint Venture, 1989).

While upland pastures and rangelands provide some potential nesting sites, intensive grazing practises and high stocking rates (continuous grazing at higher than recommended stocking rates) have led to changes in the botanical composition of pastures. Tall, native species have been replaced by invader species such as smooth bromegrass (*Bromus inermis* L.) and Kentucky bluegrass (*Poa pratensis* L.) (Waller and Schmidt, 1983). These do not grow as tall and thus provide only poor quality nesting cover.

In order to increase the nesting potential of pastures and rangelands, increases in the proportion of high quality dense nesting cover (DNC) grasses in the sward are required.

Successful nesting occurs with stands of tall, dense cover; in fact, waterfowl seem to prefer this type of cover (Duebbert and Lokemoen, 1976; Duebbert et al., 1981; Higgins, 1977; Kirsch et al., 1978). Providing the tallest and most dense vegetation possible has been recommended as the goal of pasture management for DNC (Kirsch et al., 1978). However, since different waterfowl prefer different grasses and different sward heights, a mix of several grasses, differing in height, would be preferable. There are a number of different grasses that could be used for establishing DNC. Tall wheatgrass [Thinopyrum ponticum (Podp.) Barkw. & D.R. Dewey] is an introduced grass with excellent potential for tall DNC. In addition to providing DNC, re-establishing native grasses into existing pastures may allow producers to develop a multiple-land use system, in which late-season grazing could occur after the nesting period was over (that is, after mid-July).

Sod-seeding may be an effective way to establish DNC. It is less expensive and maintains ground cover during the establishment period (compared to tillage). Several factors can affect the successful establishment of plants that have been sod-seeded. The species, cultivar, method of seeding, soil fertility, competition from resident vegetation, occurrence of diseases and pests, and weather will all influence establishment and survival (Bryan, 1985). It is not known at the present time if all candidate DNC grass species respond similarly to sod-seeding.

Sod-seeding native grasses does present certain challenges. Environmental conditions, such as temperature, soil moisture, precipitation and type of resident vegetation, greatly affect sod-seeded grass establishment, development and survival. Stand failures often occur because of competition from the resident vegetation. Different management practises will affect the degree of success achieved with sod-seeded grass stands. Suppression of the resident vegetation has been recognized as an important component of sod-seeding management systems.

This study was conducted to determine the feasibility of establishing stands of dense nesting cover (DNC) through sod-seeding. The objectives were 1) to evaluate different sod-suppression techniques for the establishment of tall wheatgrass under two types of resident vegetation and 2) to compare the relative response of different perennial grass species to seedbed preparation techniques.

2.0 LITERATURE REVIEW

2.1 Sod-Seeding

Sod-seeding refers to a practise where a crop is seeded into vegetation in pastures and rangelands, with only partial disturbance of the resident vegetation (Hervey, 1960). Since no preseeding tillage occurs, seeding equipment for sod-seeding must be able to effectively penetrate the surface residue and the soil without plugging, and create seed grooves that are even in depth to provide good seed placement (adequate seed to soil contact) with adequate cover to prevent the seed from drying out (Baker, 1973). Reducing competition for light, soil, nutrients and water by the resident vegetation greatly increases the establishment of sod-seeded plants.

There are several advantages to sod-seeding compared to the more traditional method involving pre-seeding cultivation. Sod-seeding is well suited to fragile land where erosion, stones or salinity make cultivation difficult or impossible (Harris, 1990; Marshall and Naylor, 1984a; Sprague, 1960). Because less soil disturbance occurs in the sod-seeding system compared to cultivation, the soil is less prone to wind and water erosion (Bowes and Zentner, 1992; Bryan et al., 1984; Hervey, 1960). Sod-seeding also requires less time, labour and energy than conventional seedbed preparation, making it less expensive (Bowes and Zentner, 1992; Rogers et al., 1983; Waddington and Bowren 1976). Although some fragile lands that may once have been broken will slowly revert back to native vegetation, sod-seeding is a much quicker method of revegetation than the process of natural succession (Hart et al., 1985; Hervey, 1960).

Establishing stands of dense-nesting cover for waterfowl nesting requires a high level of management for several years. This not only requires intensive labour, but also means fields are out of production for several years. Duebbert et al. (1981) report that fields containing quackgrass [Agropyron repens (L.) Beauv.], smooth bromegrass, Canada thistle [Cirsium arvense (L.) Scop.], leafy spurge (Euphorbia podperae L.) or perennial weeds require combinations of herbicides and intensive cultivation for one or more years for proper control prior to grass establishment. Intensive cultivation, however, can be detrimental to the soil. Herbicides can be as effective as tillage in controlling weeds and would reduce some of these negative requirements associated with establishing DNC in a conventional manner.

Despite the potential advantage of sod-seeding over conventional establishment techniques, establishment can still be variable (Hervey, 1960). For example, while establishment of big bluestem (Andropogon gerardii Vitman), indiangrass [Sorghastrum nutans (L.) Nash], and switchgrass (Panicum virgatum L.) was superior under sod-seeding compared with conventional seeding into a Kentucky bluegrass, blue grama [Bouteloua gracilis (H.B.K.) Lag. ex Steud.], western wheatgrass [Pascopyrum smithii Rydb. (Love)] and buffalograss [Buchole dactyloides (Nutt.) Englem.] sod, establishment of side-oats grama [Bouteloua curtipendula (Michx.) Torr.] was unaffected by establishment method (Hart et al., 1985). Superior establishment of certain grasses under sod-seeding was attributed to better seed-to-soil contact (Hart et al., 1985). Emergence of Italian ryegrass (Lolium multiflorum) and perennial ryegrass (Lolium perenne L.) was greater in sod-seeded plots (Squires and Elliott, 1975). Hervey (1960) attempted to seed tall wheatgrass, by sod-seeding and by conventional methods, into a sand dropseed (Sporobolus cryptandrus)/forb sod, and found poor survival resulted in all cases. The author attributed this to inadequate soil surface cover that led to erosion (Hervey, 1960). Comparable establishment of sod-seeded bromegrass, Russian wild ryegrass [Psathyrostachys juncea (Fischer) Nevski] and alfalfa (Medicago sativa L.) was found between sod-seeded and rotovated plots (Waddington and Bowren, 1976). The rotovated plots suppressed the sward of dandelion (Taraxacum officinale L.), alfalfa, alsike clover (Trifolium hybridum L.), creeping red fescue (Festuca rubra L.), bromegrass and crested wheatgrass [Agropyron cristatum (L.) Gaertner] to a greater degree than herbicides, but produced a looser seedbed and allowed for dandelion re-infestation (Waddington and Bowren, 1976).

Poorer establishment of sod-seeded perennial ryegrass, sand bluestem [Andropogon gerardii var. paucipilus (Nash) Fern.], switchgrass, smooth bromegrass and intermediate wheatgrass [Thinopyrum intermedium (Host) Barkw. & D.R. Dewey] as compared to conventional seedbed preparation has been reported in studies on sites consisting mainly of bunchgrasses (King et al., 1989; Marshall and Naylor, 1984a). Poor establishment was attributed to possible herbicide residues and leachates from the plant residue (Marshall and Naylor, 1984a), low precipitation and competition for moisture, poorer seed-to-soil contact and increased weed competition (King et al., 1989), and the physical impedance of the trash layer (King et al., 1989; Marshall and Naylor, 1984a).

Roth et al. (1985) reported higher alfalfa yields in the year of establishment and in the following year when sod-seeded after chemical suppression of the resident vegetation using either glyphosate or paraquat as compared to conventional seeding methods. In contrast, Hart et al. (1985) found that although big bluestem, indiangrass and switchgrass had greater establishment under sod-seeding as compared to discing, total vegetative yields (including the Kentucky bluegrass, blue grama, western wheatgrass and buffalograss resident vegetation) and seeded species yields were not different between treatments after four years. This led the authors to conclude that the advantage of sod-seeding was a more rapid rate of establishment (Hart et al., 1985). Conventional seedings took longer to establish, but did eventually produce comparable dry matter yields (Hart et al., 1985).

Management practises will influence the success of sod-seeded grass establishment. Careful selection of the grass species and seeding equipment used and the application of pesticides will affect stand establishment. The competition from the resident vegetation should be reduced or eliminated (Bryan et al., 1984). In fact, Panciera and Jung (1984) concluded that factors such as the cultivar, planting date and weed control affect the successful establishment of switchgrass more than tillage.

2.2 Dense Nesting Cover Assessment

Nesting cover quality of a sward can be assessed using a Robel pole (Robel et al., 1970). The Robel pole consists of a pole that is marked every 5 to 10 cm. The height at which 100% visual obstruction occurs is measured; that is, the height at which the pole is no longer visible. Robel pole measurements give an accurate estimation of the density (as well as the height) of a stand and are a useful measure of the nesting potential of a sward (Duebbert et al., 1981; Robel et al., 1970).

Height measurements alone as an estimate of the DNC potential of a stand are not adequate, as other features such as foliar density are not taken into consideration (Jones, 1968). Robel pole measurements have been correlated to the density and weight of vegetation present (Robel et al., 1970).

2.3 Grass Species Characteristics

Yields of native grasses are generally less than those of introduced grasses (Kilcher and Looman, 1983; Knowles, 1987; Lawrence and Ratzlaff, 1989). However, native grasses should be considered for nesting cover as they do not break down under the winter snowpack (Duebbert et al., 1981; Frank and Woehler, 1969) and they increase the biodiversity and quality of nesting cover. There is limited information available on growth and development of native grasses, and in many previous experiments, only total dry matter yields have been recorded.

2.3.1 Tall Wheatgrass

Tall wheatgrass [Thinopyrum ponticum (Podp.) Barkw. & D.R. Dewey] is an introduced, cool-season bunchgrass that has good saline and flooding tolerance (Duebbert et al., 1981; Harris, 1990). It is drought tolerant, even in the seedling stage (Frischknecht, 1951). It also is very winter-hardy, as it did not suffer from winter injury when evaluated in

Saskatchewan (Lawrence, 1978). Another beneficial trait of tall wheatgrass for DNC stands is its resistance to lodging under the winter snowpack, thereby providing dense cover for nesting waterfowl in the spring (Duebbert et al., 1981). Tall wheatgrass develops slowly early in the season (as indicated by low early season dry matter yields), but had comparable yields to intermediate wheatgrass (a high yielding check) by the end of the season (Lawrence, 1978; Lawrence and Warder, 1979). Late summer cut yields of 2705 kg ha^{-1} were reported, while fall cuts yielded 2325 kg ha^{-1} with conventional seedbed preparation in Saskatchewan (Lawrence, 1978).

2.3.2 Green Needlegrass

Green needlegrass (Stipa viridula Trin.) is a native, cool-season bunchgrass (Duebbert et al., 1981; Harris, 1990). The culms grow 50-100 cm in height (Agriculture Canada, 1979). Roots of green needlegrass can penetrate to depths of 127 cm; however, most of the roots grow in the upper 91 cm (Judd, 1938). Green needlegrass has been reported not to suffer from winter injury in Saskatchewan (Lawrence, 1978; Lawrence and Troelsen, 1964). Although dormancy is a characteristic of green needlegrass, the cultivar 'Lodorm' has been selected for low seed dormancy (Duebbert et al., 1981).

Green needlegrass was found to develop to the four leaf stage by the end of the first growing season when grown in a native pasture, and required approximately 800 growing degree-days to do so (Frank and Hofmann, 1989). Thus, green needlegrass establishes very slowly. The yield of green needlegrass is comparable to domestic grasses four years after establishment (Kilcher and Looman, 1983). A 3-year average yield of 641 kg ha^{-1} with conventional seeding practises was reported in semi-arid areas of Saskatchewan (Kilcher and Looman, 1983). In a two-year study, Lawrence (1978) reported dry matter accumulation in a late summer cut of 1443 kg ha^{-1} and in a fall cut of 1374 kg ha^{-1} with conventional seedbed preparation in Saskatchewan.

2.3.3 Northern Wheatgrass

Northern wheatgrass [Elymus lanceolatus (Scribner & J.G. Smith) Gould] is a cool-season rhizomatous grass (Duebbert et al., 1981). The culms grow 40-70 cm in height (Agriculture Canada, 1979). Northern wheatgrass has winter hardiness comparable to crested wheatgrass, meadow bromegrass (Bromus biebersteinii Roem) and intermediate wheatgrass (Lawrence and Ratzlaff, 1989). Northern wheatgrass has been found to attain maximum yields within one year after seeding, but yields were half of domestic grass yields, with a 3-year average yield of 746 kg ha^{-1} under conventional seeding practises in Saskatchewan (Kilcher and Looman, 1983). Others report low yields as well, with 5-year means ranging from 1201-1401 kg

ha^{-1} at Swift Current, Saskatchewan (Lawrence and Ratzlaff, 1989), an 8-year average yield of 1286 kg ha^{-1} at Saskatoon, Saskatchewan and a 2-year average yield of 1190 kg ha^{-1} at Scott, Saskatchewan (Knowles, 1987).

2.3.4 Switchgrass

Switchgrass (Panicum virgatum L.) is a tall, native, warm-season rhizomatous grass (Duebbert et al., 1981; Weaver and Fitzpatrick, 1932). The mature plant attains heights of 90-180 cm, with leaves 35-60 cm long and 0.8-1.4 cm wide (Weaver and Fitzpatrick, 1932). Switchgrass provides good DNC, as it resists flattening under the winter snowpack and retains its leaves over the winter period (Duebbert et al., 1981; Frank and Woehler, 1969). Under native prairie conditions, switchgrass was found to tiller and produce rhizomes within five to seven weeks after germination (Weaver and Fitzpatrick, 1932). Roots are extensive, attaining depths of 1.5 m in one growing season under ideal growing conditions (Weaver and Fitzpatrick, 1932). Switchgrass is drought tolerant (Hope and McElroy, 1990).

'Dacotah' switchgrass is adapted to Northern locations as it matures early, is vigorous and can reseed itself, although it grows 10 to 15 cm shorter than mature plants of other switchgrass cultivars (Barker et al., 1990). Because warm-season grasses are more productive under high temperatures than cool-season grasses, switchgrass can extend the length of the grazing season in a multiple-land use system by providing mid-summer grazing opportunities (George et al., 1979; Hope and McElroy, 1990; Waller and Lewis, 1979).

Switchgrass yields of 8000 kg ha^{-1} on low fertile soil without amendments have been reported in West Virginia (Balasko et al., 1984) and approximately 4500 to 9500 kg ha^{-1} with conventional seedbed preparation in West Virginia (Stout et al., 1986). Rapid development of permanent roots by switchgrass was one possible reason given for high dry matter, as dry matter accumulation of switchgrass was found to be related to root weight (Hsu et al., 1985b). Warm-season (C_4) grasses have leaf protein concentrations about half that of cool-season (C_3) grasses and generally have higher photosynthesis per unit leaf area and more dry matter production per unit of water transpired (Brown, 1978).

Establishment of warm-season grasses can be difficult and slow (Hsu et al., 1985b; Vassey et al., 1985). Temperature has a large influence on establishment; base soil temperatures for switchgrass germination have been estimated to be approximately 11°C (Hsu and Nelson, 1986). Switchgrass emergence and development was found to be more temperature-dependent than other C_4 grasses such as Caucasian bluestem [<u>Bothriochloa caucasica</u> (Trin.) C.E. Hubb], big bluestem and indiangrass, as it required more time to emerge at lower temperatures (20°C versus 30°C) (Hsu et al., 1985b). Moisture conditions will also influence development. Sanderson (1992) found switchgrass development to be greater in spring and late summer than in mid-summer, and attributed this to higher rainfall during these periods.

Switchgrass was found to exhibit sufficient winter hardiness to survive winter conditions in southern Ontario (Hope and McElroy, 1990). The authors suggested that switchgrass could overcome plant loss due to winterkill by regrowth of tillers. In fact, plants exposed to -22°C temperatures had survival rates of only 50%, however vigorous regrowth could occur by vegetative means.

2.4 Plant Establishment Under Sod-Seeding

Sod-seeded grasses are placed under conditions of intense competition. Plants have many different characteristics, such as the rate of leaf development, method of reproduction (by seed or vegetatively by rhizomes) and photosynthetic pathway, to adapt to their environment and reduce the competition for resources with other vegetation. These characteristics help plants find a niche in the community.

2.4.1 Shoot Development

The development rate of grasses will affect their survival under sod-seeding conditions. For example, a greenhouse study of nine cool- and nine warm-season grasses found that, in a 28°/23°C day/night temperature regime, warm-season grasses developed to the third-leaf stage 15 to 24 days after seeding whereas cool-season grasses required 20 to 30 days (Newman and Moser, 1988b). Thus, in this situation, warm-season species may have an increased chance of establishment and survival. A rapid rate of grass emergence could be very beneficial under sod-seeding conditions. Chemical or mechanical suppression of the resident vegetation prior to sod-seeded grass emergence creates a window when competition is reduced. Seedlings with rapid emergence have more time to develop before the resident vegetation regrows.

Under conventional seedbed preparation, overwinter survival was positively correlated with seedling size in the fall (number of leaves, leaf area, blade length, seedling height and plant weight) (White, 1984; White and Currie, 1980). Crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass [Agropyron intermedium subsp. trichophorum (Link) Reichb. ex Hegi] and Russian wild ryegrass seedlings with more than two leaves in the fall survived the winter period (White, 1984; White and Currie, 1980). More than 70% of the plants with three leaves and 90% with four or more leaves displayed either no winter damage or only light damage (White and Currie, 1980). Effects of winter damage were still apparent in the fall of the second season (White, 1984). Plant survival in consecutive growing seasons is thus also affected by winter damage.

Seedling size was stated to have a greater effect on regrowth the following spring than winter injury (White, 1984). It is important to have maximum growth before the onset of winter; a difference of one or two leaves could still result in twice the difference of growth, depending on the amount of winter injury (White, 1984). These observations show the importance of maximizing growth of plants in the year of establishment. Hence any management practise that increases plant size at the end of the growing season will increase overwinter survival of sod-seeded plants.

2.4.2 Root Development

Rapid root development is essential for successful plant establishment and development, especially in situations where intense competition for soil water and nutrients occurs (Briske and Wilson, 1977; Plummer, 1943). Nutrient and water uptake in wheat (Triticum aestivum L.) has been positively correlated with the number of adventitious roots (Black, 1970). The development of a root system is critical for the initial successful establishment of grass species prior to drought (Plummer, 1943). Little previous research has been conducted on root development under sod-seeding conditions.

Adventitious roots are produced from either the crown area, from the coleoptilar node or from other nodes above the seed node (Hyder et al., 1971; Newman and Moser, 1988a). Adventitious root dry weight was found to be greater for cool-season grasses than for warm-season grasses (Newman and Moser, 1988b). For most grasses in the study, adventitious roots had developed by the third leaf emergence (Newman and Moser, 1988b).

Root development will affect the successful establishment of plants (Hyder et al., 1971; Plummer, 1943). Blue grama seedlings lacking adventitious roots did not survive the growing season (Hyder et al., 1971; Wilson and Briske, 1979). In a study of twelve grass species, Plummer (1943) reported that seedlings that had slow root development also had slow shoot development and were more difficult to establish as compared to seedlings with more rapid root development. Plants with four adventitious roots can survive the winter period in Manitoba (Brent Wark, biologist Ducks Unlimited, personal communication).

2.5 Factors Affecting Sod-Seeded Grasses

2.5.1 Environmental Factors

The germination and early seedling development periods are critical stages for grass establishment. Most grass species are sensitive to adverse environmental conditions during this period (Frischknecht, 1951; Plummer, 1943; Samson and Moser, 1982).

2.5.1.1 Temperature

Critical and optimum values of air temperature for the growth and development of plants exist. As temperatures move outside this optimum range, plant growth decreases (Gist and Mott, 1957). The optimal temperature for germination of cool-season grasses is approximately 20°C (Bokhari et al., 1975; McGinnies, 1960). Higher temperatures (30°C) result in earlier germination but lower total germination, while lower temperatures (10°C) result in slower germination rates (Hill et al., 1985; McGinnies, 1960). The optimum temperature for germination of the warm-season grasses, blue grama and buffalo grass, was found to be 30°C (Bokhari et al., 1975). Base temperatures for warm-season grass germination are between 8.3 and 10.9°C (Hsu et al., 1985a).

Temperature also influences seedling development rates. Although many researchers have found plants to be affected more by the amount of available water (Barker et al., 1989; Bowes and Zentner, 1992; Hart et al., 1985; Vassey et al., 1985), Frank and Hofmann (1989) found the morphological development of western wheatgrass, blue grama, needleandthread (<u>Stipa</u> <u>comata</u> Trin. and Rupr.), green needlegrass and prairie junegrass [Koeleria pyramidata (Lam.) Beauv.] to be affected more by air temperature.

Green needlegrass morphological development, as measured by the Haun growth stage (Haun, 1973), was linearly related to accumulated growing degree-days (r^2=0.96), requiring about 800 growing degree-days to produce 4 leaves (Frank and Hofmann, 1989). Fulbright et al. (1985) found increased green needlegrass emergence, shoot and seminal root lengths, and an increased number and length of adventitious roots with an increased day/night temperature from 20/15°C to 25/20°C. Italian ryegrass, prairie grass (Bromus catharticus) and tall fescue (Festuca arundinacea Schreb.) seedlings were found to have the greatest development rates at day/night temperatures of 24/19°C compared with temperatures ranging from 15/10°C to 30/25°C, while vegetative development after appearance of the first tiller was greatest at temperatures of 21/16°C (Hill et al., 1985). Warm-season seedling development was greater at 25 and 30°C as compared to 20°C (Hsu et al., 1985b).

Root development is also affected by air temperatures. For example, leaf number and extension rate, tiller development, and shoot and root growth rates of big bluestem, Caucasian bluestem, indiangrass and switchgrass were all lower at 20°C compared with 25-30°C (Hsu et al., 1985b). Root to shoot ratios of Italian ryegrass, tall fescue and prairie grass were found to decrease with increasing temperatures (Hill et al., 1985). Temperatures greater than 15°C were necessary for blue grama adventitious root development (Briske and Wilson, 1977; Briske and Wilson, 1978; Wilson and Briske, 1979).

2.5.1.2 Available Moisture

All stages of a plant's growth and development are affected by available moisture (Glendening, 1942). Studies have concluded that adequate moisture is the most important factor affecting establishment and growth of sod-seeded alfalfa, big bluestem, indiangrass, switchgrass and side-oats grama (Bowes and Zentner, 1992; Hart et al., 1985). Susceptibility to moisture stress depends on grass species and stage of development (Knapp, 1984). Knapp (1984) found that plants in the reproductive stage were more severely affected by drought than plants in the vegetative stage of growth.

Germination can be delayed and/or decreased with low moisture conditions (Bokhari et al., 1975; McGinnies, 1960; Pemadasa and Amarasinghe, 1982). Vassey et al. (1985) attributed observed differences in switchgrass seedling densities between years to differences in precipitation during the establishment period. Available soil moisture also affects survival of established seedlings (Frischknecht, 1951). Switchgrass growth was greater on soils with adequate soil moisture and high water holding capacities (Stout et al., 1986). Barker et al. (1989) attributed the variation in yield of crested, western and intermediate wheatgrasses, and reed canarygrass (Phalaris arundinacea L.) to total available water.

Adventitious roots fail to develop when the soil surface is dry, due to their close proximity to the soil surface (Wilson and Briske, 1979). Two or more damp or wet days, enough to maintain a moist soil surface, were required for the development of blue grama adventitious roots (Briske and Wilson, 1977; Wilson and Briske, 1979). The rate of root elongation also influences the success of seedling establishment; roots must elongate sufficiently to remain in moist soil (Briske and Wilson, 1978).

Different grass species show different sensitivities to water stress. Rapidly-induced stress (comparable to moisture stress occurring in shallow, coarse-textured soils) caused bromegrass, crested wheatgrass, northern wheatgrass and green needlegrass to incur reduced numbers of leaves as compared to unstressed controls (Reekie and Redmann, 1991). Green needlegrass, on the other hand, was affected most adversely by gradual water stress (comparable to stress in deep, fine-textured soils), with the number of leaves on a plant subjected to gradual stress being much lower than on plants subjected to rapid stress (Reekie and Redmann, 1991). Rapid stress had less effect on young leaves, thus plants subjected to rapid stress had a young leaf age structure, which could respond quickly as water availability increased (Reekie and Redmann, 1991).

2.5.1.3 Light Interception

Light affects such parameters as the germination, establishment, development and yield of sod-seeded plants. In a sod-seeding situation, control of the resident vegetation reduces shading, thereby increasing the amount of light available for the introduced seedlings. Negative effects of shading include decreased number and height of shoots produced, decreased number of roots and reduced plant yield (Cooper, 1966; Gist and Mott, 1957; Gist and Mott, 1958; Watkins, 1940). Under conditions of low sunlight, plants produce more top growth and less root growth (Cooper, 1967; Pritchett and Nelson, 1951; Watkins, 1940). This can place the seedlings under soil moisture stress, as seedlings with shallow root systems compete for water with resident vegetation that has extensively-developed root systems (Cooper, 1967; Wilkinson and Gross, 1964). Poorly developed root systems can also reduce the winter hardiness of seedlings.

Shade from the resident vegetation can also influence the microclimate (Conant and Risser, 1974; Cooper, 1966). As shading from the resident vegetation increases, air and soil temperatures decrease (Cooper, 1966). This can reduce temperature fluctuations, but can also result in sub-optimum growing conditions. As Donald (1958) points out, the effects are not simple. Multiple interactions between the lack of light, water, and even nutrients can occur (Donald, 1958). These interactions for competition for environmental parameters may influence the degree to which the seedling is affected by the resident vegetation (Donald, 1958). This emphasizes the difficulty in determining reasons for sod-seeding failures and comparing between sites and years.

2.5.2 Surface Residue from the Resident Vegetation

Residue from the resident vegetation can decrease establishment of sod-seeded plants due to physical impedance of seedlings or through chemical interference (Marshall and Naylor, 1984b; Squires and Elliott, 1975).

Physical impedance can occur when trash is pressed into drill slits, affecting seed-to-soil contact, closure of the drill slits and/or the amount of water available to the seed (Marshall and Naylor, 1984a; Marshall and Naylor, 1984b). Chemical interference can occur through phytotoxicity or herbicide residues (Marshall and Naylor, 1984b). However, the physical impedance of the residue to emerging seedlings and reduced soil moisture are the main factors for stand failures (Marshall and Naylor, 1984b; Squires and Elliott, 1975).

2.5.3 Nutrient Availability

Nitrogen fertilization has been found by many researchers (Black and Wight, 1972; Cosper et al., 1967; Jung et al., 1990; Harlan and Kneebone, 1953; Lorenz and Rogler, 1972; Taliaferro et al., 1975) to increase both cool- and warm-season grass yields. Lorenz and Rogler (1972) found mixed prairie vegetation yield increases with nitrogen fertilization even when plants were under moisture stress. Thus, fertilizing grass stands may be one potential management practise used to increase forage production, thereby increasing the quality of DNC.

Different species and cultivars will respond differently to fertilization and responses will vary according to environmental conditions (Jung et al., 1990). Nitrogen fertilization has been found to increase the cool-season component of stands and decrease warm-season components (Cosper et al., 1967; Lorenz and Rogler, 1972; Rehm et al., 1976). The time and rate of fertilizer application will vary the degree to which warm-season grasses are affected (Lorenz and Rogler, 1972; Rehm et al., 1976). Decreased nitrogen fertilizer rates, and applying fertilizer in late spring (when warm-season grasses are initiating growth) causes less cool-season encroachment (Lorenz and Rogler, 1972; Rehm et al., 1976). Increased forb and weedy intrusion into native rangelands can occur with fertilization (Taliaferro et al., 1975). If this is the case, in effect, the addition of nitrogen fertilization would increase the competition sod-seeded plants face.

2.6 Suppression of the Resident Vegetation

Suppression of the resident vegetation is often sited as the most critical step to establishment of sod-seeded plants. Sod-seeding became feasible with the development of herbicides, as seedling establishment requires control or suppression of the resident vegetation to reduce competition (Bentley and Clements, 1989a; Bryan et al., 1984; Samson and Moser, 1982). Resident vegetation can also be suppressed mechanically, though this is usually not as effective as chemical suppression (Bentley and Clements, 1989b).

2.6.1 Chemical Suppression

Chemical suppression of the resident vegetation is considered to be more important to sod-seeded grass stands than the equipment used, the seed or the weather (Bush et al., 1989). Bowes and Zentner (1992) found that smooth bromegrass production was higher in areas where the resident vegetation was suppressed using herbicide or rotovation than those which had not been suppressed.

Samson and Moser (1982) conducted studies on switchgrass and intermediate wheatgrass sod-seeded into Kentucky bluegrass and annual bromegrass (Bromus species) pastures. Results indicated that 85% suppression of the resident vegetation was necessary for successful establishment of sod-seeded switchgrass (Samson and Moser, 1982).

Herbicides provide a window of suppression but do not usually completely kill the resident vegetation. Bluegrass was found to recover from glyphosate applications, as its long-term yield was not affected (Bowes and Zentner, 1992). Herbicides differ in the length of time that the suppression period will last and in the plants they control (Elliott, 1960; Malik and Waddington, 1990). The stage of development of the resident vegetation at the time of herbicide application is also very important (Lee, 1965). As the seedling stage of sod-seeded grasses is the most critical stage of establishment, it is vital to reduce the competition from the resident vegetation at this time (Samson and Moser, 1982).

The method of herbicide application also affects the degree of control attained. Broadcast applications of glyphosate, paraquat and atrazine have been shown to result in greater establishment than band applications (Samson and Moser, 1982). Greater switchgrass heights and total dry matter yield were achieved with broadcast applications of herbicides than with band applications (Bryan et al., 1984).

A number of studies have shown that band applications of glyphosate, paraquat and atrazine did not suppress the resident vegetation sufficiently (Bryan et al., 1984; Roth et al., 1985; Samson and Moser, 1982).

Grass establishment in a sod-seeding regime is affected by the time between herbicide application and seeding. Successful establishment of grasses sod-seeded directly after or up to two weeks after application of glyphosate and paraquat has been reported in stands of alfalfa, alsike clover, dandelion, creeping red fescue, bromegrass and crested wheatgrass, while longer intervals between herbicide application and seeding reduced establishment (Waddington and Bowren, 1976). Establishment was poor after an interval greater than 2 weeks, possibly due to recovery of the resident vegetation, with a concomitant increase in competition for light, nutrients, and water (Waddington and Bowren, 1976). Bush et al. (1989) found that warm-season grasses emerged within 8 weeks of seeding. This indicates that the window of suppression required by herbicides should be at least 8 weeks for successful emergence of warm-season grasses.

2.6.1.1 Glyphosate

Glyphosate is the most popular herbicide used for sod-suppression. Glyphosate is a non-selective, translocated herbicide. Bush et al. (1989) observed less seedling mortality and increased vigour of sod-seeded warm-season grasses when rhizomatous resident vegetation was suppressed with glyphosate. As the rate of glyphosate was increased from 0.6 to 1.1 kg ha^{-1}, sod-seeded switchgrass populations increased from 0.5-0.7 to 2.4-3.4 plants 0.1 m^{-2} (Bush et al., 1989). In instances where warm-season grass stands failed to establish and survive without suppression of the rhizomatous resident vegetation, stands at the same locations and years survived when chemical suppression took place (Bush et al., 1989).

Hagood (1988) concluded that the greater the control of the resident vegetation achieved with glyphosate, the greater alfalfa dry matter yields. Greater alfalfa yields with suppression (by glyphosate or paraquat) as compared to conventional seeding methods (pre-seeding tillage) have also been reported by Roth et al. (1985). Waller and Schmidt (1983) observed better control of Kentucky bluegrass (98%) than smooth bromegrass (79%) with a 1.12 kg ha^{-1} rate of glyphosate.

2.6.1.2 Sethoxydim

Sethoxydim is another herbicide sometimes used to suppress vegetation in sod-seeding trials. Sethoxydim is a translocated herbicide used for grassy weed control. In a three-year study, Brewster and Spinney (1989) reported that sethoxydim provided 90% suppression of Kentucky bluegrass and smooth bromegrass, however rattail fescue (Vulpia myuros L.) was not controlled and annual bluegrass (Poa annua L.) was suppressed by less than 10%. Hagood (1988) and Malik and Waddington (1990) have observed that glyphosate and paraquat controlled resident vegetation consisting of tall fescue, bromegrass, Kentucky bluegrass, and/or creeping red fescue, to a greater degree than sethoxydim, resulting in greater legume establishment.

2.6.1.3 Paraquat

Paraquat is a non-selective, contact herbicide. Control of resident vegetation using paraquat is usually less effective than when glyphosate is used (Samson and Moser, 1982; Waddington and Bowren, 1976; Welty et al., 1981). Paraquat has a shorter duration of suppression than glyphosate, which may in some cases result in an inadequate window of time for establishment of sod-seeded crops (Squires, 1976; Welty et al., 1981). Therefore, although glyphosate may kill the resident vegetation more slowly, it has a longer duration of suppression; this allows time for the seedlings to germinate, and then provides suppression when it is most critical (Squires, 1976).

Satisfactory alfalfa establishment occurred with spring applications of paraquat, although the suppression effect on the resident vegetation, predominantly Kentucky bluegrass and forbs, was no longer evident the fall of the second season after application (Bowes and Friesen, 1967). However, unsuccessful establishment of alfalfa resulted when paraquat was applied in the fall because poor suppression the following spring resulted in no differences in the amount of resident vegetation present between the sprayed and unsprayed plots (Bowes and Friesen, 1967).

2.6.1.4 2,4-D

Broadleaf plants can offer some competition to sod-seeded seedlings. Herbicides such as 2,4-D can be used to decrease the broadleaf forb component of the resident vegetation (Hurd, 1955; Murray et al., 1991; Thilenius et al., 1974). 2,4-D is a translocated herbicide used for broadleaf weed control. Thilenius et al. (1974) found that 2,4-D applications changed the graminoid:forb ratio from 3:7 to 8:2, thus increasing grass yields. Full recovery of the broadleaf component may occur 4 to 5 years after the 2,4-D application (Murray et al., 1991). Little literature is available on the use of 2,4-D in sod-seeding situations.

2.6.2 Mechanical Suppression

In sod-seeding situations, resident vegetation can also be suppressed by mechanical means. For example, Taylor and Allinson (1983) reduced the competition from the resident vegetation by cutting it. In this case, the height and frequency of clipping, and the position of the growing point at the time of cutting influences the degree to which the resident vegetation is suppressed (Dibbern, 1948; Ehrenreich and Aikman, 1963). Ehrenreich and Aikman (1963) state that forbs are very susceptible to cutting, as their growing point is high above the ground.

Root growth is affected to a greater degree than top growth by clipping (Dibbern, 1948). Once defoliated, less photosynthesis can take place, and the root reserves are used for new growth (Dibbern, 1948; Ehrenreich and Aikman, 1963). Mowing in the spring can weaken plants to a great degree, as plants depend on the root reserves as a food source until new growth and photosynthesis take place (Ehrenreich and Aikman, 1963).

The more frequent the clipping, the greater the suppression of the resident vegetation (Dibbern, 1948; Ehrenreich and Aikman, 1963). However, even a single clipping treatment can suppress vegetation. For example, Dibbern (1948) found a reduced number of smooth bromegrass stems and vegetal dry weights after a single clipping treatment and determined that the effect lasted throughout the growing season and into the following season (although the difference between the control and the clipping treatments was reduced as the season progressed). On the other hand, Bentley and Clements (1989b) found that mowing did not successfully suppress the perennial ryegrass resident vegetation and did not reduce plant competition.

Taylor and Allinson (1983) reported that alfalfa, birdsfoot trefoil (Lotus corniculatus L.), red clover (Trifolium pratense L.), and crownvetch (Coronilla varia L.) successfully established when sod-seeded into timothy (Phleum pratense L.), smooth bromegrass, orchardgrass (Dactylis glomerata L.) and tall fescue sods, once the competition from the resident vegetation was reduced by clipping treatments. However, Williams et al. (1985) found that the frequency of mowing the sward had no significant effect on the establishment and yield of white clover (Trifolium repens L.) seedlings 28 days after seeding. Italian ryegrass seedlings were also found to have poor emergence in a perennial ryegrass resident sod that had undergone a mowing treatment, as the resident vegetation had not been sufficiently suppressed (Bentley and Clements, 1989b).

Scarification of the soil surface by light cultivation (harrowing or light discing) temporarily suppresses grass growth, providing a seedbed without killing the grass and decreasing the potential of erosion compared to conventional seeding practises (Graber, 1928). Scarification can also be used to help kill partially suppressed plants (by chemical or other means) and can improve the seedbed (Elliott, 1960). That is, scarification could be conducted in addition to other suppression methods, such as by herbicides and/or mowing, to provide additional control.

2.7 Conclusions

Previous studies have emphasized the importance of resident vegetation suppression for successful establishment of sod-seeded grasses. Without adequate suppression, the establishment, growth and survival of sod-seeded grasses is reduced. One of the most important reasons for suppressing the resident vegetation is to reduce competition for water. To a lesser extent, the competition for light, nutrients and space must also be decreased. Both tillage and herbicides have been used for vegetation suppression.

Although studies have been conducted to determine the yield of tall wheatgrass, green needlegrass, northern wheatgrass and switchgrass (Balasko et al., 1984; Kilcher and Looman, 1983; Knowles, 1987; Lawrence, 1978; Lawrence and Ratzlaff, 1989; Lawrence and Warder, 1979; Stout et al., 1986), few detailed measurements of the growth and development of these grasses when sod-seeded under dry subhumid conditions, such as found in Manitoba, have been conducted.

3.0 EVALUATION OF SOD-SUPPRESSION TECHNIQUES FOR ESTABLISHMENT OF SOD-SEEDED TALL WHEATGRASS

3.1 Introduction

Several factors, such as the environment (precipitation, temperature, soil type) and competition with the resident vegetation for light, nutrients and water, affect sod-seeded plants. Management practises that will enhance the successful establishment, development and survival of sod-seeded grasses need to be developed.

Tall wheatgrass is currently being used by wildlife organizations to provide short-term DNC (approximately 10-year stands). Establishment in tilled seedbeds has been highly successful, however little is known about the establishment of tall wheatgrass under sod-seeding. Therefore, the objective of this study was to evaluate different sod-suppression techniques for the establishment of tall wheatgrass [Thinopyrum ponticum (Podp.) Barkw. & D.R. Dewey] under two types of resident vegetation.

3.2 Methodology

3.2.1 Field Trial Establishment and Management

Field experiments were established at Gladstone and

Portage La Prairie, MB in 1991 and 1992. The soil type at Portage was a Neuhorst clay. At Gladstone, the soil type in 1991 was an Isafold clay, while in 1992 the experiment was conducted on an Isafold very fine sandy clay loam (Appendix 1, Table A.1). The resident grasses consisted mainly of timothy at Portage, and smooth bromegrass and Poa species at Gladstone in both years. Timothy had been seeded at Portage 13 years prior to plot establishment and it had not been fertilized during this period. The 1991 Gladstone site had not been tilled or fertilized since 1950. The 1992 Gladstone site had been seeded to alfalfa and bromegrass in 1980, but had not been disturbed since. It had been fertilized with 90 kg ha^{-1} of 11-51-0 five years prior to plot establishment.

The experimental design in each case was a split plot, with scarification (harrowing) as the main plot and suppression treatment as subplots. Each experiment was replicated four times. The dimensions of the subplots were 2 x 10 meters. Scarification of the main plots was done by passing over the plots six times in opposite directions prior to seeding with a single diamond-toothed harrow. Numerous passes were required in an effort to emulate larger, heavier field equipment. The suppression treatments (subplots) were: 1) mowing the resident vegetation to a 5 cm height immediately prior to seeding, 2) 2,4-D amine at a rate of 4.5 L ha^{-1} [2250 g active ingredient (a.i.) ha^{-1}] (1991 only), or glyphosate at a rate of 2.5 L ha^{-1} (890 g a.i. ha^{-1}) (1992 only),

3) sethoxydim at a rate of 4.4 L ha^{-1} (809.6 g a.i. ha^{-1}) with surfactant, Assist, 4) paraquat at a rate of 3 L ha^{-1} (600 g a.i. ha^{-1}), 5) 50 kg N ha^{-1} (34-0-0), and 6) a control in which no suppression took place. The nitrogen treatment was included 1) to determine if the addition of nitrogen fertilizer sufficiently increased the quality of DNC without any suppression and 2) to act as a treatment of maximum competition to the seedlings.

The glyphosate treatment was applied two days prior to seeding. The paraquat was sprayed immediately prior to seeding in 1991 and two days prior to seeding in 1992. In 1991, the 2,4-D and sethoxydim were sprayed six days after seeding (DAS) at Gladstone, and the day of seeding at Portage. In 1992, the sethoxydim was sprayed two DAS at Gladstone and one DAS at Portage. All herbicides were applied using a compressed air bike sprayer in 100 L of water ha^{-1}. Nitrogen was broadcast by hand over the entire plot. Appropriate pest control measures were conducted every year (Tables 3.1 and 3.2). The area at Gladstone was fenced to exclude cattle grazing.

In 1991, the trial at Gladstone was seeded on May 17 and the trial at Portage on May 22. In 1992, the trial at Gladstone was seeded on May 13 and the trial at Portage on May 14. Tall wheatgrass (common seed) was seeded at a rate of 10 kg ha^{-1} (193 viable seeds m^{-2} in 1991 and 181 viable seeds m^{-2} in 1992) using a Connor Shea Coulter Coil Tyne sod-seeding

Table 3.1 Herbicides applied in tall wheatgrass experiment in 1991 and 1992 at Portage La Prairie and Gladstone, MB.

Year	Location	Date	Herbicide	Rate (L product/ha)
1991	Portage	May 22	Paraquat	3.0
		May 22	2,4-D	4.5
		May 22	Poast (& Assist)	4.4
		June 21	Lontrel	1.5
		August 4	Buctril M	1.5
		Sept. 24	Lontrel	1.0
1991	Gladstone	May 17	Paraquat	3.0
		May 23	2,4-D	4.5
		May 23	Poast (& Assist)	4.4
		July 16	Buctril M	1.0
1992	Portage	May 13	Paraquat	3.0
		May 13	Round-up	2.5
		May 15	Poast (& Assist)	4.4
		June 19	Lontrel	1.0
		July 12	Lontrel	1.5
1992	Gladstone	May 11	Paraquat	3.0
		May 11	Round-up	2.5
		May 15	Poast (& Assist)	4.4
		July 12	Buctril M	1.0

Table 3.2 Insecticides applied in tall wheatgrass experiment in 1991 and 1992 at Portage La Prairie and Gladstone, MB.

Year	Location	Date	Insecticide	Rate (L product/ha)
1991	Portage	August 4	Sevin	2.5
1991	Gladstone	May 29	Hopper Stopper	around plot borders
		June 2	Hopper Stopper	around plot borders
		June 5	Sevin XLR (Carbaryl)	2.5
1992	Gladstone	June 9	Sevin XLR (Carbaryl)	2.5

drill (row spacing was 15 cm) (Prairie Agricultural Machinery Institute, 1986). Seeding depth was 1.5 to 2.5 cm in both years at Portage and in 1992 at Gladstone. At Gladstone in 1991, seeding depth ranged from 0.5 to 2.0 cm. The soil was packed twice after seeding (using a lawn packer) to improve seed-to-soil contact. Increased seed-to-soil contact is desirable to ensure water will be conducted from the soil to the seed (Collis-George and Sands, 1959). The number of ungerminated Italian ryegrass seeds has been found to increase, while emergence decreased, as a result of poor seed-to-soil contact (Marshall, 1982). Bluegrass plant establishment was higher when the seed was covered as compared to when it was uncovered (Lee, 1965).

3.2.2 Measurements

3.2.2.1 Environmental Conditions

Daily maximum, minimum and mean air temperatures at Stevenson screen height (1.5 metres) were measured throughout the growing season using a Campbell Scientific Model CR10 datalogger set up near the experimental area at both sites in both years. Daily precipitation was monitored during the growing season in both years at Portage and in 1992 at Gladstone. Precipitation data from a nearby Environment Canada station was used for the Gladstone site in 1991.

Gravimetric soil water content between 0 and 10 cm was measured at weekly intervals during the emergence period. On the first two dates, measurements were taken in the main plot treatments only; that is, two measurements were taken per replicate: one in the scarified main plot and one in the unscarified main plot. Successive measurements were conducted in four plots per replicate: treatments that had been scarified and had some chemical suppression of grasses [either the Poast, Paraquat and Round-up (in 1992) treatments], those that had been scarified with no chemical suppression of grasses occurring [either the mowing, 2,4-D (in 1991), nitrogen and check treatments], those that had not undergone scarification but had been chemically suppressed for grasses, and those treatments that had not been scarified or chemically suppressed. These treatments were measured to compare the effects of chemical suppression on the resident grass species, provided by the Round-up, Poast and Paraquat treatments early in the season, to non-chemical suppression methods. Soil samples were oven-dried at 80°C for a minimum of forty-eight hours, and then weighed to calculate the gravimetric water content.

3.2.2.2 Resident Vegetation

The degree of light interference by the resident vegetation was monitored using a Licor Model LI-185B quantum meter with a line quantum sensor (1 meter long). Light interception was interpreted as being a measure of the competition for light provided by the resident vegetation. Measurements were taken at frequent intervals throughout the growing season. Readings were taken beneath and above the canopy. The sensor was placed perpendicular to the seeded rows to determine the photon flux density (μmole m^{-2} sec^{-1}). Percent interception of photosynthetically active radiation by the canopy was calculated as follows:

$$\%\ \text{light interception} = \frac{(\text{photon flux above} - \text{photon flux below})}{\text{photon flux above the canopy}} \times 100.$$

Aerial dry matter accumulation of the resident vegetation (another measure of the competition provided by the resident species) was measured 96 and 95 DAS at Portage in 1991 and 1992, respectively, and 101 and 86 DAS at Gladstone in 1991 and 1992, respectively. One quarter-metre square area was hand-harvested to ground level in each subplot. Plant samples were oven-dried at 80°C for a minimum of forty-eight hours, and then weighed.

3.2.2.3 Plant Establishment, Development and Survival

Plant establishment, development and survival was determined three to four times during each season on plants growing in two one-meter lengths of row per subplot. The same rows were used in each subplot at each site to remove any variation due to seeding equipment. The number of plants within these rows were counted and marked with rings. In-season plant survival was determined in 1992 for the intervals between counts. In-season survival was measured on the total number of plants within the two one-meter rows. For example, at Portage in 1992, the plant density 27 DAS was 65 plants m^{-2} (the glyphosate treatment under scarification - Table 3.5). These plants were then marked with rings. Forty DAS, 60 of the ringed plants remained. The in-season survival rate was then calculated as follows:

$$\text{survival rate (\%)} = \frac{\text{number of remaining live plants}}{\text{original total number}} \times 100.$$

Thus the survival rate in the example would be $\frac{60}{65} \times 100$, or 92% (Table 3.15). Plant development was determined by measuring the height and Haun stage (Haun, 1973) of ten randomly selected seedlings per subplot.

3.2.2.4 Second-Year Measurements

The experiment established at Portage in 1991 was monitored in 1992, and those experiments established in 1992 were monitored in the spring of 1993. Measurements included plant population density, development (Haun scale and plant height) and overwinter survival rate (percentage of ringed plants in late fall that had spring regrowth). The Gladstone experiment established in 1991 was not monitored the following growing season. The difficulty in finding the seeded rows and the encroachment of similar grasses made it impossible to find the sod-seeded tall wheatgrass plants.

A Robel pole (Robel et al., 1970) was used to assess the nesting cover quality of the 1991 stand at Portage 470 and 520 DAS. Measurements were taken at a distance of four meters and a height of one meter (Duebbert et al., 1981; Robel et al., 1970). Robel pole readings were taken in two locations per subplot. An average of the two measurements was analyzed.

3.2.3 Statistical Analysis

Results were analyzed using the GLM procedure of the Statistical Analysis Systems (SAS Institute, North Carolina, 1985). Due to the exploratory nature of the experiment, p=0.10 was used. Means were separated using the Fischer Protected Least Significant Difference test (p=0.10) after the GLM indicated significant differences (p=0.10). Significant interaction mean separations were calculated according to Gomez and Gomez (1984). Relationships between environmental measurements, plant density, height, Haun stage and survival rates were determined using correlation analysis. Correlations are discussed only when sufficient spread of the data occurred to avoid having a line drawn between a cluster of data and a single data point. The sample size for all correlations was 12. Data was combined across sites when correlating Haun measurements in the establishment year and year after establishment measurements. The 2,4-D treatment at Portage in 1991 was not included in the combined analysis.

3.3 Results and Discussion

Measurements to be discussed are those that were taken within the season of establishment, unless stated otherwise.

3.3.1 Environmental Conditions

3.3.1.1 Air Temperature

Air temperature was recorded to characterize the sites and years and to allow for comparisons between years. At Portage, air temperatures during the growing season were lower in 1992 than in 1991 (and often lower than the average) during the period of June through September (Table 3.3, Figures 3.1 and 3.2). In 1991, temperatures were above the long-term average in May, June and August (Table 3.3, Figure 3.1). An optimal temperature for germination of cool-season grasses is 20°C (Bokhari et al., 1975; McGinnies, 1960). In 1991, maximum temperatures often reached or exceeded 25°C (Figure

3.1). Although the mean air temperature in 1992 was often below 20°C, the daily maximum temperature was often above or equal to this temperature (Figure 3.2).

Table 3.3 Monthly mean air temperature, precipitation and long-term average[z] at Portage La Prairie, MB in 1991 and 1992.

	Temperature (°C)				Precipitation (mm)		
	1991	1992	Norm[z]		1991	1992	Norm[z]
May	14.1	12.8	11.6		59.0	12.6	56.8
June	18.8	15.4	17.1		75.0	44.0	75.0
July	19.5	16.3	19.8		95.0	109.0	76.9
August	20.3	16.3	18.4		10.0	49.0	78.8
September	12.2	10.8	12.5		68.0	50.0	50.1
Mean	17.0	14.3	15.9	Total	307.0	264.6	337.6

[z] Long-term average (1961-1990) at Portage La Prairie, MB (Environment Canada). The 30-year average is the most recent period for which data has been compiled.

At Gladstone, air temperature was again higher in 1991 than in 1992 (Table 3.4, Figures 3.3 and 3.4). Temperatures in 1991 were close to the long-term average, however temperatures in 1992 were below the average throughout most of the growing season (Table 3.4). During the period of May 19th to August 9th, 1991, there were only 3 days in which the daily maximum temperature did not reach or exceed 20°C and 17 days in which the mean temperature reached or exceeded 20°C (Figure 3.3). During the same period in 1992, the maximum temperature

Table 3.4 Monthly mean air temperature, precipitation and long-term average[z] at Gladstone, MB in 1991 and 1992.

	Temperature (°C)				Precipitation (mm)		
	1991	1992	Norm[z]		1991	1992	Norm[z]
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
September	12.2	10.9	12.1		74.8	71.0	55.7
Mean	16.9	14.3	15.5	Total	386.8	296.0	316.7

[z] Long-term average (1973-1990) at Gladstone, MB (Environment Canada). The 17-year average is the most recent period for which data has been compiled.

did not attain or exceed 20°C on 26 days and the mean temperature reached or exceeded 20°C on only 8 days (Figure 3.4). Early seedling growth rates of cool-season grasses are greatest where day/night temperatures are approximately 24/19°C (Fulbright et al., 1985; Hill et al., 1985). Vegetative growth after the first tiller appeared was reported to be greatest at temperatures of 21/16°C (Hill et al., 1985). Therefore, temperatures in 1992 may have been low enough to seriously decrease plant development rate.

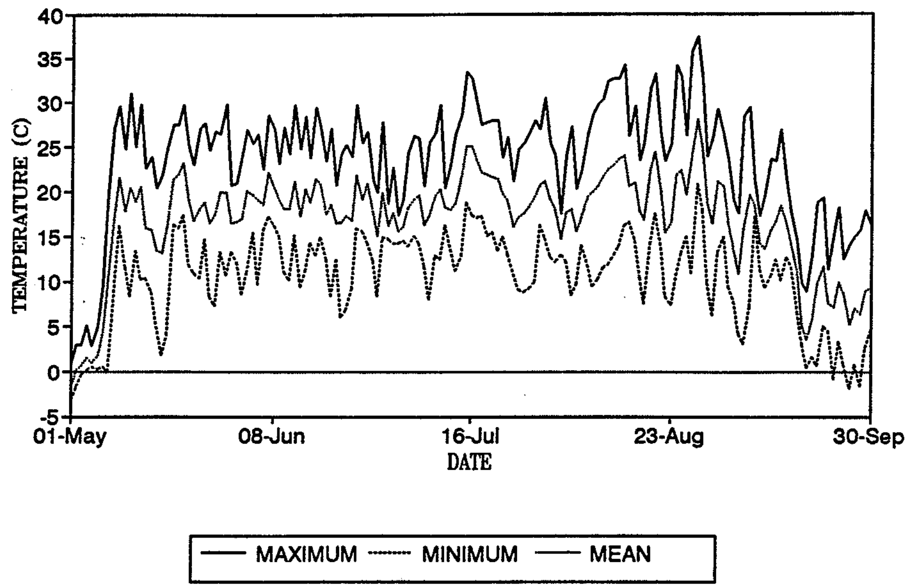


Figure 3.1 Maximum, minimum and mean air temperature at Portage La Prairie, MB in 1991.

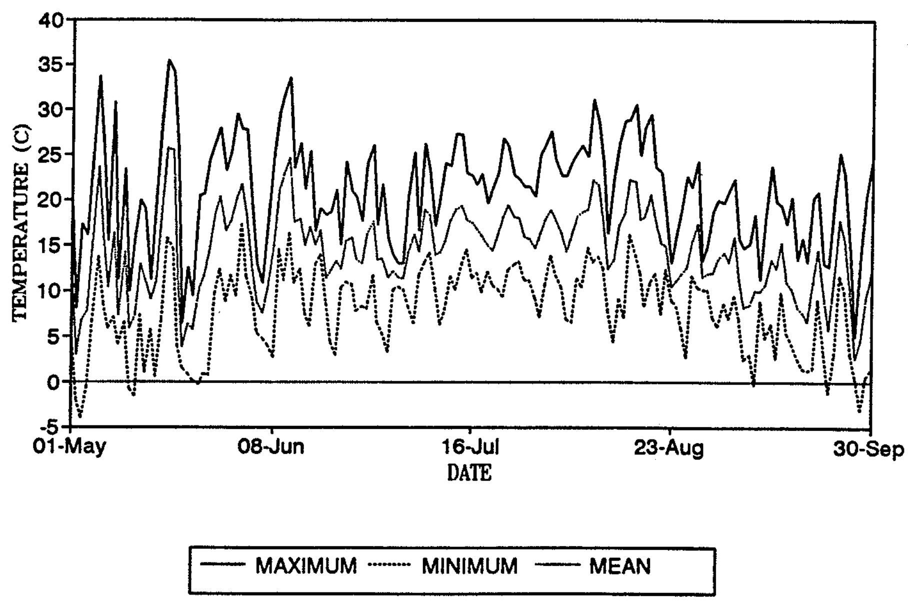


Figure 3.2 Maximum, minimum and mean air temperature at Portage La Prairie, MB in 1992.

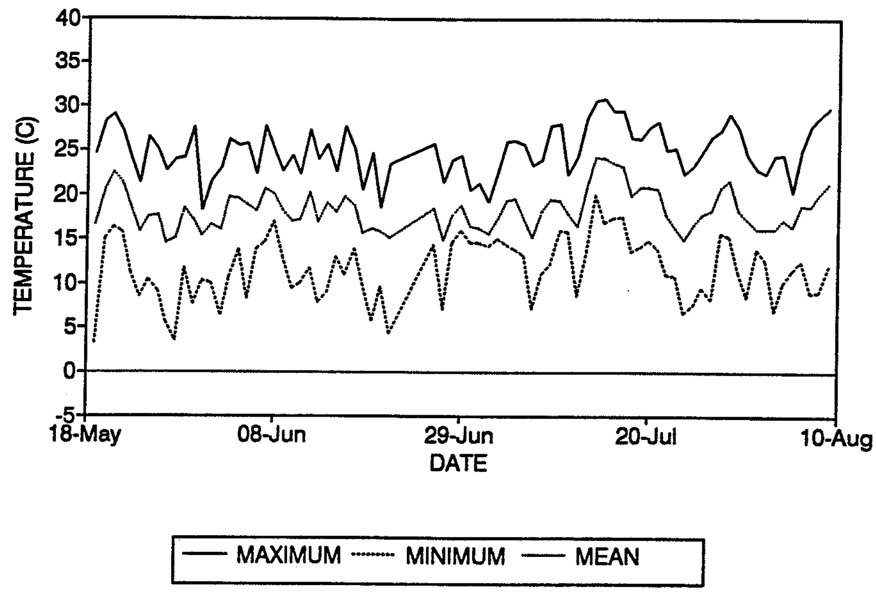


Figure 3.3 Maximum, minimum and mean air temperature at Gladstone, MB in 1991.

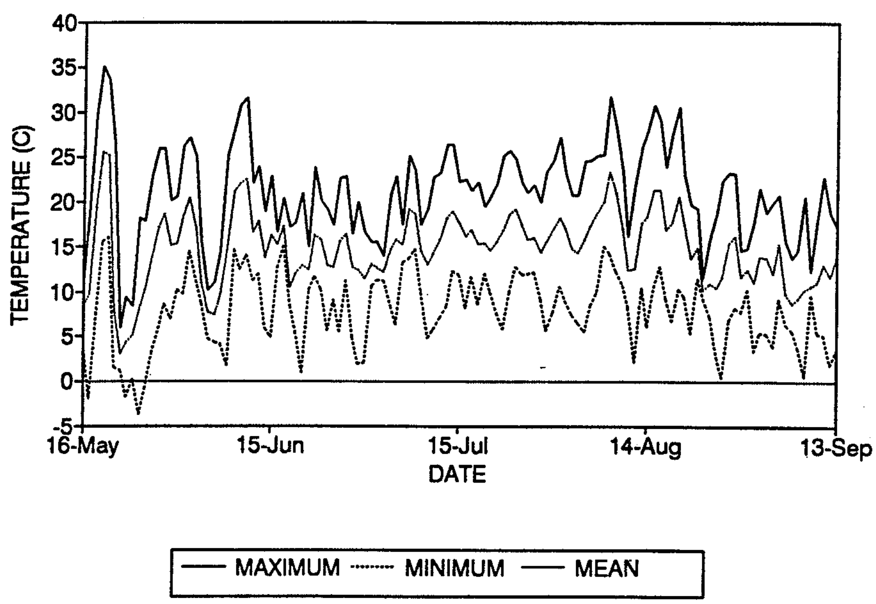


Figure 3.4 Maximum, minimum and mean air temperature at Gladstone, MB in 1992.

3.3.1.2 Precipitation

Precipitation varied between sites and years. Precipitation at Portage from May 1 to September 30 in 1991 and 1992 was below the long-term average and was lower in 1992 than in 1991 (Table 3.3, Figures 3.5 and 3.6). Early season (May and June) conditions were especially dry in 1992 (Table 3.3). In both years, precipitation in July was above-average, while precipitation in August was below average (Table 3.3).

Early season conditions at Gladstone were drier than the long-term average, especially in 1992 (Table 3.4). Precipitation was lower in 1992 than in 1991 (Table 3.4, Figures 3.7 and 3.8). In both years, above-average precipitation occurred in July and September (Table 3.4). Precipitation from May 15 to September 13 at Gladstone was 305 mm in 1991 and 233 mm in 1992 (Figures 3.7 and 3.8). In comparison, precipitation at Portage during this period was 224 and 229 mm in 1991 and 1992, respectively.

3.3.1.3 Soil Moisture

Soil moisture was measured during the emergence period in all trials. At Portage, soil moisture levels appeared higher during this period in 1992 than in 1991 (Figures 3.9, 3.10a and 3.11a). Similar differences between years occurred early in the season at Gladstone as well; although approximately 26

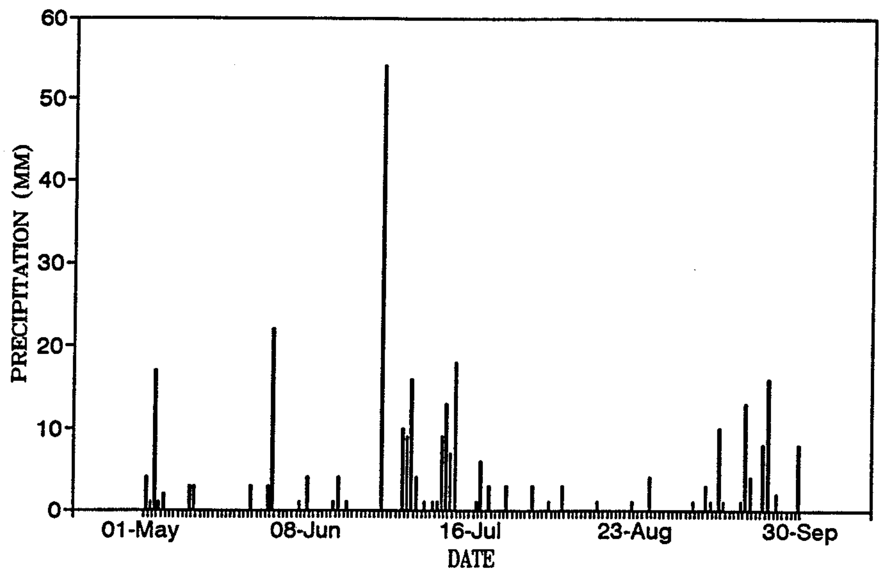


Figure 3.5 Seasonal precipitation at Portage La Prairie, MB in 1991.

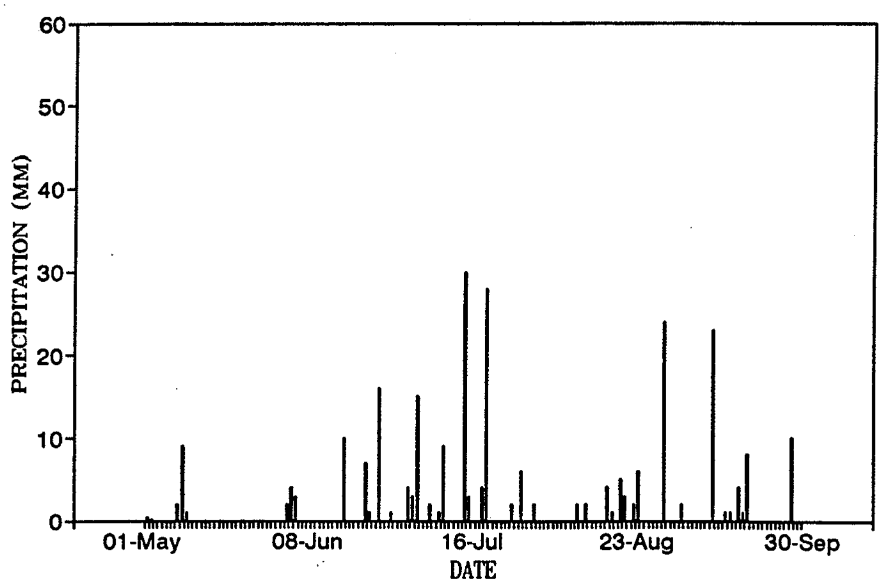


Figure 3.6 Seasonal precipitation at Portage La Prairie, MB in 1992.

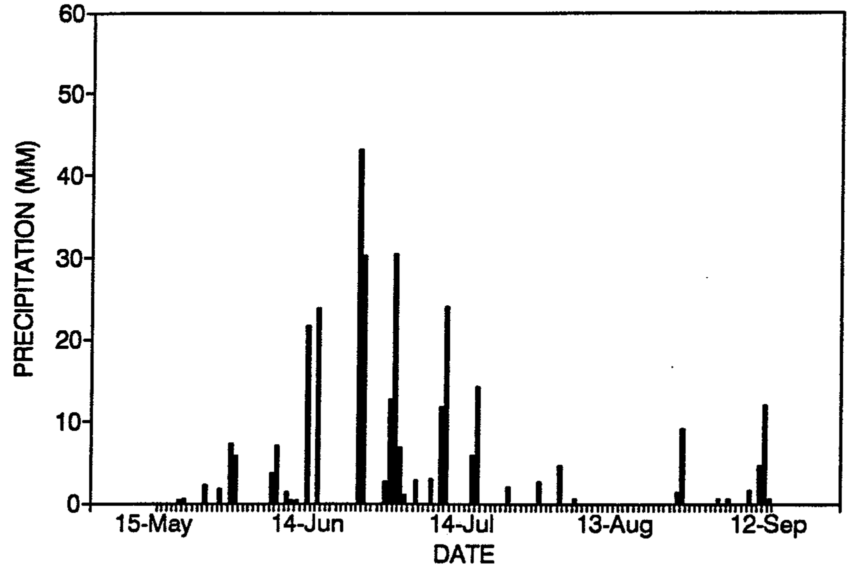


Figure 3.7 Seasonal precipitation at Gladstone, MB in 1991.

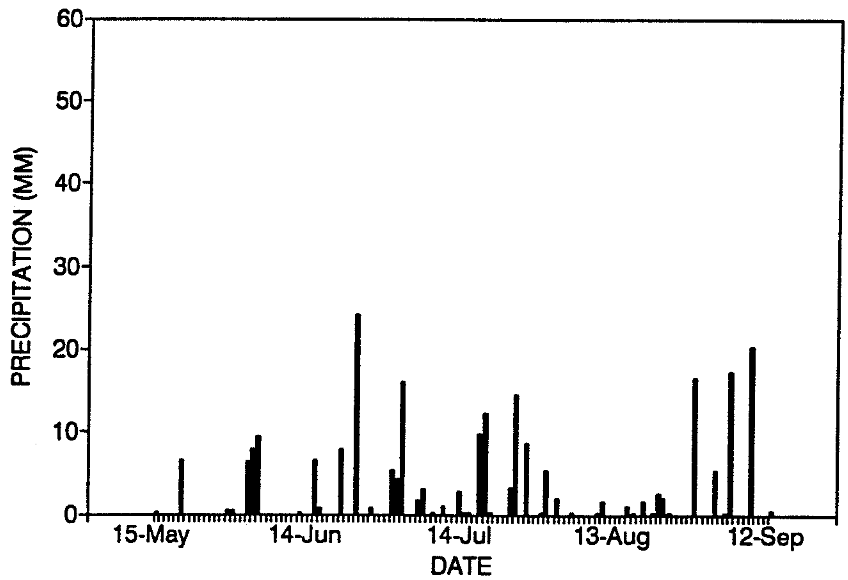


Figure 3.8 Seasonal precipitation at Gladstone, MB in 1992.

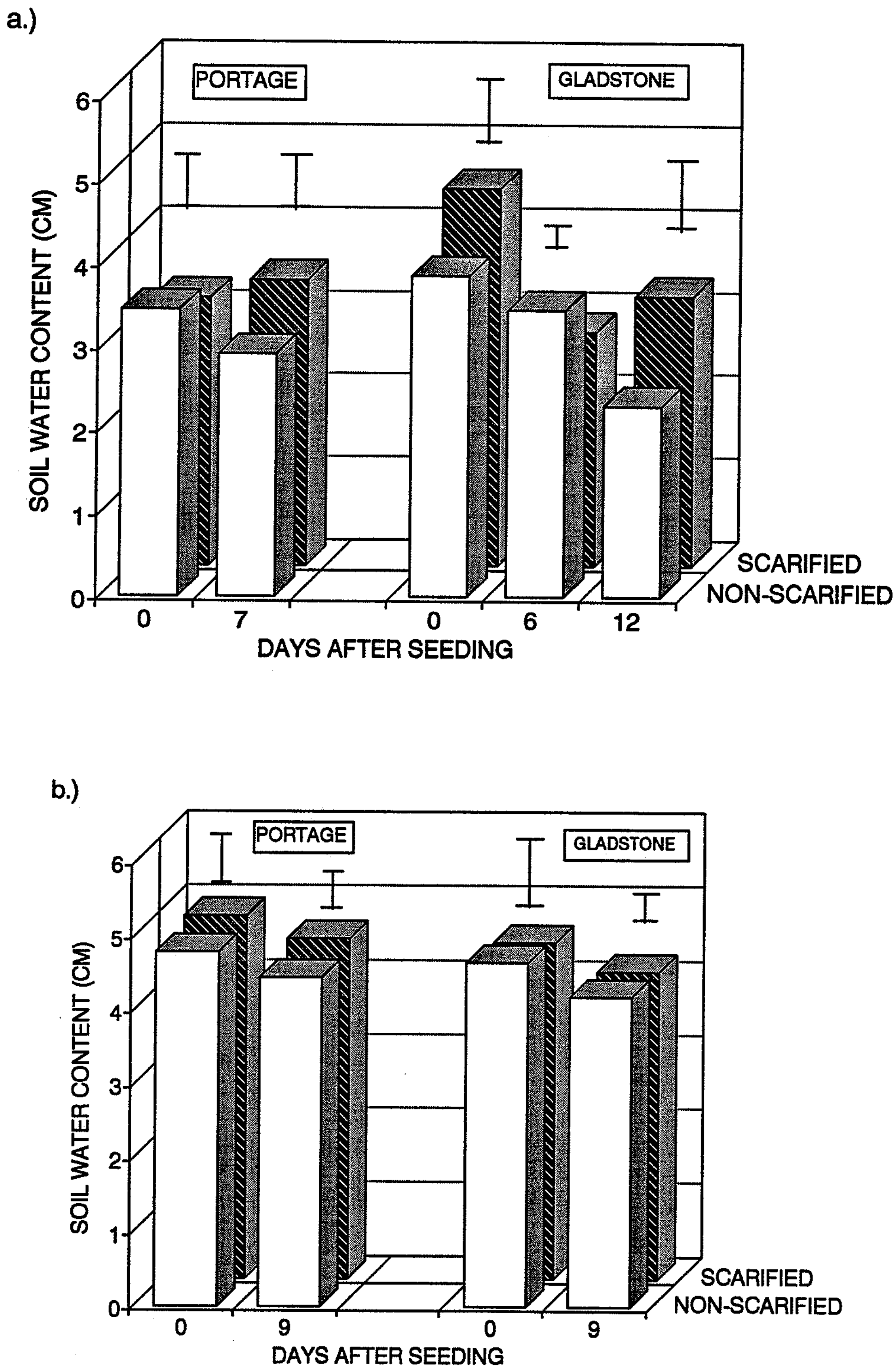
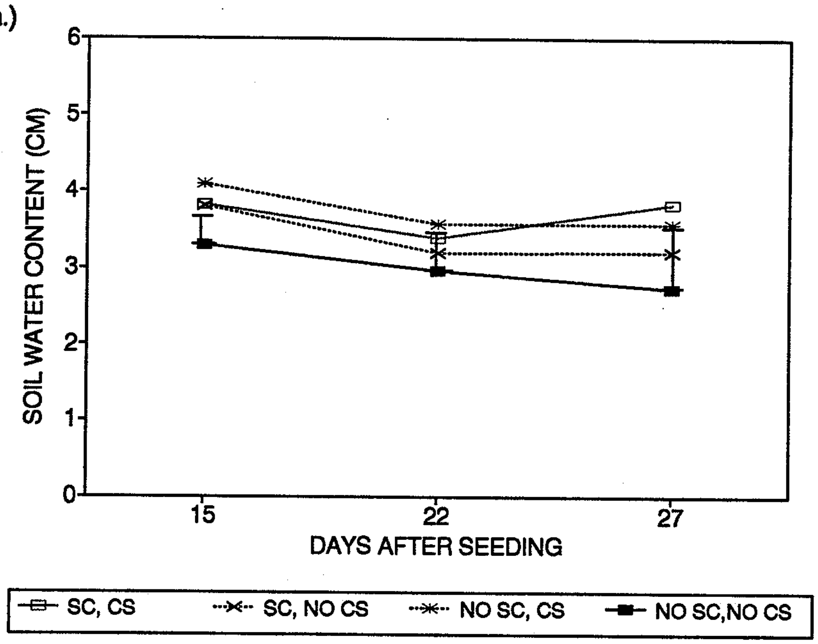


Figure 3.9 Influence of scarification on volumetric soil water content (cm) to a 10 cm depth at Portage La Prairie and Gladstone, MB in a.) 1991 and b.) 1992. Vertical bars indicate LSD(0.10).

a.)



b.)

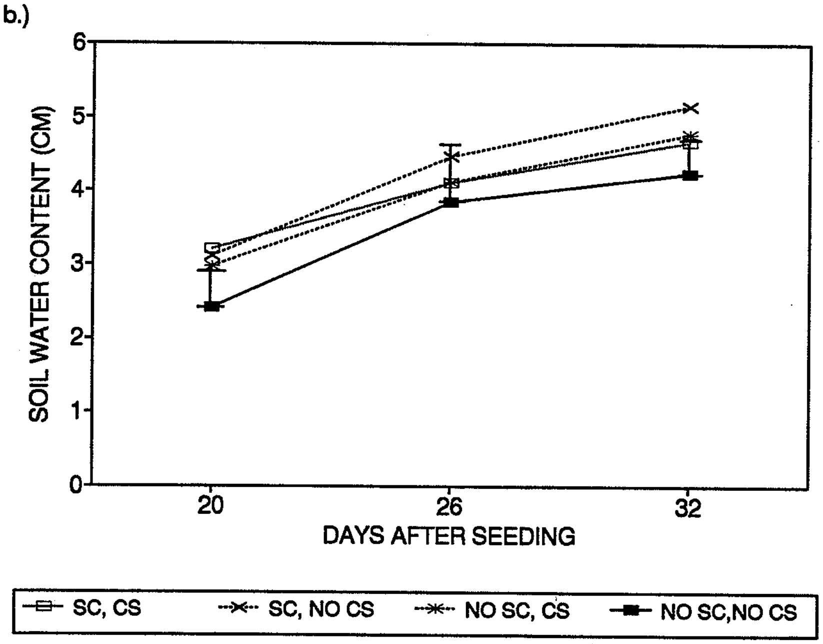
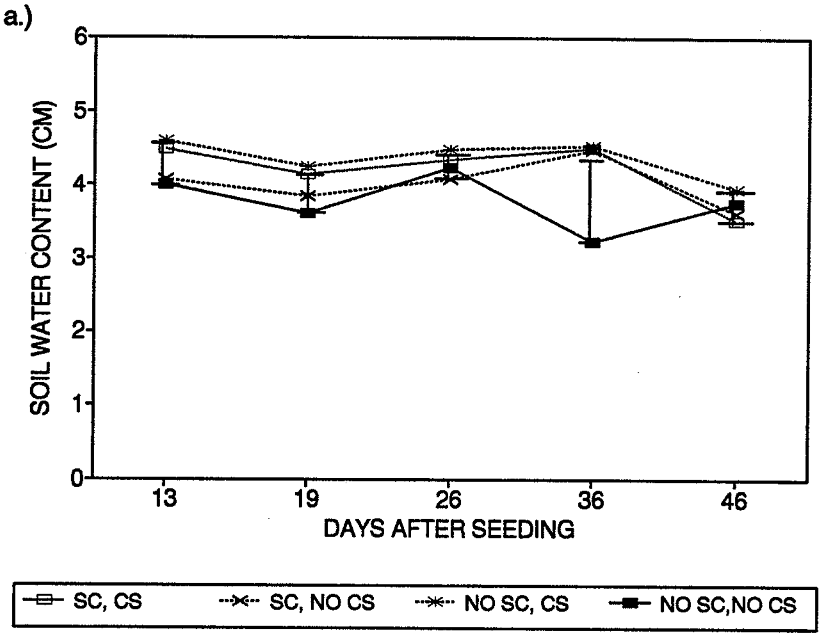


Figure 3.10 Influence of scarification (SC) and chemical suppression (CS) on volumetric soil water content (cm) to a 10 cm depth in 1991 at a.) Portage La Prairie and b.) Gladstone, MB. Vertical bars indicate LSD(0.10).

a.)



b.)

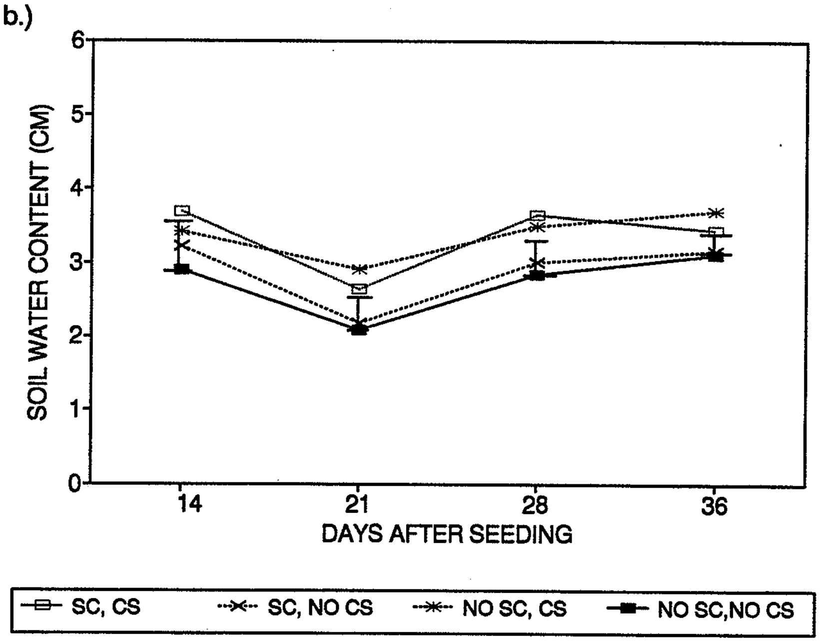


Figure 3.11 Influence of scarification (SC) and chemical suppression (CS) on volumetric soil water content (cm) to a 10 cm depth in 1992 at a.) Portage La Prairie and b.) Gladstone, MB. Vertical bars indicate LSD(0.10).

and 32 DAS, soils appeared drier in 1992 than 1991 (Figures 3.9, 3.10b and 3.11b). In general, the Portage sites had higher soil moisture levels than the Gladstone sites.

There was no consistent effect of scarification on soil moisture in 1991 or 1992 (Figures 3.9, 3.10 and 3.11). Chemical suppression increased the soil moisture on all sampling dates at Portage in 1991, early in the season at Gladstone in 1991 (20 DAS) and at Portage in 1992 (13, 19 and 26 DAS), and at Gladstone in 1992 (Figures 3.10 and 3.11). Competition from the resident vegetation would be reduced in the chemically suppressed treatments, thus greater soil moisture would be available to the tall wheatgrass seedlings.

3.3.2 Competition From the Resident Vegetation

3.3.2.1 Competition for Light

Since tall wheatgrass seedling populations were not as dense as the resident vegetation during the entire season in the establishment years, measures of percent light interception reflect the light interception of the resident vegetation and not the introduced grasses. The competition for light was expected to be different at the two sites due to differences in the resident vegetation and in growing conditions.

At Portage in 1991, a significant scarification effect indicated that scarification decreased light interception by the resident vegetation 23 and 27 DAS (Figure 3.12a). This may be attributed to the fact that the 2,4-D and nitrogen treatments (and check treatment 27 DAS) exhibited greater light interception without scarification than when scarification took place, thus providing the most competition to the developing wheatgrass seedlings. Other treatment did not perform significantly differently under the two scarification treatments. This resulted in a significant main plot x subplot interaction.

Suppression treatments significantly affected the competition for light by the resident vegetation throughout the season. The Poast and Gramoxone treatments resulted in the lowest percent light interception of the resident vegetation early in the season, while the nitrogen treatment resulted in the highest (Figure 3.12b). Poast provided the greatest season-long control of timothy at the Portage site, followed by Gramoxone, and then the remaining treatments (Figure 3.12b). This is in contrast with the results of Hagood (1988), who found that Gramoxone provided greater suppression of tall fescue than Poast. Translocation of Poast may have allowed greater timothy suppression compared with Gramoxone, which is a contact herbicide.

At Gladstone in 1991, scarification increased the resident vegetation light interception 89 DAS (Figures 3.13a).

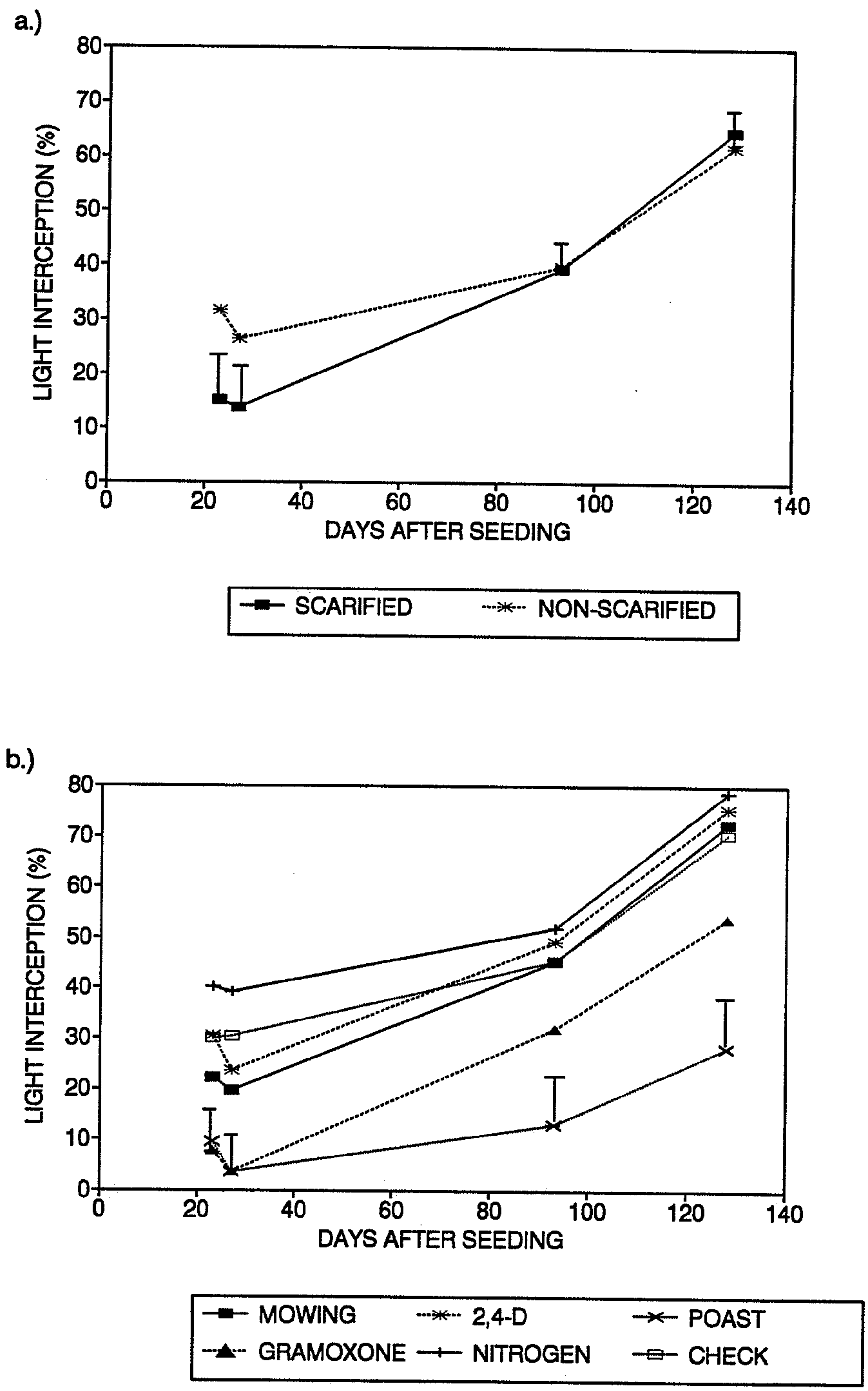


Figure 3.12 Influence of a.) scarification and b.) suppression treatment on light interception (%) of the resident vegetation at Portage La Prairie MB in 1991. Vertical bars indicate LSD(0.10).

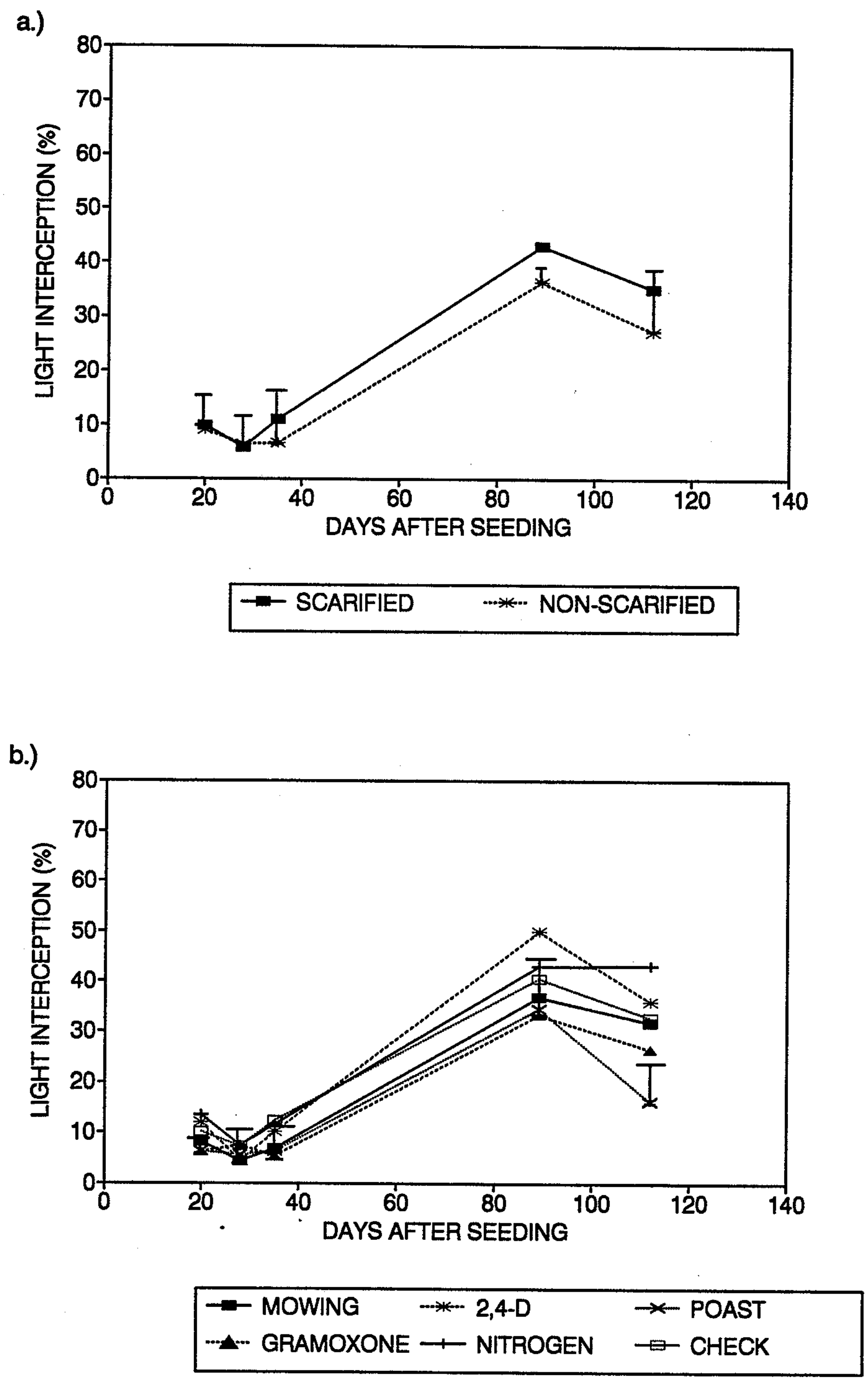


Figure 3.13 Influence of a.) scarification and b.) suppression treatment on light interception (%) of the resident vegetation at Gladstone, MB in 1991. Vertical bars indicate LSD(0.10).

Thus, in this instance, the resident vegetation seemed to be stimulated by the scarification treatment. No significant interactions occurred (Appendix 2, Table A2.2). Significant suppression treatment effects were observed on a number of dates (20, 35, 89 and 112 DAS) (Appendix 2, Table A2.2). Generally, the Poast and Gramoxone treatments provided the greatest reduction in light competition, while the resident vegetation in the nitrogen, check and 2,4-D treatments provided the most intense competition for light (Figure 3.13b). The mowing provided a moderate level of reduction in light interception. At the end of the season (112 DAS), the resident vegetation light interception was lowest in the Poast treatments and highest in the nitrogen treatments (Figure 3.13b).

At Portage in 1992, significant scarification effects indicated that scarification decreased the competition for light 68 and 76 DAS (Figure 3.14a). No significant interactions occurred (Appendix 2, Table A2.3). Throughout the season, the Poast, Gramoxone and Round-up treatments had the lowest percent light interception, indicating the best season-long reduction in growth of the resident vegetation (Figure 3.14b).

At Gladstone in 1992, scarification effects indicated that scarification decreased the competition for light 26 DAS (Figure 3.15a). A significant main plot x subplot interaction indicated that the nitrogen and check treatments without

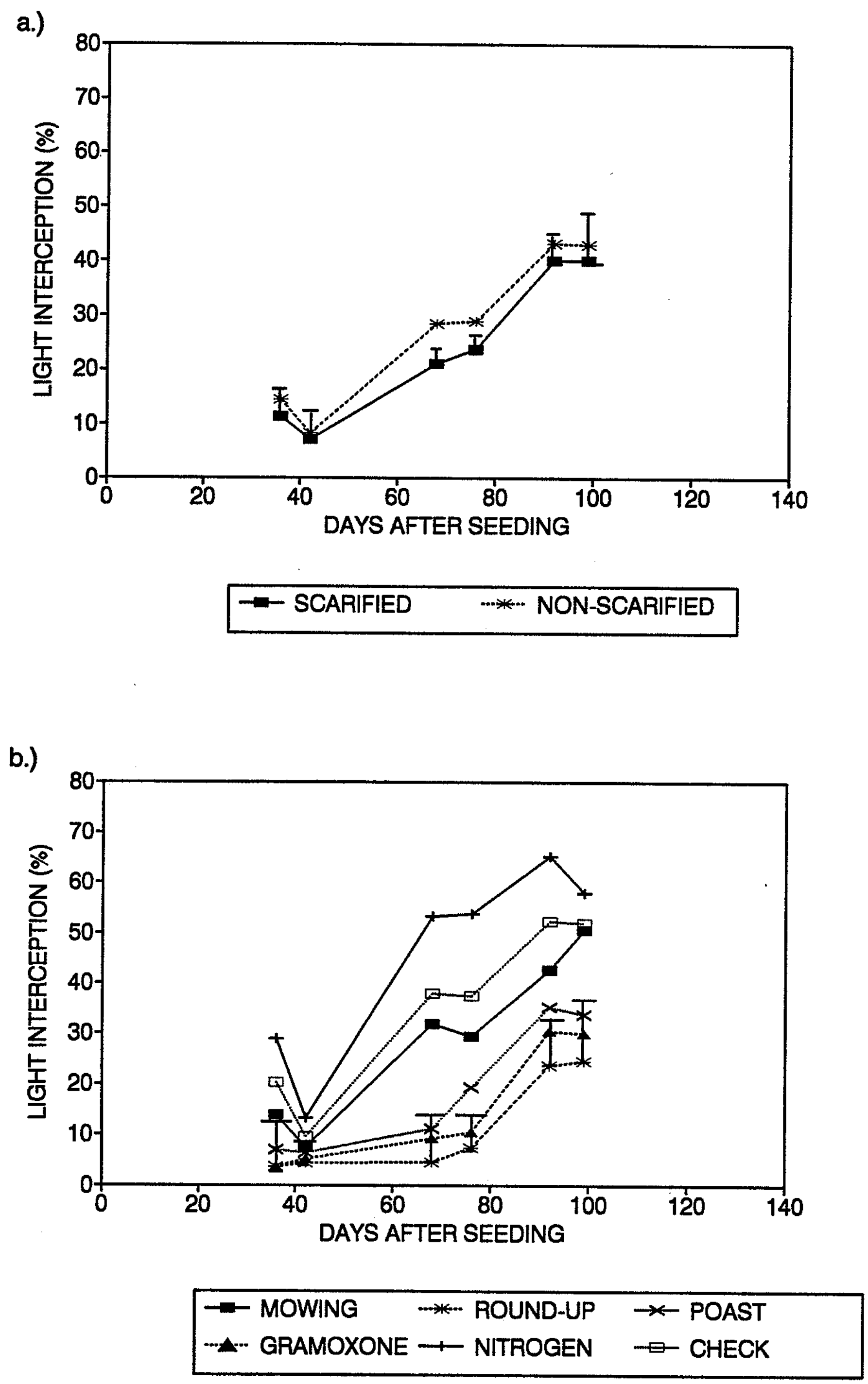


Figure 3.14 Influence of a.) scarification and b.) suppression treatment on light interception (%) of the resident vegetation at Portage La Prairie, MB in 1992. Vertical bars indicate LSD(0.10).

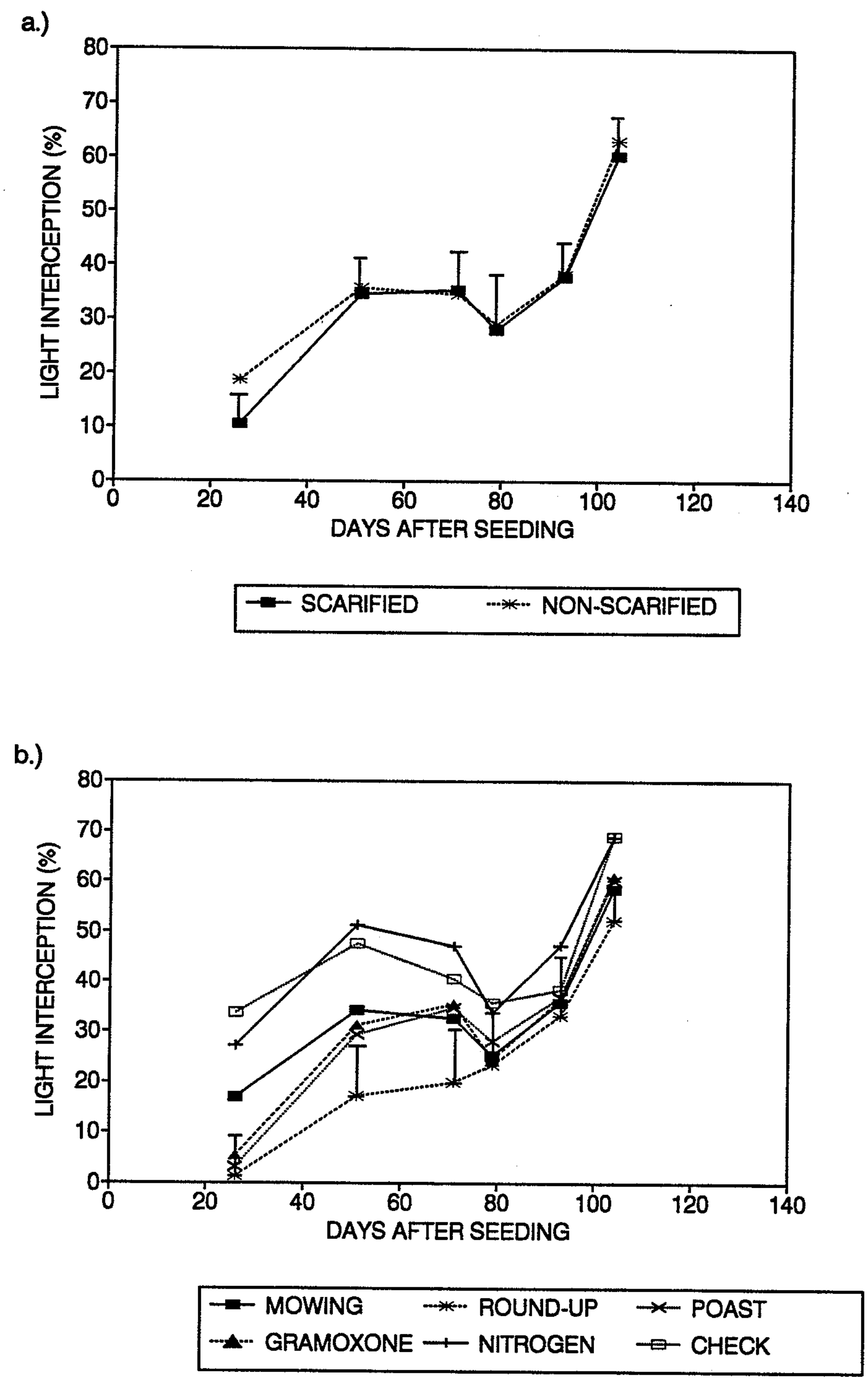


Figure 3.15 Influence of a.) scarification and b.) suppression treatment on light interception (%) of the resident vegetation at Gladstone, MB in 1992. Vertical bars indicate LSD(0.10).

scarification provided greater competition for light than when scarified (Appendix 2, Table A2.4). The remaining treatments were not significantly differently under the two scarification treatments. This was similar to results at Portage in 1991. Significant suppression treatment effects indicated that the Poast, Gramoxone and Round-up treatments reduced the competition for light to the greatest extent early in the season (26 DAS). However, later in the season, Round-up had the lowest percent light interception (Figure 3.15b).

Decreases in light interception were observed 42 DAS at Portage in 1992 and 79 DAS at Gladstone in 1992 (Figures 3.14 and 3.15). This appeared to be related to low precipitation (Tables 3.3 and 3.4). Also, the resident vegetation would have been elongating or heading at these times, and less light may have been intercepted due to loss of lower leaves. Elongation of the stems might have opened up the canopy.

Across all years and sites, the greatest reduction in competition for light was achieved by the Round-up, Poast and Gramoxone treatments. Round-up and Gramoxone have been found to suppress the resident vegetation to a greater degree than Poast by some researchers (Hagood, 1988; Malik and Waddington, 1990), while several studies have found that Round-up provides greater suppression than Gramoxone (Samson and Moser, 1982; Waddington and Bowren, 1976; Welty et al., 1981). The duration of suppression provided by Round-up is also reported to be longer than that provided by Gramoxone (Squires, 1976;

Welty et al., 1981). This is also evident in this study as, at Gladstone in 1992, Round-up had the greatest long-term effect on light suppression of any of the treatments.

The nitrogen and 2,4-D treatments did not effectively reduce the competition for light. The nitrogen was broadcast and thus available to the resident vegetation as well as the seedlings. Thus it was a treatment that provided the maximum amount of competition for the tall wheatgrass seedlings. 2,4-D decreases the broadleaf forb component of the resident vegetation (Hurd, 1955; Murray et al., 1991; Thilenius et al., 1974). However, the resident vegetation at both Gladstone and Portage consisted mainly of grasses, which 2,4-D does not suppress. Similar to other studies (Bentley and Clements, 1989b; Williams et al., 1985), mowing did not successfully reduce competition.

Results of this study showed that under good growing conditions and inadequate suppression, the resident vegetation can impede the light available to the tall wheatgrass seedlings by up to 70% (Figures 3.12 to 3.15). This places a high degree of stress on the seedlings, and emphasizes the need to suppress the resident vegetation.

3.3.2.2 Resident Vegetation Aerial Dry Matter Accumulation

Aerial dry matter accumulation measurements were taken at the end of the season in each establishment year. While Poast and Gramoxone provided the greatest suppression of dry matter at Portage in 1991, a significant main plot x subplot interaction indicated that the resident vegetation dry matter production in the Gramoxone plots was greater in the scarified compared to the unscarified treatments at the end of the season (Figure 3.16a). Scarification may have aerated the soil and increased nutrient availability through mineralization of dead plant material in this instance. This is the only site at which scarification increased production in Gramoxone plots. The Poast treatment was unaffected by scarification treatment (Figure 3.16a).

At Gladstone in 1991, there were no significant interactions or scarification effects; however, a significant suppression treatment effect (Appendix 2, Table A2.5) indicated that nitrogen and check treatments generally had the highest dry matter accumulation, while the Poast treatment generally had the lowest (Figure 3.16b).

At Portage in 1992, the Round-up, Gramoxone, as well as the Poast treatments under scarification provided the best control of the resident vegetation (Figure 3.17a). Nitrogen fertilization increased dry matter accumulation, with the vegetation in the scarified nitrogen treatment being statistically greater than in the unscarified treatment (Figure 3.17a). The unscarified Poast treatment had higher dry matter accumulation than the scarified treatment.

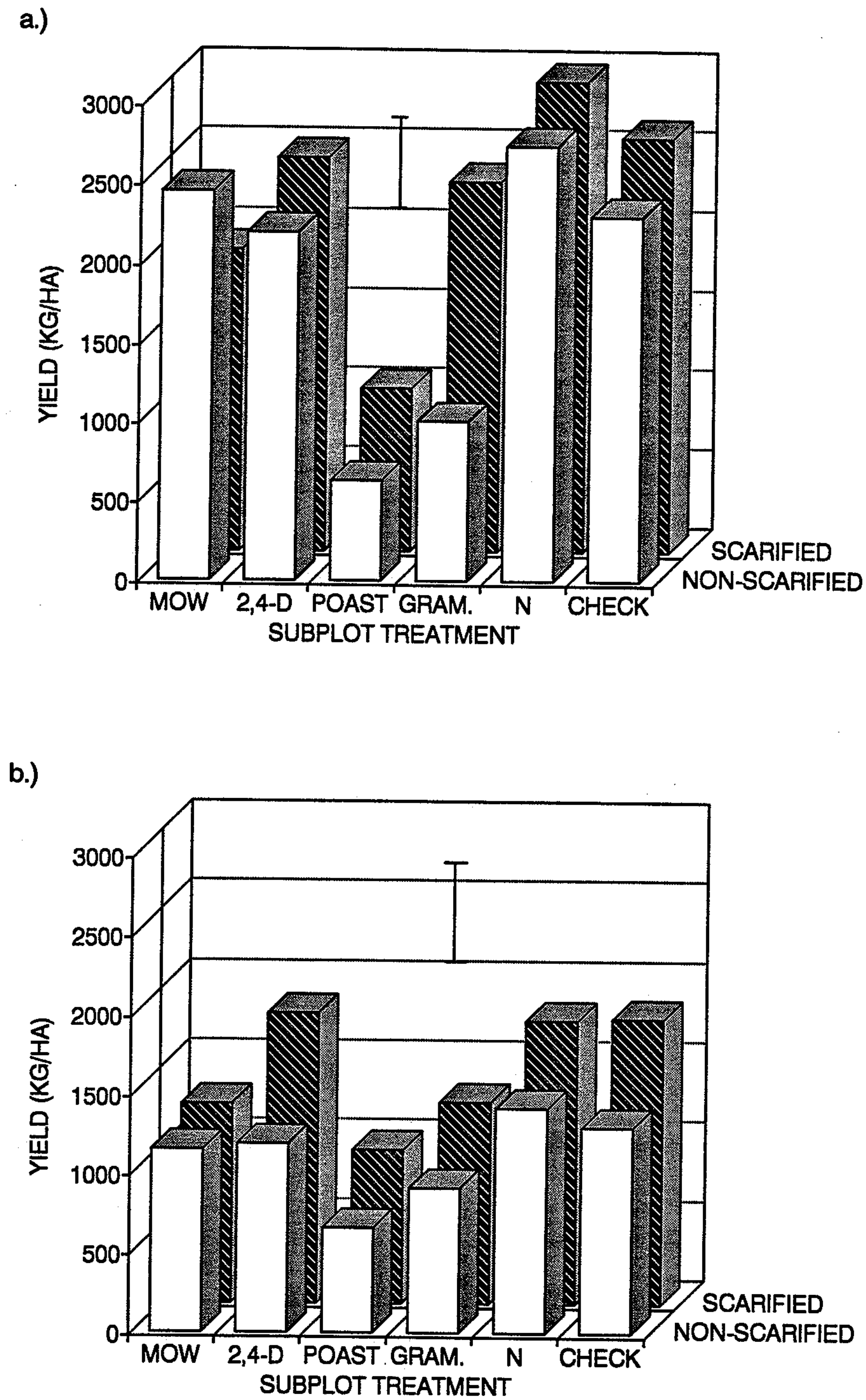
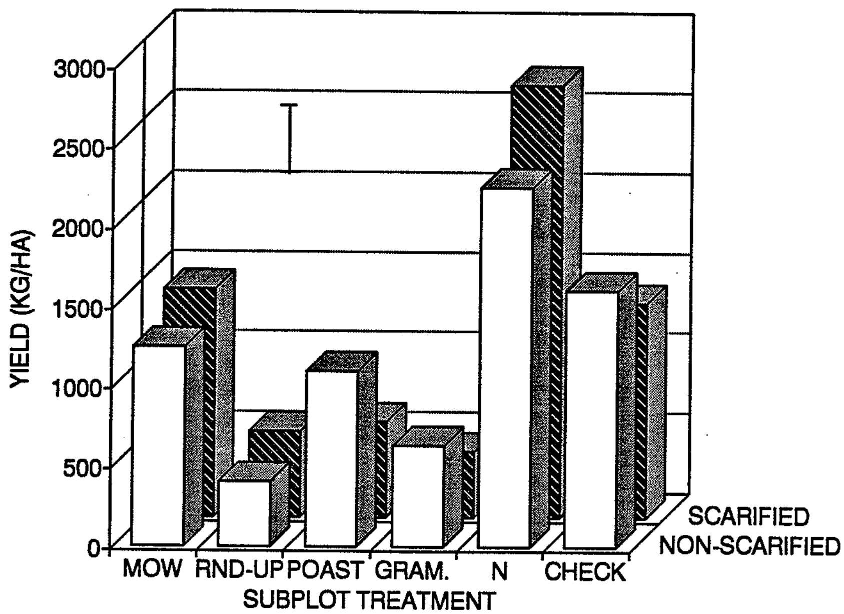


Figure 3.16 Influence of scarification and suppression treatment on aerial dry matter accumulation of the resident vegetation (kg/ha) in 1991 a.) 96 DAS at Portage La Prairie and b.) 101 DAS at Gladstone, MB. Vertical bars indicate LSD(0.10).

a.)



b.)

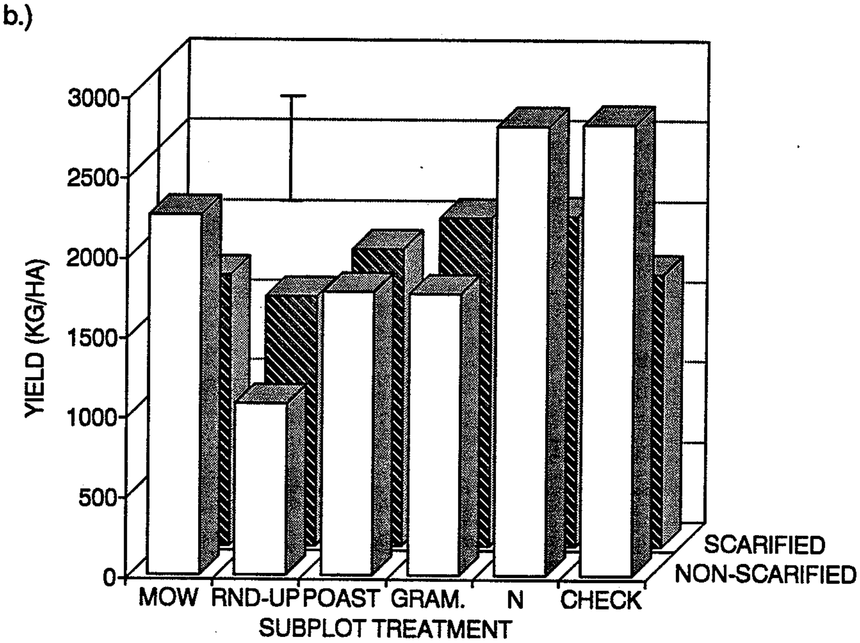


Figure 3.17 Influence of scarification and suppression treatment on aerial dry matter accumulation of the resident vegetation (kg/ha) in 1992 a.) 95 DAS at Portage La Prairie and b.) 86 DAS at Gladstone, MB. Vertical bars indicate LSD(0.10).

The resident vegetation dry matter accumulation appeared to be greater at Portage in 1991 as compared to 1992 (Figures 3.16a and 3.17a). This may be due to environmental conditions, as 1992 was cooler and drier than 1991 (Table 3.3).

At Gladstone in 1992, the Round-up treatment resulted in the lowest aerial dry matter accumulation of the resident vegetation (Figure 3.17b). Others have also found that glyphosate suppresses vegetation to a greater degree than either paraquat (Samson and Moser, 1982; Waddington and Bowren, 1976; Welty et al., 1981) or sethoxydim (Hagood, 1988; Malik and Waddington, 1990). Glyphosate has a longer duration of suppression than paraquat allowing more time for sod-seeded seedlings to germinate and become established (Squires, 1976). A significant main plot x subplot interaction at Gladstone in 1992 (Appendix 2, Table A2.5) was attributed to the fact that scarification decreased dry matter yields in nitrogen and check treatments, while other treatments were unaffected by scarification treatment (Figure 3.17b).

Of the treatments tested, herbicides provided the best suppression of the resident vegetation. Others also have found excellent suppression of the resident vegetation with these herbicides, increasing the establishment and development of sod-seeded grasses (Bowes and Zentner, 1992; Bush et al., 1989; Lee, 1965; Samson and Moser, 1982; Waddington and Bowren, 1976; Waller and Schmidt, 1983). The herbicide effect on the resident vegetation was fairly stable across scarification treatments, indicating that suppression by herbicides was not affected by a further mechanical suppression treatment. The 2,4-D and mowing treatments provided only poor suppression of the resident vegetation, as was seen with the light interaction effects (Section 3.3.2.1). Bentley and Clements (1989b) also reported that mowing did not successfully control the resident vegetation and did not reduce the plant competition.

To determine if light interception measurements were an indicator of competition from the resident vegetation, correlations were calculated between aerial dry matter and light interception measurements collected at approximately the same time. Significant positive relationships were found at all sites (0.879, 0.889, 0.908 and 0.802 at Portage in 1991 and 1992 and at Gladstone in 1991 and 1992, respectively) ($p=0.10$). It was thus possible to use light interception measurements as a measure of the degree of competition provided by the resident vegetation as opposed to measuring aerial dry matter accumulation, which was more time-consuming.

3.3.3 Tall Wheatgrass Establishment

No significant interactions, scarification or suppression treatment effects occurred at Portage in 1991 (Table 3.5). No significant interactions or suppression treatment effects were observed at Portage in 1992, although scarification effects occurred 27 DAS (Table 3.5). In this case, scarification increased tall wheatgrass densities. The general lack of treatment effects at Portage suggests that the resident vegetation was not competitive enough to reduce tall wheatgrass establishment. This is reflected in the fact that plant density was not significantly negatively correlated with either % light interception or dry matter accumulation of the resident vegetation (Tables 3.6 and 3.7).

Plant densities were higher in 1992 at Portage than in 1991 (Table 3.5). This may be due to less competition from the resident vegetation in 1992 compared to 1991 (Figures 3.16a and 3.17a). Also, soil moisture levels were higher during the establishment period in 1992 than in 1991 (Figures 3.9, 3.10a and 3.11a). As well, the soil in 1992 was higher in available NO_3-N, P and K than in 1991 (Appendix 1, Table A1.1).

The only significant effect at Portage in 1992 was the scarification effect 27 DAS (Table 3.5). A covariate analysis was conducted of the soil moisture and plant density count 27 DAS at Portage in 1992. Results did not change significantly from the analysis of variance (Appendix 2, Table A2.10), indicating that the observed scarification effect 27 DAS in 1992 was not due to soil moisture differences.

At Gladstone in 1991, no significant interactions or scarification effects occurred, although there were

Table 3.5 Influence of scarification and suppression treatment on tall wheatgrass density (plants m^{-2})* at Portage La Prairie, MB in 1991 and 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING 1991 36	69	92	128	1992 27	40	68	99
SCAR[z]	MOWING	25	21	18	21	70	76	73	68
SCAR[z]	2,4-D	30	24	19	24	-	-	-	-
SCAR[z]	ROUND-UP	-	-	-	-	65	66	64	63
SCAR[z]	POAST	24	14	13	18	46	49	50	49
SCAR[z]	GRAMOXONE	40	21	24	30	63	53	46	46
SCAR[z]	NITROGEN	24	23	18	23	60	65	63	61
SCAR[z]	CHECK	20	15	15	16	41	41	44	43
NO SCAR[z]	MOWING	15	15	9	11	51	60	60	54
NO SCAR[z]	2,4-D	34	25	21	20	-	-	-	-
NO SCAR[z]	ROUND-UP	-	-	-	-	53	54	48	53
NO SCAR[z]	POAST	15	11	10	9	46	43	41	40
NO SCAR[z]	GRAMOXONE	35	15	16	20	46	44	45	45
NO SCAR[z]	NITROGEN	34	31	26	25	38	48	50	46
NO SCAR[z]	CHECK	36	33	21	18	51	61	56	53
	Mean	28	21	18	20	53	55	53	52
$L.S.D._{(0.10)}$		23	15	12	18	27	26	27	25
MP		ns	ns	ns	ns	*	ns	ns	ns
SP		ns	ns	ns	ns	ns	ns	ns	ns
MP X SP		ns	ns	ns	ns	ns	ns	ns	ns

* significant at p=0.10
[z] scarification

suppression treatment effects on plant density on the last sampling date (112 DAS) (Table 3.8). The Poast treatment generally had the highest plant densities and the 2,4-D treatment the lowest.

Table 3.6 Correlation coefficients* between year of establishment parameters at Portage La Prairie, MB in 1991.

	Dry Matter of Res. Veg.[z]	Light Int. of Res. Veg.[y]	Plant Density	Haun Stage	Plant Height
Dry Matter of Res. Veg.[z]	-	0.879*	0.460	-0.698*	-0.316
Light Int. of Res. Veg.[y]	-	-	0.460	-0.716*	-0.282
Plant Density	-	-	-	0.018	0.188
Haun Stage	-	-	-	-	0.826*
Plant Height	-	-	-	-	-

* significant at p=0.10
z Dry Matter Accumulation of Resident Vegetation
y Light Interception of Resident Vegetation

Table 3.7 Correlation coefficients* between year of establishment parameters at Portage La Prairie, MB in 1992.

	Dry Matter of Res. Veg.[z]	Light Int. of Res. Veg.[y]	Plant Density	Haun Stage	Plant Height
Dry Matter of Res. Veg.[z]	-	0.889*	0.210	-0.859*	-0.692*
Light Int. of Res. Veg.[y]	-	-	0.125	-0.958*	-0.903*
Plant Density	-	-	-	-0.062	-0.204
Haun Stage	-	-	-	-	0.922*
Plant Height	-	-	-	-	-

* significant at p=0.10
z Dry Matter Accumulation of Resident Vegetation
y Light Interception of Resident Vegetation

Scarification significantly increased tall wheatgrass densities on the last two sampling dates at Gladstone in 1992 (76 and 106 DAS) (Table 3.8). Suppression treatment effects on plant densities occurred throughout the season (Table 3.8). The Gramoxone treatment consistently resulted in higher plant

Table 3.8 Influence of scarification and suppression treatment on tall wheatgrass density (plants m^{-2})* at Gladstone, MB in 1991 and 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING 1991 63	87	112	1992 36	58	76	106
SCAR[z]	MOWING	25	16	14	26	23	23	15
SCAR[z]	2,4-D	18	13	9	-	-	-	-
SCAR[z]	ROUND-UP	-	-	-	38	36	39	38
SCAR[z]	POAST	29	23	18	14	9	9	8
SCAR[z]	GRAMOXONE	40	25	18	56	56	54	49
SCAR[z]	NITROGEN	21	15	11	28	28	24	18
SCAR[z]	CHECK	20	19	13	40	43	40	29
NO SCAR[z]	MOWING	26	20	15	26	19	18	11
NO SCAR[z]	2,4-D	13	10	8	-	-	-	-
NO SCAR[z]	ROUND-UP	-	-	-	6	9	6	6
NO SCAR[z]	POAST	40	24	21	15	9	11	8
NO SCAR[z]	GRAMOXONE	18	19	13	36	28	26	19
NO SCAR[z]	NITROGEN	19	15	13	18	15	13	9
NO SCAR[z]	CHECK	24	18	10	23	16	15	9
	Mean	24	18	14	27	24	23	18
$L.S.D._{(0.10)}$		18	11	10	24	23	19	19
MP		ns	ns	ns	ns	ns	*	*
SP		ns	ns	*	*	*	*	*
MP X SP		ns	ns	ns	ns	*	*	*

* significant at p=0.10
[z] scarification

densities. Round-up and Gramoxone have been found to increase the establishment of forage grasses by several researchers (Bowes and Zentner, 1992; Samson and Moser, 1982; Waddington and Bowren, 1976). It was observed in the present experiment that Round-up required a greater length of time to suppress the resident vegetation, thus the quicker suppression provided by the Gramoxone may have benefitted establishment. Squires (1976) also reported that Round-up suppresses vegetation more slowly than Gramoxone.

Significant main plot x subplot interactions for tall wheatgrass establishment at Gladstone in 1992 indicated that suppression treatments responded differently to scarification treatments. Round-up, Gramoxone and the check treatments had higher plant densities under scarification than when not scarified, while other treatments were unaffected by scarification treatment (Table 3.8). Although scarification generally did not decrease the competition provided by the resident vegetation (Figures 3.15a and 3.17b), it may have changed the microclimate early in the season sufficiently to increase establishment in those treatments that suppressed the resident vegetation adequately (the Round-up and Gramoxone treatments).

Establishment of tall wheatgrass in the Poast, mowing and nitrogen treatments was not affected by scarification at Gladstone in 1992. Poast treatments had low densities regardless of the scarification treatment. Observations of greater legume establishment with glyphosate or paraquat compared with sethoxydim have been attributed to superior suppression of the resident vegetation by the former herbicides (Hagood, 1988; Malik and Waddington, 1990).

Higher plant densities were observed in 1992 at Portage as compared to Gladstone (Tables 3.5 and 3.8). This may be attributed to better soil moisture conditions (Figures 3.9 and 3.11) and less competition from the resident vegetation (Figure 3.17) at Portage. As well, the resident vegetation in Portage, being a bunchgrass (timothy), could not be expected to be as competitive as the rhizomatous species (mainly smooth bromegrass and Poa species) at Gladstone. These factors may have been the reason for successful establishment at Portage, even when the resident vegetation was not suppressed.

It has been stated that a plant population density of 65 plants m^{-2} is necessary for adequate dense nesting cover (Brent Wark, biologist Ducks Unlimited, personal communication). The only treatments that resulted in tall wheatgrass populations similar to 65 plants m^{-2} were the mowing, Round-up and nitrogen treatments under scarification at Portage in 1992. However, Robel pole measurements at Portage in 1992 do show that the 1991 stand did provide adequate cover the next season (Section 3.3.6.5). Therefore, adequate DNC may be obtained with fewer plants. Densities of 10 seedlings m^{-2} result in adequate forage grass stands (King et al., 1989; Launchbaugh, 1966; Peters et al., 1989; Samson and Moser, 1982). Many of the treatments did attain this level.

Correlations between plant establishment measured at the end of the season and the associated light interception and dry matter measurements were calculated (Tables 3.6, 3.7, 3.9

and 3.10). At Gladstone in 1991, tall wheatgrass establishment 112 DAS was correlated with the light interception measurement conducted 112 DAS and the dry matter measurement conducted 101 DAS. At this site, as the degree of competition from the resident vegetation increased, the number of established tall wheatgrass plants decreased (Table 3.9).

Table 3.9 Correlation coefficients* between year of establishment parameters at Gladstone, MB in 1991.

	Dry Matter of Res. Veg.[z]	Light Int. of Res. Veg.[y]	Plant Density	Haun Stage	Plant Height
Dry Matter of Res. Veg.[z]	-	0.908*	-0.614*	-0.061	-0.163
Light Int. of Res. Veg.[y]	-	-	-0.544*	-0.269	-0.273
Plant Density	-	-	-	0.433	0.098
Haun Stage	-	-	-	-	0.592*
Plant Height	-	-	-	-	-

* significant at p=0.10
[z] Dry Matter Accumulation of Resident Vegetation
[y] Light Interception of Resident Vegetation

Table 3.10 Correlation coefficients* between year of establishment parameters at Gladstone, MB in 1992.

	Dry Matter of Res. Veg.[z]	Light Int. of Res. Veg.[y]	Plant Density	Haun Stage	Plant Height
Dry Matter of Res. Veg.[z]	-	0.802*	-0.153	-0.437	-0.474
Light Int. of Res. Veg.[y]	-	-	-0.137	-0.583*	-0.600*
Plant Density	-	-	-	0.494	0.516*
Haun Stage	-	-	-	-	0.993*
Plant Height	-	-	-	-	-

* significant at p=0.10
[z] Dry Matter Accumulation of Resident Vegetation
[y] Light Interception of Resident Vegetation

No significant correlation coefficients were observed at Gladstone in 1992 or either year at Portage. No relationship was expected at Portage due to the fact that successful establishment occurred, regardless of whether the resident vegetation was suppressed or not. The lack of correlation at Gladstone in 1992 may be due to the fact that the Round-up treatment was shown to suppress the resident vegetation to the greatest extent at Gladstone in 1992, however, it was the Gramoxone treatment that led to the greatest establishment.

3.3.4 Tall Wheatgrass Development

3.3.4.1 Haun Stage Measurement

Morphological development of tall wheatgrass plants was determined using the Haun growth stage scale (Haun, 1973). Scarification affected the development rate of tall wheatgrass on many different occasions at both Portage and Gladstone in both years (Tables 3.11 and 3.12). In all cases, scarification increased tall wheatgrass development.

Scarification increased the Haun stage values even though it did not significantly suppress the resident vegetation. Although scarification did not suppress the resident vegetation or reduce the competition for light (Appendix 2,

Table 3.11 Influence of scarification and suppression treatment on tall wheatgrass development (Haun stage)* at Portage La Prairie, MB in 1991 and 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING 1991 36	69	92	128	1992 27	40	68	99
SCAR[z]	MOWING	1.9	3.3	4.2	5.9	1.4	2.1	3.3	4.8
SCAR[z]	2,4-D	1.8	3.8	4.0	6.4	-	-	-	-
SCAR[z]	ROUND-UP	-	-	-	-	1.4	2.4	5.5	8.7
SCAR[z]	POAST	1.9	4.0	6.0	8.9	1.4	2.2	4.6	7.3
SCAR[z]	GRAMOXONE	1.8	4.6	5.8	7.4	1.4	2.5	4.5	8.3
SCAR[z]	NITROGEN	1.6	3.9	3.4	4.6	1.4	2.1	3.0	3.3
SCAR[z]	CHECK	1.6	3.9	4.6	5.6	1.3	1.9	3.0	4.3
NO SCAR[z]	MOWING	1.8	3.6	5.3	5.3	1.2	1.8	2.5	3.1
NO SCAR[z]	2,4-D	1.4	3.0	2.9	4.6	-	-	-	-
NO SCAR[z]	ROUND-UP	-	-	-	-	1.2	2.0	3.6	8.8
NO SCAR[z]	POAST	1.7	3.0	4.3	6.7	1.2	1.9	3.0	5.2
NO SCAR[z]	GRAMOXONE	1.7	3.7	6.9	8.0	1.2	2.1	3.7	8.3
NO SCAR[z]	NITROGEN	1.4	3.1	3.3	4.4	1.1	1.7	2.2	3.1
NO SCAR[z]	CHECK	1.3	2.7	2.9	3.7	1.1	1.7	2.4	3.1
	Mean	1.7	3.6	4.5	6.0	1.3	2.0	3.4	5.7
$L.S.D._{(0.10)}$		0.3	1.1	1.9	1.3	0.2	0.4	1.2	2.7
MP		*	ns	ns	*	*	*	*	ns
SP		*	ns	*	*	ns	*	*	*
MP X SP		ns	ns	ns	ns	ns	ns	ns	ns

* significant at p=0.10
z scarification

Tables A2.1 to A2.5), it may have changed the microclimate around the seed or seedling early in the season. The effect of scarification on the resident vegetation may have dissipated before light interception and aerial dry matter

Table 3.12 Influence of scarification and suppression treatment on tall wheatgrass development (Haun stage)* at Gladstone, MB in 1991 and 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING 1991 63	87	112	1992 36	58	76	106
SCAR[z]	MOWING	2.6	3.3	3.6	1.2	1.7	1.5	1.5
SCAR[z]	2,4-D	1.6	2.7	3.6	-	-	-	-
SCAR[z]	ROUND-UP	-	-	-	2.0	4.3	6.1	5.8
SCAR[z]	POAST	2.6	3.6	4.0	1.4	1.6	1.7	1.4
SCAR[z]	GRAMOXONE	2.3	3.4	3.3	1.7	2.5	2.2	2.0
SCAR[z]	NITROGEN	2.1	3.1	2.7	1.3	1.7	1.5	1.4
SCAR[z]	CHECK	1.9	3.0	3.8	1.3	1.7	1.7	1.2
NO SCAR[z]	MOWING	1.8	3.0	2.5	1.2	1.5	1.3	1.3
NO SCAR[z]	2,4-D	2.0	3.0	1.7	-	-	-	-
NO SCAR[z]	ROUND-UP	-	-	-	1.6	2.0	2.2	2.6
NO SCAR[z]	POAST	2.0	3.6	3.4	1.1	1.5	1.3	1.2
NO SCAR[z]	GRAMOXONE	2.2	3.3	3.9	1.7	2.1	2.0	2.0
NO SCAR[z]	NITROGEN	1.6	3.2	3.2	1.0	1.6	1.3	1.2
NO SCAR[z]	CHECK	1.7	2.8	2.7	1.1	1.6	1.3	1.2
	Mean	2.0	3.2	3.2	1.4	2.0	2.0	1.9
$L.S.D._{(0.10)}$		0.5	0.5	1.5	0.3	0.8	1.1	1.3
MP		*	ns	ns	*	*	*	ns
SP		*	*	ns	*	*	*	*
MP X SP		*	ns	ns	ns	*	*	*

* significant at p=0.10
[z] scarification

accumulation measurements were conducted. As shading from the resident vegetation increases, air and soil temperatures decrease (Cooper, 1966). Scarification may have decreased the light competition sufficiently, breaking up the sod thatch, aerating the soil and decreasing shading, to increase temperature, which would then result in increased development. Several researchers (Frank and Hofmann, 1989; Fulbright et al., 1985; Hill et al., 1985; Hsu et al., 1985b) have found that temperature plays an important role in grass development.

Suppression treatments affected Haun measurements 36, 92 and 128 DAS at Portage in 1991 (Table 3.11). The number of leaves on plants in the Poast and Gramoxone treatments increased throughout the season. By the end of the season, both treatments resulted in plants with the highest Haun stage values. Significant suppression treatment effects at Gladstone in 1991 (Table 3.12), indicated that the mowing, Poast and Gramoxone treatments had the highest Haun values 63 DAS, while on the 87 DAS sampling date, the Poast treatment generally had the greatest Haun stage values and the 2,4-D and the check the lowest. At Portage in 1992, Haun stage values of plants in the Round-up and Gramoxone treatments increased during the growing season to a greater extent than in other treatments. By the end of the season, these treatments had the highest number of leaves per plant, while the mowing, nitrogen and check treatments had the lowest. The Poast thus provided an intermediate degree of suppression. A similar trend for Round-up was observed at Gladstone in 1992. Initially, both Round-up and Gramoxone treatments resulted in the greatest plant development. However, at the end of the season, only the Round-up treatment resulted in significantly higher Haun stage values than other treatments (Table 3.12). The greater competition suppression provided by Round-up at this site (Figures 3.15b and 3.17b) seemed to benefit grass development.

No significant interactions occurred at Portage in 1991 or 1992 (Table 3.11). At Gladstone in 1991, the Poast and mowing treatments had significantly higher Haun stage values 63 DAS when scarified than when not scarified (Table 3.12). At Gladstone in 1992, significant scarification x subplot interactions in a number of instances indicated that plants in the Round-up treatments which had undergone scarification consistently had higher Haun stages than plants in all other treatments (Table 3.12). No other treatments performed significantly better under scarification at any date at the Gladstone site in 1991 or 1992.

Chemical suppression was found to enhance plant development. This was true even in instances where chemical suppression did not affect plant density (Portage, Table 3.5). Higher Haun stage levels in the chemical treatments could be attributed to higher levels of soil moisture during emergence (Figures 3.10 and 3.11) or greater control of the resident vegetation (Figures 3.12 to 3.17). Others also have reported that chemical suppression of the resident vegetation will increase plant development and/or yields of sod-seeded plants (Bowes and Zentner, 1992; Bush et al., 1989; Roth et al., 1985). Plants at Gladstone had fewer leaves compared to plants grown at Portage (Tables 3.11 and 3.12). This may also be attributed to less competition from resident vegetation (Figure 3.17) and higher soil moisture conditions (Figures 3.9 to 3.11).

For perennial grasses, development of three or more leaves is desirable to reduce the risk of winterkill and to maximize regrowth the following season (White, 1984). This critical limit was achieved for all treatments in both years at Portage (Table 3.11). Tall wheatgrass plants at Gladstone, especially in 1992, did not always achieve this critical limit by the end of the growing season (Table 3.12). Therefore, the risk of winter injury and reduced regrowth would be expected to be high. At Gladstone in 1992, the only treatment to successfully reduce resident vegetation competition sufficiently, for maximum leaf development past this critical threshold, was the Round-up treatment under scarification (Table 3.12).

The Haun stage measurements at the end of the season were correlated with the light interception and dry matter measurements taken at approximately the same time (Tables 3.6, 3.7, 3.9 and 3.10). For example, at Portage in 1991, the Haun stage measurement determined 128 DAS was correlated with the light interception measurement conducted 128 DAS and the dry matter measurement conducted 96 DAS. Significant negative relationships were found at Portage in 1991 and 1992 and with the light interception at Gladstone in 1992 (Tables 3.6, 3.7

and 3.10). It was interesting to note that while light competition and dry matter were not correlated with establishment at Portage, they were correlated with plant development.

3.3.4.2 Tall Wheatgrass Height

Scarification effects occurred at Portage in 1991 and Gladstone in 1991 and 1992 (Tables 3.13 and 3.14). In each instance, scarification increased tall wheatgrass heights.

Suppression treatments affected plant height 92 and 128 DAS at Portage in 1991, with Gramoxone resulting in the tallest plants (Table 3.13). No significant suppression treatment effects occurred at Gladstone in 1991 (Table 3.14). At Portage in 1992, the chemical treatments generally resulted in the tallest plants (Table 3.13). The mowing, nitrogen and check treatments all had significantly shorter plants than other treatments at the end of the season (99 DAS). Bentley and Clements (1989b) reported that Italian ryegrass plants grown in plots where the resident vegetation was mowed were stunted. They attributed this to the fact that the competition from the resident vegetation had not been sufficiently reduced by the mowing treatment. A similar explanation would apply in the present study. At Gladstone in 1992, the suppression treatment affected plant heights on all dates (Table 3.14). Plants attained the greatest heights in the Round-up treatment. Thus, by the end of the first growing season, only the chemical suppression treatments significantly increased tall wheatgrass heights.

Table 3.13 Influence of scarification and suppression treatment on tall wheatgrass height (cm)* at Portage La Prairie, MB in 1991 and 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING 1991 36	69	92	128	1992 27	40	68	99
SCAR[z]	MOWING	7.2	11.6	16.9	19.8	6.4	8.7	14.0	16.6
SCAR[z]	2,4-D	7.9	17.2	17.5	24.5	-	-	-	-
SCAR[z]	ROUND-UP	-	-	-	-	7.2	9.5	13.6	20.4
SCAR[z]	POAST	7.7	13.7	15.3	23.6	6.8	9.5	14.7	22.1
SCAR[z]	GRAMOXONE	9.1	13.1	19.4	23.4	7.6	10.1	13.6	22.1
SCAR[z]	NITROGEN	8.6	13.1	14.3	16.2	7.3	9.3	13.8	17.8
SCAR[z]	CHECK	7.5	16.5	15.3	19.8	7.4	8.5	12.2	17.4
NO SCAR[z]	MOWING	7.5	11.4	15.7	21.4	6.6	7.7	10.6	13.7
NO SCAR[z]	2,4-D	7.0	8.2	11.3	15.4	-	-	-	-
NO SCAR[z]	ROUND-UP	-	-	-	-	7.1	9.9	14.2	23.0
NO SCAR[z]	POAST	6.7	6.0	8.9	18.3	8.2	9.0	13.0	18.7
NO SCAR[z]	GRAMOXONE	8.3	12.4	19.3	24.3	7.4	10.0	15.1	24.0
NO SCAR[z]	NITROGEN	7.7	13.2	15.8	17.8	6.8	9.2	13.0	15.4
NO SCAR[z]	CHECK	6.3	8.9	9.9	14.1	7.5	8.3	10.8	13.9
	Mean	7.6	12.1	15.0	19.9	7.2	9.1	13.2	18.8
$L.S.D._{(0.10)}$		1.9	4.7	5.1	3.6	1.8	1.8	3.4	6.0
MP		ns	*	*	*	ns	ns	ns	ns
SP		ns	ns	*	*	ns	*	*	*
MP X SP		ns	*	ns	*	ns	ns	ns	ns

* significant at p=0.10
[z] scarification

Table 3.14 Influence of scarification and suppression treatment on tall wheatgrass height (cm)* at Gladstone, MB in 1991 and 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING 1991 63	87	112	1992 36	58	76	106
SCAR[z]	MOWING	8.3	7.5	11.6	4.6	6.1	6.4	6.6
SCAR[z]	2,4-D	6.1	6.9	6.7	-	-	-	-
SCAR[z]	ROUND-UP	-	-	-	7.0	13.8	20.9	27.2
SCAR[z]	POAST	9.9	8.5	7.6	3.1	5.2	6.2	7.8
SCAR[z]	GRAMOXONE	9.8	8.4	4.9	6.4	9.6	11.6	10.0
SCAR[z]	NITROGEN	9.0	7.9	6.4	5.1	6.4	6.6	5.0
SCAR[z]	CHECK	7.1	7.0	7.2	5.7	5.9	6.8	6.3
NO SCAR[z]	MOWING	5.5	6.3	5.4	3.9	5.0	5.2	5.6
NO SCAR[z]	2,4-D	6.4	5.4	5.3	-	-	-	-
NO SCAR[z]	ROUND-UP	-	-	-	4.7	7.3	8.9	11.5
NO SCAR[z]	POAST	6.7	7.0	6.9	3.1	4.4	4.7	6.0
NO SCAR[z]	GRAMOXONE	6.8	4.5	9.8	4.4	7.2	8.0	10.3
NO SCAR[z]	NITROGEN	5.5	6.7	6.7	3.0	5.1	4.4	4.9
NO SCAR[z]	CHECK	5.4	4.8	5.0	3.3	4.9	4.0	4.8
	Mean	7.2	6.7	7.0	4.5	6.7	7.8	8.8
$L.S.D._{(0.10)}$		3.0	2.7	4.6	1.8	1.9	3.5	5.4
MP		*	*	ns	*	*	*	*
SP		ns	ns	ns	*	*	*	*
MP X SP		ns	ns	ns	ns	*	*	*

* significant at p=0.10
z scarification

At Portage in 1991, significant main plot x subplot interactions occurring 69 and 128 DAS indicated that the 2,4-D, Poast and check treatments performed significantly better in the scarified compared with unscarified plots, while other treatments were not affected by scarification (Table 3.13). No significant interactions occurred at Gladstone in 1991 or at Portage in 1992. At Gladstone in 1992, significant main plot x subplot interactions occurred 58, 76 and 106 DAS (Table 3.14). The treatment of Round-up with scarification had the tallest wheatgrass plants as compared to all other treatments. Other than the Gramoxone 58 DAS, scarification did not significantly influence plant height in the other treatments.

In 1992, the Gladstone site had greater increases in plant height with Round-up than the Portage site (Tables 3.13 and 3.14). The Gladstone site provided a less favourable growing environment, and thus, plants at Gladstone may have benefitted more from competition reduction. The Portage location seemed to have a higher soil moisture in 1992 than at Gladstone (Figures 3.9b and 3.11) and the resident vegetation at Portage (timothy) was less competitive than at Gladstone (mainly smooth bromegrass and Poa species).

Significant negative correlations occurred between plant height measured at the end of the season and the corresponding light competition and dry matter measurements at Portage in 1992 and between light interception and plant height at Gladstone in 1992 (Tables 3.7 and 3.10). Temperatures and precipitation (especially early-season precipitation at Portage) were lower in 1992 than in 1991 (Tables 3.3 and 3.4) and the resident vegetation dry matter accumulation appeared to be greater in 1992 (Figures 3.16 and 3.17), causing more adverse growing conditions. This may have caused an increased plant response to suppression of the resident vegetation in 1992 as compared to 1991.

3.3.5 In-season Tall Wheatgrass Survival Rates

In-season plant survival rates were monitored in 1992 trials only. Survival rates varied from 32-99% throughout the season and were higher at Portage than at Gladstone (Table 3.15). The latter observation was attributed to increased soil moisture (Figures 3.9b and 3.11) and decreased competition from the resident vegetation (Figure 3.17) at Portage.

No significant interactions, scarification or suppression treatment effects were observed in the trial at Portage in 1992 (Table 3.15). Nor were there any significant main plot x subplot interactions at Gladstone in 1992. Significant scarification effects at Gladstone, however, indicated that scarification improved the in-season survival of tall wheatgrass between the first two dates, 36-58 and 58-76 DAS (Table 3.15). The beneficial effect of the superior vegetation suppression provided by Round-up is quite evident when viewing the tall wheatgrass survival rates at Gladstone. The Round-up treatments had the highest survival rates.

Table 3.15 Influence of scarification and suppression treatment on in-season survival (%)* between the dates shown at Portage La Prairie and Gladstone, MB in 1992.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING					
		PORTAGE			GLADSTONE		
		27-40	40-68	68-99	36-58	58-76	76-106
SCAR[z]	MOWING	98	89	88	80	82	62
SCAR[z]	ROUND-UP	92	90	96	89	93	97
SCAR[z]	POAST	96	87	90	65	74	63
SCAR[z]	GRAMOXONE	87	85	91	88	92	89
SCAR[z]	NITROGEN	92	93	97	79	90	68
SCAR[z]	CHECK	90	94	91	82	87	70
NO SCAR[z]	MOWING	91	87	91	65	79	46
NO SCAR[z]	ROUND-UP	90	88	96	89	66	88
NO SCAR[z]	POAST	80	82	93	47	66	58
NO SCAR[z]	GRAMOXONE	87	88	99	78	81	71
NO SCAR[z]	NITROGEN	88	90	90	32	82	43
NO SCAR[z]	CHECK	93	87	92	54	79	66
	Mean	90	88	93	71	81	68
$L.S.D._{(0.10)}$		12	12	9	22	16	21
MP		ns	ns	ns	*	*	ns
SP		ns	ns	ns	*	ns	*
MP X SP		ns	ns	ns	ns	ns	ns

* significant at p=0.10
[z] scarification

Correlations between the Haun stage measurement and the percent in-season survival in 1992 were calculated to determine if the morphological development of the plant affected plant survival. Significant correlations did not occur at Portage, however, positive correlations were detected for the Gladstone site (Table 3.16). The data did not seem to indicate a critical leaf number for maximum in-season survival due to too much scatter of the data.

Table 3.16 Correlation coefficients* between in-season survival and Haun stage in year of establishment at Portage La Prairie and Gladstone, MB.

			Date 1[z] Haun Stage	Date 2[y] Haun Stage	Date 3[x] Haun Stage
Portage	1992	Survival	0.150	-0.064	0.428
Gladstone	1992	Survival	0.526*	0.420	0.733*

* significant at p=0.10
[z] Portage = 40 DAS Gladstone = 58 DAS
[y] Portage = 68 DAS Gladstone = 76 DAS
[x] Portage = 99 DAS Gladstone = 106 DAS

3.3.6 Year After Establishment Measurements

Plant density, Haun stage, height and survival measurements were conducted at Portage 364 DAS in 1992 on the experiments established in 1991. Robel pole measurements of 1991 studies were taken in the fall of 1992. While scarification and suppression treatment effects were significant, no significant main plot x subplot interactions occurred at Portage for any of the measurements. Therefore, scarification and suppression treatments affected year-after-establishment measurements independently. Measurements were also taken in the spring of 1993 on the experiments established in 1992. These were conducted 379 DAS at Portage and 398 DAS at Gladstone. No significant main plot x subplot interactions occurred at Portage in 1993.

3.3.6.1 Overwinter Survival

Overwinter survival was measured in 1993. There were no significant treatment effects at Portage, nor were there any interactions or scarification effects at Gladstone (Table 3.17). However, a significant suppression effect at Gladstone

Table 3.17 Influence of scarification and suppression treatment on overwinter survival (%)* at Portage La Prairie and Gladstone, MB in 1993.

HARROWING SYSTEM	SUBPLOT TREATMENT	DAYS AFTER SEEDING	
		PORTAGE	GLADSTONE
		379	398
SCAR[z]	MOWING	91	28
SCAR[z]	ROUND-UP	95	85
SCAR[z]	POAST	93	45
SCAR[z]	GRAMOXONE	90	51
SCAR[z]	NITROGEN	94	24
SCAR[z]	CHECK	93	28
NO SCAR[z]	MOWING	90	8
NO SCAR[z]	ROUND-UP	97	43
NO SCAR[z]	POAST	83	33
NO SCAR[z]	GRAMOXONE	92	22
NO SCAR[z]	NITROGEN	72	25
NO SCAR[z]	CHECK	88	13
	Mean	90	34
$L.S.D._{(0.10)}$		12	35
MP		ns	ns
SP		ns	*
MP X SP		ns	ns

* significant at p=0.10
[z] scarification

in 1993 indicated that overwinter survival was significantly greater in Round-up treatments (Table 3.17). In fact, only the Round-up treatment under scarification resulted in an overwinter survival rate above 50% (Table 3.17).

The effect of the different environments and growing conditions between sites is again apparent, with the overwinter survival rate at Portage being 2-3 times greater than at Gladstone (Table 3.17), largely due to the more aggressive resident vegetation found at Gladstone. This may also be due in part to differences in precipitation between the two sites during the coldest months of the year (December to April), causing differences in the snow cover (Appendix 1, Tables A1.2 to A1.4).

The relationship between fall Haun stage and overwinter survival (Table 3.18) indicated that a critical leaf number of three leaves was required for maximum overwinter survival (Figure 3.18). This corresponds with observations by White (1984) and White and Currie (1980). In the present study,

Table 3.18 Correlation* between establishment year Haun stage and performance of tall wheatgrass in year after establishment (data combined over sites and years).

Year After Establishment	Haun Stage (Establishment Year)
Overwinter Survival	0.800*
Plant Density	0.476*
Haun Stage	0.909*

* significant at p=0.10

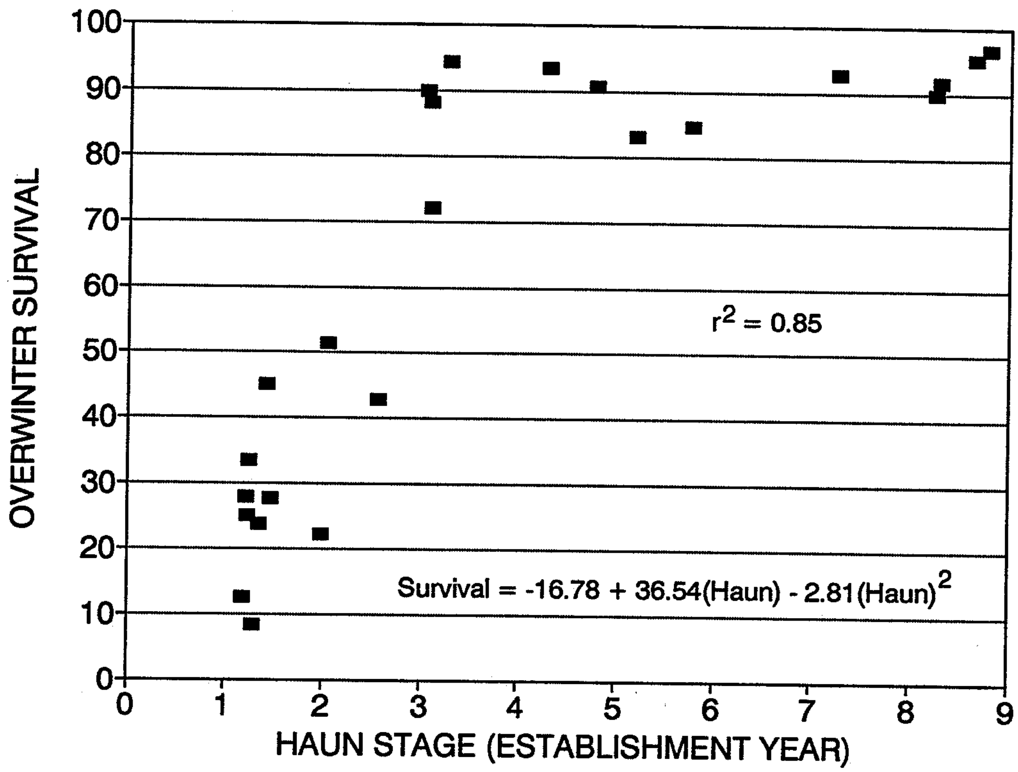


Figure 3.18 Relationship between tall wheatgrass fall Haun stage (establishment year) and overwinter survival.

plants with less than three leaves had less than 60% survival (Figure 3.18). These observations may explain the significant Round-up effect at Gladstone, as Round-up was the only treatment to achieve a Haun stage above 3 by the end of the first season (Table 3.12).

3.3.6.2 Year After Establishment Plant Population Density

In 1992, there were no significant differences in tall wheatgrass plant densities at Portage early in the season, indicating no significant differences between treatments after the first winter (Table 3.19). Significant scarification effects for plant density at Portage in 1993 indicated that scarification in 1992 increased plant density in 1993. No significant suppression effects were observed at Portage in 1993 (Table 3.19).

At Gladstone in 1993, a significant main plot x subplot interaction indicated that plant densities were higher in the Round-up and Gramoxone treatments under scarification than under non-scarification conditions, while other treatments were unaffected by scarification treatment (Table 3.19). In fact, there were virtually no plants in the unscarified treatment, regardless of herbicide used. At Gladstone, only Round-up and Gramoxone under scarification produced anything close to an acceptable plant population density for DNC (Table 3.19). This was attributed to greater first-year suppression

Table 3.19 Influence of scarification and suppression treatment on year after establishment tall wheatgrass density (plants m^{-2})* at Portage La Prairie and Gladstone, MB in 1992 and 1993.

		DAYS AFTER SEEDING		
		PORTAGE		GLADSTONE
HARROWING	SUBPLOT	1992	1993	1993
SYSTEM	TREATMENT	364	379	398
SCAR[z]	MOWING	9	60	3
SCAR[z]	2,4-D	15	-	-
SCAR[z]	ROUND-UP	-	60	30
SCAR[z]	POAST	8	53	1
SCAR[z]	GRAMOXONE	14	36	24
SCAR[z]	NITROGEN	20	54	3
SCAR[z]	CHECK	9	36	6
NO SCAR[z]	MOWING	16	48	1
NO SCAR[z]	2,4-D	15	-	-
NO SCAR[z]	ROUND-UP	-	44	3
NO SCAR[z]	POAST	15	36	3
NO SCAR[z]	GRAMOXONE	18	48	5
NO SCAR[z]	NITROGEN	11	36	1
NO SCAR[z]	CHECK	14	48	1
	Mean	14	47	7
$L.S.D._{(0.10)}$		17	22	9
MP		ns	*	*
SP		ns	ns	*
MP X SP		ns	ns	*

* significant at p=0.10
[z] scarification

of the resident vegetation with these herbicides (Figure 3.15b and 3.17b). Results from the Gladstone site suggest that where competition from the resident vegetation is intense, only superior suppression of the resident vegetation will produce an acceptable tall wheatgrass plant population density in the year after establishment.

The initial suppression provided by the scarification in the year of establishment did affect the development and in-season survival of the tall wheatgrass plants (Tables 3.11 to 3.15). Scarification may have had effects other than those of suppressing the resident vegetation in the year of establishment, such as aerating the soil and making more nutrients available as it may have broken up the organic matter and manure present at this site.

The density of plants in the year after establishment was positively correlated with the plant morphological development at the end of the first season (Table 3.18). This is in accordance with White (1984) and White and Currie (1980), who found that as the number of leaves of crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass and Russian wild ryegrass seedlings found in the fall increased, the greater the overwinter survival. A critical fall plant leaf number for tall wheatgrass density for the following season could not be determined, due to too much scatter of the data.

3.3.6.3 Year After Establishment Plant Leaf Number

No significant interactions or scarification effects for Haun stage were observed in 1992 or in 1993 (Table 3.20).

While there were no significant suppression effects at Gladstone in 1993, significant suppression treatments at Portage in 1992 and 1993 indicated that Poast and Gramoxone

Table 3.20 Influence of scarification and suppression treatment on year after establishment tall wheatgrass development (Haun stage)* at Portage La Prairie and Gladstone, MB in 1992 and 1993.

		DAYS AFTER SEEDING		
		PORTAGE		GLADSTONE
HARROWING	SUBPLOT	1992	1993	1993
SYSTEM	TREATMENT	364	379	398
SCAR[z]	MOWING	5.1	6.1	1.5
SCAR[z]	2,4-D	6.0	-	-
SCAR[z]	ROUND-UP	-	8.1	4.9
SCAR[z]	POAST	8.2	9.3	3.3
SCAR[z]	GRAMOXONE	7.2	7.2	2.1
SCAR[z]	NITROGEN	4.3	4.8	1.3
SCAR[z]	CHECK	3.3	4.2	1.2
NO SCAR[z]	MOWING	5.4	4.6	1.0
NO SCAR[z]	2,4-D	5.8	-	-
NO SCAR[z]	ROUND-UP	-	8.2	1.8
NO SCAR[z]	POAST	6.8	4.5	1.7
NO SCAR[z]	GRAMOXONE	7.5	5.3	2.6
NO SCAR[z]	NITROGEN	5.5	3.0	1.7
NO SCAR[z]	CHECK	5.1	4.7	1.0
	Mean	5.9	5.8	2.0
$L.S.D._{(0.10)}$		3.7	3.3	1.9
MP		ns	ns	ns
SP		*	*	ns
MP X SP		ns	ns	ns

* significant at p=0.10
[z] scarification

(1992) and Round-up (1993) generally had the highest Haun stage measurements the year after establishment (Table 3.20).

The average spring Haun scale measurements at Gladstone was less than half of those at Portage (Table 3.20). Growth of three or more leaves has been stated to be a critical threshold for the least winter damage and maximum regrowth the next season (White, 1984). Plants at Gladstone rarely achieved this threshold, whereas those at Portage did (Tables 3.11 and 3.12).

A relationship was found between the morphological stage of the plants at the end of the first season and the development the following spring (Table 3.18). Significant correlations occurring suggested that the greater the number of tall wheatgrass leaves in fall, the greater the development the following spring (Table 3.18). In fact, it was reported that seedling development had a greater effect on regrowth than winter injury (White, 1984). A critical fall plant leaf number for tall wheatgrass development for the following season could not be determined due to too much scatter of the data.

3.3.6.4 Year After Establishment Plant Height

There were no significant scarification effects for second-year tall wheatgrass heights at any of the sites (Table 3.21). Significant suppression effects were observed at all three sites. The Round-up (Portage 1993 and Gladstone 1993), Gramoxone (Portage 1992 and Gladstone 1993) and Poast (Portage 1993) generally had the tallest plants, while the nitrogen and

Table 3.21 Influence of scarification and suppression treatment on year after establishment tall wheatgrass height (cm)* at Portage La Prairie and Gladstone, MB in 1992 and 1993.

		DAYS AFTER SEEDING		
		PORTAGE		GLADSTONE
HARROWING	SUBPLOT	1992	1993	1993
SYSTEM	TREATMENT	364	379	398
SCAR[z]	MOWING	20.1	22.4	4.6
SCAR[z]	2,4-D	17.5	-	-
SCAR[z]	ROUND-UP	-	23.4	17.7
SCAR[z]	POAST	22.5	27.4	9.6
SCAR[z]	GRAMOXONE	23.7	24.3	9.6
SCAR[z]	NITROGEN	15.1	20.1	4.5
SCAR[z]	CHECK	15.6	20.7	5.0
NO SCAR[z]	MOWING	19.6	17.1	2.1
NO SCAR[z]	2,4-D	20.1	-	-
NO SCAR[z]	ROUND-UP	-	25.8	11.8
NO SCAR[z]	POAST	20.8	20.8	5.7
NO SCAR[z]	GRAMOXONE	24.9	20.2	15.9
NO SCAR[z]	NITROGEN	17.4	14.3	9.0
NO SCAR[z]	CHECK	19.2	17.3	4.1
	Mean	19.7	21.2	8.3
$L.S.D._{(0.10)}$		6.9	6.7	7.1
MP		ns	ns	ns
SP		*	*	*
MP X SP		ns	ns	*

* significant at p=0.10
[z] scarification

check treatments generally produced the shortest plants in both 1992 and 1993 at Portage.

3.3.6.5 Robel Pole Measurements

Robel pole measurements were conducted the year after establishment at Portage in 1992 only. Residual cover attaining a Robel pole height of 20 cm or more provides adequate nesting cover (Duebbert et al., 1981). While all treatments tested in this study achieved this height, a significant suppression effect indicated that the Poast and Gramoxone treatments resulted in superior cover (Figure 3.19). Greater visual obstruction in these treatments was attributed to superior suppression of the resident vegetation (Figures 3.12b and 3.16a) and increased soil water (Figure 3.10a) in the year of establishment (1991). Although tall wheatgrass densities were not found to be influenced by Gramoxone and Poast in the year of establishment (Table 3.5), the Robel pole measurements suggest that by the end of the second season, chemical suppression increased the density and rankness of the stand. Results of this study suggest that while scarification increased some growth parameters at Portage, visual obstruction was only significantly increased through the use of chemical suppression, as there were no significant interactions or scarification effects (Appendix 2, Table A2.28).

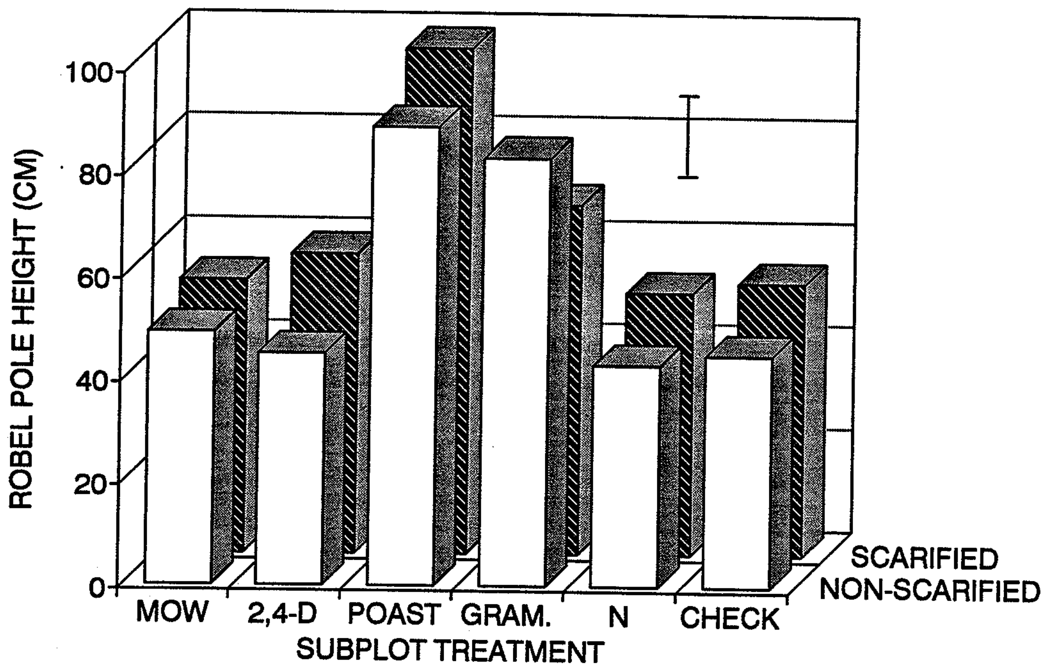


Figure 3.19 Influence of scarification and suppression treatment on Robel pole measurements in 1992 at Portage La Prairie, MB. Vertical bars indicate LSD(0.10).

3.4 Conclusions

Results at Portage indicate that in this growing environment, chemical suppression did not enhance plant population density or survival in the year of establishment and in the successive year. However, chemical suppression did increase plant development and significantly increased the denseness of the stand, according to the Robel pole measurements. Scarification was found to increase plant development at both sites. At Gladstone, chemical suppression was necessary for successful plant establishment, development and survival both in the establishment year and in the following year. Mowing did not result in sufficient reduction of competition to increase establishment, development or survival of plants.

Plants were required to develop to a critical leaf number of three leaves by the end of the first growing season for maximum overwinter survival. This critical limit was achieved in both years at Portage, however, tall wheatgrass plants at Gladstone, especially in 1992, did not always achieve this stage. At Gladstone in 1992, the treatment of Round-up under scarification was the only treatment to result in plants with three leaves or greater.

4.0 EVALUATION OF SOD-SEEDED GRASSES

4.1 Introduction

Sod-seeded grass seedlings face more adverse growing conditions than conventionally-planted seedlings, mainly because of competition from resident vegetation. It is not known whether all grasses respond similarly to the stresses associated with sod-seeding. It may be possible that some desirable DNC grass species would require a tilled seedbed for successful establishment. The objective of this study was to compare the relative response of switchgrass (Panicum virgatum L.), green needlegrass (Stipa viridula Trin.), tall wheatgrass [Thinopyrum ponticum (Podp.) Barkw. & D.R. Dewey], and northern wheatgrass [Elymus lanceolatus (Scribner & J.G. Smith) Gould] to seedbed preparation techniques. Studies were conducted in the field and under controlled environment conditions.

4.2 Methodology - Controlled Environment Study

4.2.1 Trial Establishment

An experiment was established to compare growth and development of a number of grass species under simulated sod-seeding and conventional seeding conditions. Soil was collected from the same Portage La Prairie and Gladstone locations as in Experiment 1. Intact soil cores were collected in aluminum pipes (12 cm wide and approximately 21 cm long) that were pushed into the soil and then removed. Disturbed soil was collected from the same sites. The disturbed soil was sieved through screens to remove the resident vegetation. Aluminum pipes were then filled with soil. During the potting process, care was taken to ensure that bulk densities were similar in the disturbed and intact soil pots. The bulk densities of undisturbed cores and disturbed soil pots at Portage were 1.1 and 1.2 g cm^{-3}, respectively. At Gladstone, the bulk densities of sod treatments and of potted bare soil treatments were 1.2 and 1.1 g cm^{-3}, respectively. Undisturbed cores (containing both soil and resident vegetation) were collected from Portage and Gladstone in the fall of 1991. All cores were left outside and covered with snow between time of sample collection and November 7, 1991 to simulate a winter period. Tubes were then moved to a growth room with a 8°/6°C day/night temperature regime. To simulate a spring period, the temperature was raised over a period of five weeks to a 21°/16°C regime. Throughout the study, cores were irrigated daily to keep pots wet to eliminate water as a limiting factor.

The experimental design was a factorial randomized complete block design, replicated four times. The treatments consisted of the different grass species: switchgrass (cv.

Dacotah), green needlegrass (cv. Lodorm), tall wheatgrass (common seed), and northern wheatgrass (cv. Critana). Seeds were pre-germinated in petri dishes and seeded to a depth of two centimetres at the rate of 10 seeds per pot.

4.2.2 Measurements

Measurements of plant emergence and development (height and Haun stage) were taken every two days for the first week after planting. Measurement frequency was then reduced to once a week, and eventually to once every ten to fourteen days. At the end of the experiment (62 DAS for Portage soil and 48 DAS for Gladstone soil), aerial dry matter accumulation of five of the seedlings and of the resident vegetation was measured. The plants and resident vegetation were harvested at soil level. The samples were oven-dried at 80°C for a minimum of forty-eight hours and then weighed.

Root number per plant was determined on five randomly selected grass plants in each pot. The grasses were excavated to a 10 cm depth on the same date vegetation was sampled for dry matter. Roots were then stored in the freezer until measured. Newman and Moser (1988b) suggested excavating seedlings to determine the number of adventitious roots in addition to measuring dry matter accumulation. It has been suggested that plants with four adventitious roots can survive the winter period (Brent Wark, biologist Ducks Unlimited, personal communication). For this reason, the percentage of plants with roots greater than 4 was determined and analyzed statistically.

4.2.3 Statistical Analysis

Results were analyzed using the GLM procedure of the Statistical Analysis Systems (SAS Institute, North Carolina, 1985). Means were separated using the Fischer Protected Least Significance Difference test, at a probability level of alpha=0.10 after the GLM indicated significant differences (p=0.10). Significant interaction mean separations were calculated according to Gomez and Gomez (1984).

4.3 Methodology - Field Study

4.3.1 Trial Establishment and Management

Field trials were conducted in 1992 at Portage La Prairie and Gladstone, MB to investigate the response of the four grass species to seedbed preparation technique. The soil type, type of resident vegetation and fertilizer regime was similar to those of Experiment 1 (Section 3.2.1).

The experimental design in both cases was a split plot design, with seedbed preparation treatments as the main plots and grass species as the subplots. The main plot treatments included a fall tillage treatment, a chemical suppression treatment, conducted in the spring, and an unsuppressed control. The subplot treatments consisted of the same perennial grass species used in the indoor study: switchgrass, green needlegrass, tall wheatgrass and northern wheatgrass. Both experiments were replicated four times. The size of the subplots was 2 x 10 meters.

The fall tillage treatment consisted of passing over the field with a rotovator in the fall (twice at Gladstone and once at Portage). Treatments were harrowed in the spring prior to seeding to smooth the seedbed. The chemical suppression treatment consisted of glyphosate at a rate of 2.5 L ha^{-1} [890 g active ingredient (a.i.) ha^{-1}] in 100 L ha^{-1} of water. The treatment was applied three days before seeding at Gladstone and one day before seeding at Portage.

Both sites were seeded on May 14, 1992. Grasses were seeded at a rate of 10 kg ha^{-1}: 1037 viable seeds m^{-2} of switchgrass, 362 viable seeds m^{-2} of green needlegrass, 185 viable seeds m^{-2} of tall wheatgrass and 369 viable seeds m^{-2} of northern wheatgrass. All grasses were seeded to a depth of 1.5 to 2.5 cm using a Connor Shea Coulter Coil Tyne sod-seeding drill (row spacing was 15 cm). The same drill was used for the fall tillage and the sod-seeded plots to avoid possible confounding effects that would arise from using different drills. The soil was packed twice after seeding (using a lawn packer) to improve seed-to-soil contact.

Appropriate pest control measures were conducted every year (Table 4.1). Rotovated plots suppress the sward to a greater degree than herbicides, but can produce a looser seedbed and can allow for weed infestation (Waddington and Bowren, 1976). Annual weeds and Canada thistle were controlled periodically in the tillage treatments. The area at Gladstone was fenced to exclude cattle.

Table 4.1 Pesticides applied in field experiments at Portage La Prairie and Gladstone, MB in 1992.

Location	Date	Pesticide	Rate (L product ha^{-1})
		Herbicides	
Portage	May 13	Round-up	2.5
	June 19	Lontrel	1.0
	July 12	Lontrel	1.5
Gladstone	May 11	Round-up	2.5
	June 9	Buctril M	1.0
	July 12	Buctril M	1.0
		Insecticide	
Gladstone	June 9	Sevin XLR (Carbaryl)	2.5

4.3.2 Measurements

4.3.2.1 Environmental Conditions

Daily maximum, minimum and mean air temperature, and precipitation were measured as described in Experiment 1 (Section 3.2.2.1). Gravimetric soil water content between 0 and 10 cm was measured at weekly intervals during the emergence period in all of the main plot treatments. Soil samples were oven-dried at 80°C for a minimum of forty-eight hours, and then weighed to calculate the gravimetric water content.

4.3.2.2 Resident Vegetation

The degree of light interference by the resident vegetation was monitored throughout the growing season in the unsuppressed and chemically suppressed plots, using the technique described in Experiment 1 (Section 3.2.2.2). Aerial dry matter accumulation of the resident vegetation was measured at the end of the growing season only (82 DAS at Portage and 85 DAS at Gladstone), using methods similar to Experiment 1 (Section 3.2.2.2).

4.3.2.3 Plant Establishment, Development, Growth and Survival

Forage establishment, development, and in-season survival were determined four to five times a season on plants growing in two one-meter rows per plot. Measurements were conducted as described in Experiment 1 (Section 3.2.2.3).

Aerial dry matter accumulation of grass species was measured 109 DAS at Portage and 113 DAS at Gladstone. One quarter-metre square area was hand-harvested to ground level in each subplot. The plant samples were oven-dried at 80°C for a minimum of forty-eight hours and then weighed. Crown and roots of ten randomly selected grass plants per plot were excavated to a 10 cm depth, on the same date dry matter was sampled. Plants for root assessment were stored in the freezer until root measurements could be conducted. Upon thawing, the roots were washed and the number of roots per plant was determined. The percentage of plants with roots greater than 4 was again determined and analyzed statistically.

4.3.3 Statistical Analysis

Results were analyzed using the GLM procedure of the Statistical Analysis Systems (SAS Institute, North Carolina, 1985). Means were separated using the Fischer Protected Least Significance Difference test after the GLM indicated significant differences ($p=0.10$). Due to the exploratory nature of the experiment, alpha=0.10 was used. Significant interaction means separation were calculated according to Gomez and Gomez (1984). Relationships between environmental measurements, plant density, height, Haun stage and survival rates were determined using correlation analysis. Scatter diagrams of the data points of the correlations indicated that the data could generally be grouped according to the main plot treatments. Correlations are discussed only when sufficient spread of the data occurred to avoid having a line drawn between a cluster of data and a single data point. The sample size for all correlations was 12.

4.4 Results and Discussion

4.4.1 Environmental Conditions

4.4.1.1 Air Temperature

In 1992, air temperature at Portage and throughout most of the growing season at Gladstone was below the long-term average from June through September (Tables 3.3 and 3.4). Fulbright et al. (1985) found increased green needlegrass emergence, shoot and seminal root lengths, and an increased number and length of adventitious roots with an increased day/night temperature of 25/20°C compared with 20/15°C. Warm-season seedling germination and growth was found to be optimum around 30°C (Bokhari et al., 1975; Hsu et al., 1985b). The mean air temperature at Portage and Gladstone in 1992 was often below 20°C (Figures 3.2 and 3.4). Therefore, emergence, development and growth of cool-, and especially warm-season grasses, may have been limited by temperature in these studies.

4.4.1.2 Precipitation

Total precipitation received at Portage from May 1 to September 30 in 1992 was below the long-term average (Table 3.3). Early season conditions were very dry at both sites, which may have limited grass germination and growth (Tables 3.3 and 3.4). Total precipitation from May 15 to September 13 at Gladstone was similar to Portage (Figures 3.6 and 3.8).

Moisture stress can affect plant establishment and development by delaying or decreasing germination of perennial grasses (Bokhari et al., 1975; McGinnies, 1960; Pemadasa and Amarasinghe, 1982) and reducing shoot (Stout et al., 1986) and root growth (Wilson and Briske, 1979). Moisture stress also reduces survival of young seedlings (Frischknecht, 1951).

4.4.1.3 Soil Moisture

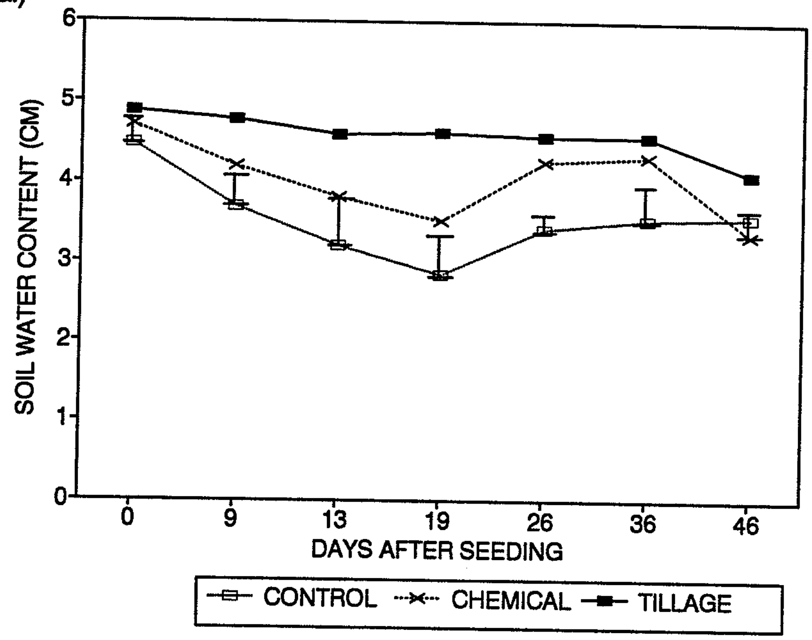
Total soil moisture appeared to be similar during the emergence period at the two sites (Figure 4.1). At Portage, soil moisture was greatest in the fall tillage treatments and lowest in the unsuppressed treatment (Figure 4.1a). Soil moisture at Gladstone was also lowest in the unsuppressed treatment (Figure 4.1b). These results indicate that seedlings in the unsuppressed treatment faced the greatest competition for water. Seedlings in the chemical suppression treatment at Gladstone faced only slightly more competition for moisture than the tillage treatment (Figure 4.1b).

4.4.2 Competition From the Resident Vegetation

4.4.2.1 Competition for Light

Measures of percent light interception in the unsuppressed and chemical suppression treatments indicate the degree of competition provided by the resident vegetation. Significant suppression treatment effects occurring throughout the season at Portage and early in the season at Gladstone (25 DAS) (Appendix 4, Tables A4.1 and A4.2) indicated that the resident vegetation in the unsuppressed treatment provided more intense competition for light than that in the chemical suppression treatment (Figure 4.2). However, a significant

a.)



b.)

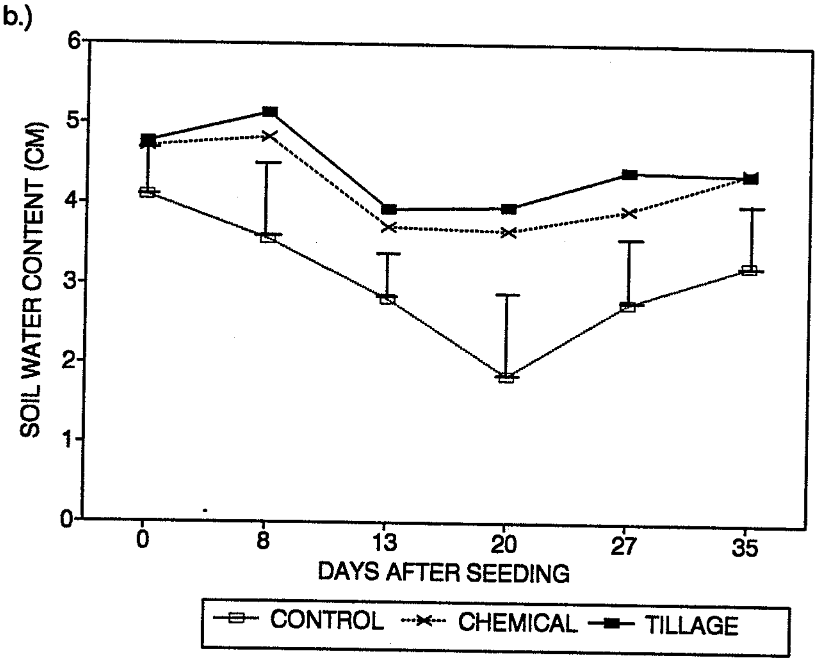


Figure 4.1 Influence of resident vegetation suppression on volumetric soil water content (cm) to a 10 cm depth at a.) Portage La Prairie.and b.) Gladstone, MB in 1992. Vertical bars indicate LSD(0.10).

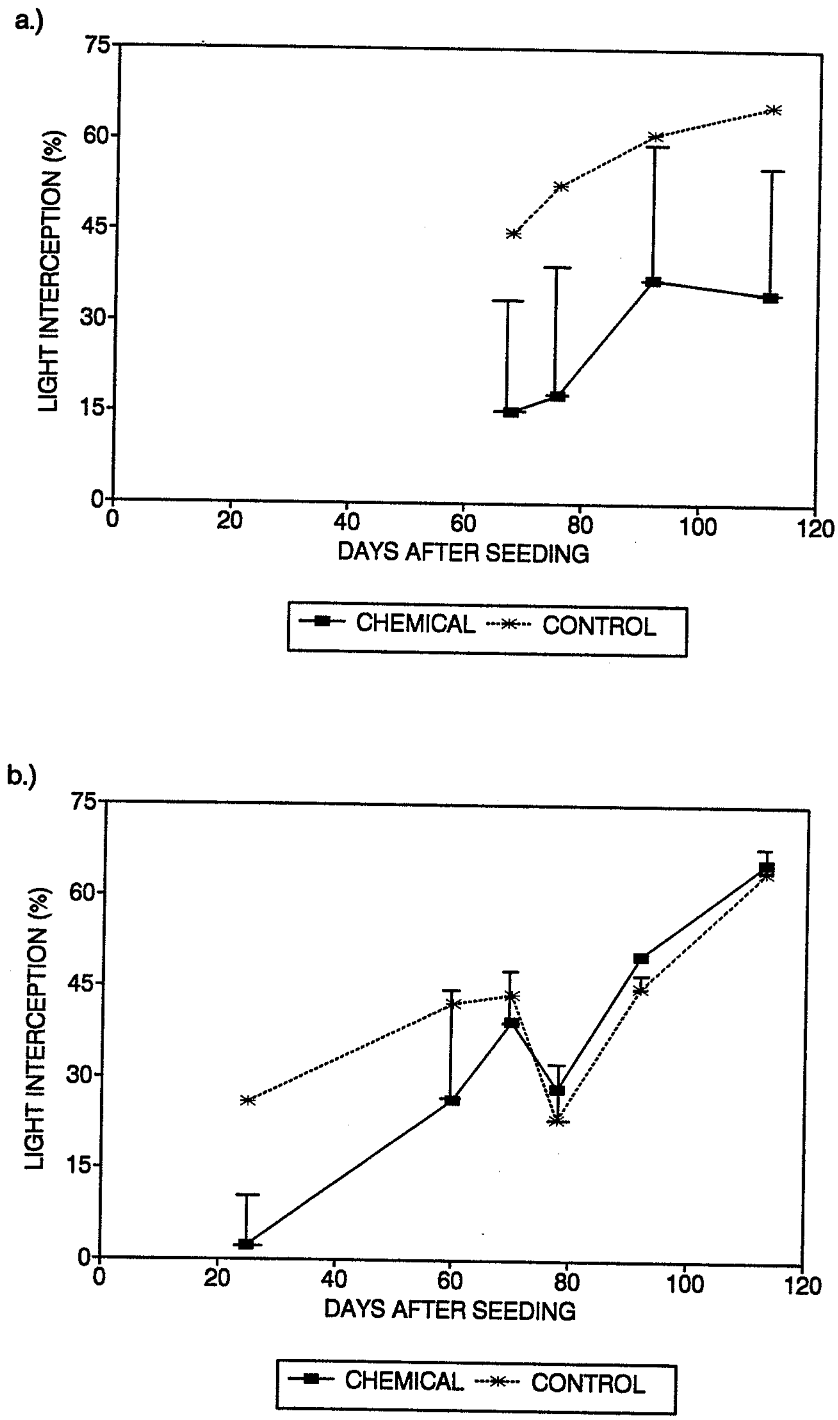


Figure 4.2 Influence of resident vegetation suppression on light interception (%) of the resident vegetation at a.) Portage La Prairie and b.) Gladstone, MB in 1992. Vertical bars indicate LSD(0.10).

suppression effect 92 DAS at Gladstone indicated that the competition was more intense in the chemical suppression treatments. A shift in species competition in the suppressed plots (that is, an increase in the proportion of smooth bromegrass) may have accounted for this observation.

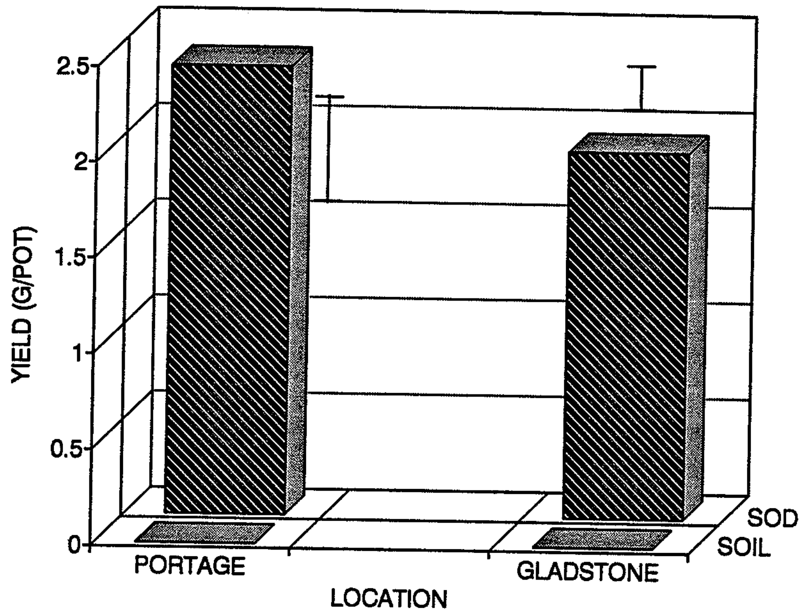
These results demonstrate that the competition for light faced by the sod-seeded grasses early in the season was greatest in the unsuppressed plots. Observations later in the season indicated that the degree of control of the resident vegetation achieved with glyphosate was greater at Portage than at Gladstone. The different response between the two sites may be related to differences in resident grass species.

A drop in light interception occurred 78 DAS at Gladstone in 1992 (Figure 4.2b). Low temperatures and low precipitation may have caused the resident vegetation to become stressed and wilted, intercepting less light and providing less competition (Figures 3.4 and 3.8). If plants were heading, less light may have been intercepted due to loss of lower leaves.

4.4.2.2 Resident Vegetation Aerial Dry Matter Accumulation

The resident vegetation accumulated more dry matter in the sod treatments than in the bare soil treatments in the indoor study (Figure 4.3a). In 1992 field trials, resident vegetation in the unsuppressed treatments accumulated the most dry matter, while the tillage treatments accumulated the least

a.)



b.)

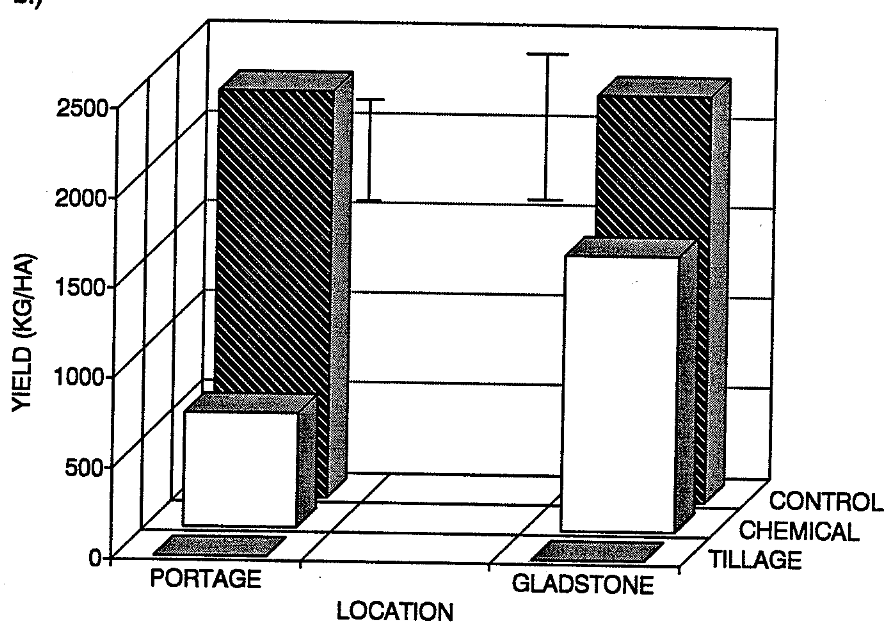


Figure 4.3 Influence of resident vegetation suppression on aerial dry matter accumulation of the resident vegetation a.) 62 DAS with the Portage La Prairie soil and 48 DAS with the Gladstone soil in indoor studies (g/pot) and b.) 82 DAS at Portage La Prairie and 85 DAS at Gladstone, MB in 1992 field studies (kg/ha). Vertical bars indicate LSD(0.10).

(Figure 4.3b). The effect of chemical suppression on the resident vegetation did not last throughout the season as regrowth of the resident vegetation did occur. This is similar to observations by other researchers (Bowes and Zentner, 1992; Waddington and Bowren, 1976). Glyphosate thus suppresses the resident vegetation in the critical establishment period, then allows regrowth. A greater amount of regrowth occurred in the glyphosate-treated plots at Gladstone than at Portage (Figure 4.3b), indicating that sod-seeded grasses in the chemically suppressed plots at Gladstone faced more adverse growing conditions than at Portage.

To determine if light interception measurements could be used as an indicator of competition from the resident vegetation, correlations were computed between resident vegetation aerial dry matter and light interception measurements taken at approximately the same time. A significant correlation was found at Portage, but not at Gladstone (0.930 and -0.416 at Portage and Gladstone, respectively).

4.4.3 Plant Establishment

4.4.3.1 Controlled Environment Study

There were no significant interactions or soil type effects in the indoor study with the Portage soil (Table 4.2).

A significant sod x grass species interaction occurred 4 DAS in the indoor study with the Gladstone soil (Table 4.3).

Table 4.2 Influence of soil type and grass species on plant population density (plants pot^{-1})* in a controlled environment study using the Portage La Prairie soil.

SOIL TYPE	SPECIES	DAYS AFTER SEEDING 6	12	23	33	47	60
SOD	SWITCHGRASS	4	5	5	5	5	4
SOD	GREEN NEEDLEGRASS	8	8	8	8	8	8
SOD	TALL WHEATGRASS	9	10	10	10	10	9
SOD	NORTHERN WHEATGRASS	9	9	9	9	9	9
SOIL	SWITCHGRASS	3	5	5	5	5	5
SOIL	GREEN NEEDLEGRASS	9	8	7	7	7	6
SOIL	TALL WHEATGRASS	10	10	10	10	10	10
SOIL	NORTHERN WHEATGRASS	9	10	10	9	9	9
	Mean	8	8	8	8	8	8
L.S.D. $(_{0.10})$		2	2	2	2	2	2
SOIL TYPE		ns	ns	ns	ns	ns	ns
SPECIES		*	*	*	*	*	*
INTERACTION		ns	ns	ns	ns	ns	ns

* significant at p=0.10

Greater tall wheatgrass emergence occurred in sod than in the bare soil treatment, while other grasses were unaffected by seedbed preparation system. The general lack of significant interactions in these studies indicates that the grasses responded similarly to the sod and soil seedbed preparation systems.

Table 4.3 Influence of soil type and grass species on plant population density (plants pot^{-1})* in a controlled environment study using the Gladstone soil.

SOIL TYPE	SPECIES	DAYS AFTER SEEDING 4	6	9	12	20	30	45
SOD	SWITCHGRASS	0	1	4	5	6	6	6
SOD	GREEN NEEDLEGRASS	5	5	7	7	7	7	7
SOD	TALL WHEATGRASS	9	9	9	9	10	10	10
SOD	NORTHERN WHEATGRASS	8	9	9	9	9	8	8
SOIL	SWITCHGRASS	1	3	6	6	5	5	5
SOIL	GREEN NEEDLEGRASS	5	7	8	8	8	8	8
SOIL	TALL WHEATGRASS	5	8	10	10	10	10	9
SOIL	NORTHERN WHEATGRASS	7	8	9	9	9	8	8
	Mean	5	6	8	8	8	8	8
L.S.D. $_{(0.10)}$		2	2	1	1	2	2	2
SOIL TYPE		*	ns	ns	ns	ns	ns	ns
SPECIES		*	*	*	*	*	*	*
INTERACTION		*	ns	ns	ns	ns	ns	ns

* significant at p=0.10

Significant grass species effects were observed throughout the season in both indoor trials (Tables 4.2 and 4.3). Switchgrass consistently had the lowest population densities, suggesting that it was the most difficult grass to establish. Reduced switchgrass establishment in this study may have been related to the low growth room temperatures. Tall and northern wheatgrasses generally had the highest population densities (Tables 4.2 and 4.3).

4.4.3.2 Field Study

Because one of the main objectives of this study was to determine whether the candidate grasses responded the same to seedbed preparation method, interactions between grass species and seedbed preparation were of particular interest in this study. The only significant main plot x subplot interaction for plant establishment in the Portage field study occurred 26 DAS. On this date, switchgrass had a significantly lower plant density in the unsuppressed compared to the chemical suppression and tillage treatments while densities of tall wheatgrass were higher in the chemical suppression than in the tillage treatments (Table 4.4). Green needlegrass and northern wheatgrass establishment, on the other hand, were unaffected by seedbed preparation technique. Therefore, it appeared that switchgrass benefitted from the competition reduction in the chemically suppressed and tilled treatments more than the other species.

Significant suppression treatment effects occurred 19, 67 and 97 DAS at Portage (Table 4.4). On the 19 DAS sampling date, the unsuppressed treatments resulted in the lowest plant densities, whereas on later sampling dates, densities were

Table 4.4 Influence of suppression treatment and grass species on plant population density (plants m^{-2})* in a field study at Portage La Prairie, MB in 1992.

		DAYS AFTER SEEDING				
SUPPRESSION	SPECIES	19	26	39	67	97
CONTROL	SWITCHGRASS	8	9	20	40	39
CONTROL	GREEN NEEDLEGRASS	3	6	14	30	26
CONTROL	TALL WHEATGRASS	40	45	48	46	44
CONTROL	NORTHERN WHEATGRASS	31	38	63	54	46
CHEMICAL	SWITCHGRASS	26	38	58	84	85
CHEMICAL	GREEN NEEDLEGRASS	11	14	16	23	26
CHEMICAL	TALL WHEATGRASS	49	51	59	60	60
CHEMICAL	NORTHERN WHEATGRASS	54	59	75	76	74
TILLAGE	SWITCHGRASS	48	56	56	54	51
TILLAGE	GREEN NEEDLEGRASS	18	10	8	9	8
TILLAGE	TALL WHEATGRASS	28	20	23	23	21
TILLAGE	NORTHERN WHEATGRASS	59	51	43	36	36
	Mean	31	33	40	45	43
$L.S.D._{(0.10)}$		23	27	31	33	29
MP		*	ns	ns	*	*
SP		*	*	*	*	*
MP x SP		ns	*	ns	ns	ns

* significant at p=0.10

greatest in the chemical suppression treatments. There may have been less soil water evaporation in the chemically suppressed compared with tilled plots as temperatures increased later in the season, and less competition with invader weeds such as thistles and annual weeds that affected tilled plots at Portage.

Significant grass species effects occurred throughout the season at Portage (Table 4.4). Green needlegrass had the lowest densities throughout the season. This suggests that green needlegrass was the most difficult of these grasses to establish. Lodorm, the cultivar of green needlegrass used in this study, has less dormancy than other cultivars (Duebbert et al., 1981), however, dormancy is still one of the important factors that may have reduced the population densities of green needlegrass in this study. Kilcher and Looman (1983) found that green needlegrass established slowly under conventional seedbed practises, but reached yields comparable to domestic grasses after four years. If dormancy was a factor in the present study, green needlegrass densities may increase in successive years. However, by that time the benefit of resident vegetation suppression from glyphosate would be reduced.

At Gladstone, significant main plot x subplot interactions occurred throughout the season, indicating that the grasses responded differently to the three seedbed preparation systems (Table 4.5). Northern wheatgrass and green needlegrass had greater population densities in the fall tillage as compared to the chemically suppressed and the unsuppressed treatments; while switchgrass had significantly lower densities in the unsuppressed plots (Table 4.5). Therefore, competition reduction in the chemically suppressed plots did not significantly increase northern wheatgrass or

Table 4.5 Influence of suppression treatment and grass species on plant population density (plants m^{-2})* in a field study at Gladstone, MB in 1992.

SUPPRESSION	SPECIES	DAYS AFTER SEEDING 18	32	60	74	103
CONTROL	SWITCHGRASS	4	6	31	35	31
CONTROL	GREEN NEEDLEGRASS	5	10	18	19	19
CONTROL	TALL WHEATGRASS	16	18	19	15	14
CONTROL	NORTHERN WHEATGRASS	30	25	23	21	18
CHEMICAL	SWITCHGRASS	59	121	174	171	175
CHEMICAL	GREEN NEEDLEGRASS	14	20	34	38	38
CHEMICAL	TALL WHEATGRASS	58	61	59	63	59
CHEMICAL	NORTHERN WHEATGRASS	43	49	58	58	55
TILLAGE	SWITCHGRASS	145	166	173	171	170
TILLAGE	GREEN NEEDLEGRASS	39	66	99	96	96
TILLAGE	TALL WHEATGRASS	76	74	74	74	74
TILLAGE	NORTHERN WHEATGRASS	149	126	119	120	121
	Mean	53	62	73	73	73
$L.S.D._{(0.10)}$		52	52	53	56	53
MP		*	*	*	*	*
SP		*	*	*	*	*
MP x SP		*	*	*	*	*

* significant at p=0.10

green needlegrass establishment above that in the unsuppressed plots, suggesting these grasses may require tillage as a seedbed preparation practise. On the other hand, switchgrass establishment was as successful in sod-seeded plots with chemical suppression as in conventionally seeded plots, perhaps due to its higher number of pure live seed applied as compared to other grasses.

Significant main effects were also observed in this study. For example, significant seedbed preparation effects occurred throughout the season at Gladstone (Table 4.5). The tillage treatments had the greatest plant densities 18 and 32 DAS. The unsuppressed treatments generally resulted in the lowest plant densities throughout the season. Higher plant densities in the tillage and chemical suppression treatments compared with the unsuppressed treatment could be due to the fact that these treatments had more soil water at the beginning of the season (Figure 4.1).

Greater plant densities in the tillage and chemical suppression treatments were also attributed to less competition from the resident vegetation (Figures 4.2 and 4.3b). In previous studies, suppression of the resident vegetation was found to be necessary for satisfactory establishment of sod-seeded smooth bromegrass, switchgrass and intermediate wheatgrass (Bowes and Zentner, 1992; Samson and Moser, 1982). In a two-year study in Nebraska, King et al. (1989) found that sod-seeded sand bluestem, switchgrass, smooth brome and intermediate wheatgrass densities decreased in untreated control plots from 4 to less than 1 plant m^{-2} 47 to 101 DAS in one year and from 55 to 3 plants m^{-2} 43 to 101 DAS in another year. However, in disced plots, plant densities were 151, 14 and 3 plants m^{-2} 47, 101 and 408 DAS in one year and 174, 24 and 14 plants m^{-2} 43, 101 and 403 DAS in another.

Plant densities in the fall tillage treatments at Gladstone were higher than those at Portage in 1992 (Tables 4.4 and 4.5). Early season conditions were very dry in 1992 at Portage, which may have reduced grass germination (Table 3.3). Also, once the competition from the resident vegetation was decreased, plants may have been able to benefit from the greater amount of available NO_3-N, P and K found in the Gladstone soil (Appendix 1, Table A1.1).

Significant grass species effects occurred throughout the season at Gladstone (Table 4.5). Green needlegrass had the lowest plant densities 18 DAS. Switchgrass generally had the highest plant densities throughout the season. It is not unexpected for the switchgrass to have high population densities in these field experiments, as a large number of pure live seed was seeded as compared to the other grasses, due to its low seed weight.

In summary, only the switchgrass, tall wheatgrass and northern wheatgrass under the chemical suppression treatment achieved the minimum plant density for nesting cover by the end of the season (that is, 65 plants m^{-2}; Brent Wark, biologist Ducks Unlimited, personal communication) at Portage in 1992. At Gladstone, switchgrass in the chemical suppression treatment and all grasses in the fall tillage treatment achieved this density. However, as was shown with the Robel pole measurements in the tall wheatgrass experiment (Section 3.3.6.5), lower densities may provide adequate DNC.

When considering the tall wheatgrass densities the year after establishment in the previous section (Section 3.3.6.2), it was observed that the only treatments with acceptable densities at Gladstone were the Round-up and Gramoxone treatments under scarification (Table 3.19). These treatments had densities of 38 and 49 plants m^{-2}, respectively, in the year of establishment (Table 3.8). In the present study, the only grass that did not achieve this density in the chemical suppression treatment was the green needlegrass at Portage (Tables 4.4 and 4.5).

The relationship between the end of the establishment season plant densities and the associated resident vegetation light interception and dry matter measurements was analyzed for both the indoor and field studies (Tables 4.6 to 4.9). No significant correlations existed in the indoor study (Tables 4.6 and 4.7).

No significant relationships were observed in the field study at the Portage site (Table 4.8), although the plant density measured 103 DAS was negatively correlated with light interception measured 92 DAS and dry matter of the resident vegetation measured 85 DAS at Gladstone in 1992 (Table 4.9). This may have been due to the different sod type at Portage. The resident vegetation at Gladstone was more competitive than the bunchgrass at Portage, thus the need for suppression of the resident vegetation appeared to be greater.

Table 4.6 Correlation coefficients* between establishment parameters in a controlled environment study using the Portage La Prairie soil.

	Resident Vegetation Dry Matter	Plant Density	Haun Stage	Plant Height	Plant Dry Matter	Frequency of Plants with Greater Than 4 Roots
Resident Vegetation Dry Matter	-	0.019	-0.815*	-0.893*	-0.924*	0.170
Plant Density	-	-	0.211	0.134	0.205	0.928*
Haun Stage	-	-	-	0.844*	0.854*	0.055
Plant Height	-	-	-	-	0.896*	-0.071
Plant Dry Matter	-	-	-	-	-	0.005
Root Number	-	-	-	-	-	-

* significant at p=0.10

Table 4.7 Correlation coefficients* between establishment parameters in a controlled environment study using the Gladstone soil.

	Resident Vegetation Dry Matter	Plant Density	Haun Stage	Plant Height	Plant Dry Matter	Frequency of Plants with Greater Than 4 Roots
Resident Vegetation Dry Matter	-	0.053	-0.925*	-0.880*	-0.827*	-0.046
Plant Density	-	-	0.082	0.339	0.327	0.928*
Haun Stage	-	-	-	0.821*	0.887*	0.272
Plant Height	-	-	-	-	0.904*	0.358
Plant Dry Matter	-	-	-	-	-	0.456
Root Number	-	-	-	-	-	-

* significant at p=0.10

Table 4.8 Correlation coefficients* between year of establishment parameters in a field study at Portage La Prairie, MB in 1992.

	Resident Vegetation Dry Matter	Resident Vegetation Light Interception	Plant Density	Haun Stage	Plant Height	Plant Dry Matter	Frequency of Plants with Greater Than 4 Roots
Resident Vegetation Dry Matter	-	0.930*	-0.004	-0.822*	-0.936*	-0.698*	-0.842*
Resident Vegetation Light Interception	-	-	0.281	-0.903*	-0.958*	-0.854*	-0.660*
Plant Density	-	-	-	-0.265	-0.161	-0.381	0.218
Haun Stage	-	-	-	-	0.906*	0.951*	0.583*
Plant Height	-	-	-	-	-	0.820*	0.726*
Plant Dry Matter	-	-	-	-	-	-	0.449
Root Number	-	-	-	-	-	-	-

* significant at p=0.10

Table 4.9 Correlation coefficients* between year of establishment parameters in a field study at Gladstone, MB in 1992.

	Resident Vegetation Dry Matter	Resident Vegetation Light Interception	Plant Density	Haun Stage	Plant Height	Plant Dry Matter	Frequency of Plants with Greater Than 4 Roots
Resident Vegetation Dry Matter	-	-0.416	-0.658*	-0.966*	-0.953*	-0.825*	-0.628*
Resident Vegetation Light Interception	-	-	-0.498*	-0.889*	-0.890*	-0.801*	-0.381
Plant Density	-	-	-	0.629*	0.547*	0.301	0.573*
Haun Stage	-	-	-	-	0.920*	0.854*	0.657*
Plant Height	-	-	-	-	-	0.908*	0.641*
Plant Dry Matter	-	-	-	-	-	-	0.500*
Root Number	-	-	-	-	-	-	-

* significant at p=0.10

4.4.4 Plant Development

4.4.4.1 Haun Stage Measurement

4.4.4.1.1 Controlled Environment Study

Significant sod x grass species interactions occurred 60 DAS in the indoor study with the Portage soil and throughout the season with the Gladstone soil. As expected, all grasses grown in the bare soil had greater Haun stage values than those grown in the sod (Tables 4.10 and 4.11). However, while all grasses had similar Haun stage values when growing in soil, northern wheatgrass had a greater number of leaves than other grasses when in sod. Significant grass species effects indicated that northern wheatgrass had the greatest number of leaves per plant throughout the study for both trials.

4.4.4.1.2 Field Study

Significant main plot x subplot interactions occurred 39 and 67 DAS at Portage and 60 DAS at Gladstone in 1992. All species had greater development in the tillage compared with the other treatments (Tables 4.12 and 4.13). At Portage, the Haun stage values of the tall and northern wheatgrasses were

Table 4.10 Influence of soil type and grass species on plant development (Haun stage)* in a controlled environment study using the Portage La Prairie soil.

SOIL TYPE	SPECIES	DAYS AFTER SEEDING 12	23	33	47	60
SOD	SWITCHGRASS	0.8	1.3	1.5	2.0	2.9
SOD	GREEN NEEDLEGRASS	1.0	1.9	2.0	2.2	2.7
SOD	TALL WHEATGRASS	1.2	1.9	2.2	3.0	3.7
SOD	NORTHERN WHEATGRASS	1.8	2.2	2.9	3.7	4.3
SOIL	SWITCHGRASS	1.2	2.1	2.9	4.4	5.2
SOIL	GREEN NEEDLEGRASS	1.1	2.0	3.0	4.6	5.7
SOIL	TALL WHEATGRASS	1.4	2.5	3.4	4.6	5.1
SOIL	NORTHERN WHEATGRASS	1.9	3.1	4.4	6.2	7.5
	Mean	1.3	2.1	2.8	3.8	4.6
L.S.D. $_{(0.10)}$		0.3	0.4	0.5	0.7	0.5
SOIL TYPE		*	*	*	*	*
SPECIES		*	*	*	*	*
INTERACTION		ns	ns	ns	ns	*

* significant at p=0.10

significantly lower in the unsuppressed than in the chemically suppressed treatments. However, there was no difference between switchgrass and green needlegrass development in the chemically suppressed and control treatments. At Gladstone, the switchgrass, tall wheatgrass and northern wheatgrass had more leaves under the chemical suppression treatments than the unsuppressed treatment. The reduced competition provided by the chemical suppression treatment did increase development

Table 4.11 Influence of soil type and grass species on plant development (Haun stage)* in a controlled environment study using the Gladstone soil.

SOIL TYPE	SPECIES	DAYS AFTER SEEDING 9	12	20	30	45
SOD	SWITCHGRASS	1.0	1.0	1.8	2.0	2.6
SOD	GREEN NEEDLEGRASS	1.0	1.0	1.8	2.0	2.2
SOD	TALL WHEATGRASS	1.0	1.1	1.9	2.1	2.9
SOD	NORTHERN WHEATGRASS	1.1	1.5	2.0	2.6	3.5
SOIL	SWITCHGRASS	1.1	1.4	2.1	3.3	4.8
SOIL	GREEN NEEDLEGRASS	1.0	1.2	2.3	3.7	5.1
SOIL	TALL WHEATGRASS	1.0	1.2	2.3	3.7	5.0
SOIL	NORTHERN WHEATGRASS	1.2	1.8	2.9	4.8	6.4
	Mean	1.1	1.3	2.1	3.0	4.1
L.S.D. $(_{0.10})$		0.1	0.1	0.2	0.2	0.4
SOIL TYPE		*	*	*	*	*
SPECIES		*	*	*	*	*
INTERACTION		*	*	*	*	*

* significant at p=0.10

above that in unsuppressed plots. However, it would appear that the green needlegrass development was no greater in the chemically suppressed plots, indicating that successful development did not occur when sod-seeded.

Suppression treatment effects occurred throughout the season at Portage and 32, 60 and 74 DAS at Gladstone in 1992 (Tables 4.12 and 4.13). Across all four species, Haun stage values were greatest in the tillage treatments and lowest in the unsuppressed treatments.

Table 4.12 Influence of suppression treatment and grass species on plant development (Haun stage)* in a field study at Portage La Prairie, MB in 1992.

SUPPRESSION	SPECIES	DAYS AFTER SEEDING 19	26	39	67
CONTROL	SWITCHGRASS	1.1	1.4	1.6	1.8
CONTROL	GREEN NEEDLEGRASS	1.0	1.0	1.3	1.5
CONTROL	TALL WHEATGRASS	1.0	1.0	1.3	1.9
CONTROL	NORTHERN WHEATGRASS	1.0	1.2	1.4	2.0
CHEMICAL	SWITCHGRASS	1.0	1.2	1.7	2.9
CHEMICAL	GREEN NEEDLEGRASS	1.0	1.1	1.5	2.1
CHEMICAL	TALL WHEATGRASS	1.0	1.3	1.9	4.1
CHEMICAL	NORTHERN WHEATGRASS	1.0	1.6	2.2	3.2
TILLAGE	SWITCHGRASS	1.3	1.5	2.7	5.1
TILLAGE	GREEN NEEDLEGRASS	1.0	1.3	2.1	5.5
TILLAGE	TALL WHEATGRASS	1.0	1.5	2.2	7.7
TILLAGE	NORTHERN WHEATGRASS	1.0	1.6	2.9	7.0
	Mean	1.0	1.3	1.9	3.7
L.S.D.$_{(0.10)}$			0.2	0.3	1.2
MP		*	*	*	*
SP		ns	*	*	*
MP x SP		ns	ns	*	*

* significant at p=0.10

Greater development in the tillage and chemical suppression treatments could be attributed to less competition

Table 4.13 Influence of suppression treatment and grass species on plant development (Haun stage)* in a field study at Gladstone, MB in 1992.

		DAYS AFTER SEEDING			
SUPPRESSION	SPECIES	18	32	60	74
CONTROL	SWITCHGRASS	1.2	1.4	1.7	1.9
CONTROL	GREEN NEEDLEGRASS	1.0	1.0	1.6	1.5
CONTROL	TALL WHEATGRASS	1.0	1.0	1.7	1.5
CONTROL	NORTHERN WHEATGRASS	1.0	1.1	1.8	1.5
CHEMICAL	SWITCHGRASS	1.0	1.6	3.3	3.6
CHEMICAL	GREEN NEEDLEGRASS	1.0	1.4	2.0	2.3
CHEMICAL	TALL WHEATGRASS	1.0	1.9	3.9	5.1
CHEMICAL	NORTHERN WHEATGRASS	1.0	1.9	3.6	4.5
TILLAGE	SWITCHGRASS	1.0	2.6	6.6	8.6
TILLAGE	GREEN NEEDLEGRASS	1.0	2.2	7.0	7.3
TILLAGE	TALL WHEATGRASS	1.0	2.8	9.3	10.0
TILLAGE	NORTHERN WHEATGRASS	1.1	2.7	7.3	9.3
	Mean	1.0	1.8	4.2	4.8
$L.S.D._{(0.10)}$		0.1	0.5	1.4	1.6
MP		ns	*	*	*
SP		ns	*	*	*
MP x SP		ns	ns	*	ns

* significant at p=0.10

from the resident vegetation compared to the unsuppressed treatment (Figures 4.2 and 4.3b). For example, Haun stage measurements conducted at the end of the season were negatively correlated with the resident vegetation light interception and dry matter measurements taken during approximately the same period in all four trials (Tables 4.6

to 4.9). Greater development in tillage treatments may also be due to more soil water at the beginning of the season (Figure 4.1). Although it was not measured, differences between treatments may have been due to differences in soil temperature, with the tillage treatments possibly having higher soil temperatures than other treatments.

Significant grass species effects occurred 26, 39 and 67 DAS at Portage (Table 4.12). The switchgrass and northern wheatgrass had the greatest number of leaves, while the green needlegrass had the lowest 26 and 39 DAS. Both the tall and northern wheatgrasses had the greatest number of leaves 67 DAS. At Gladstone, green needlegrass had the lowest number of leaves per plant 32 and 74 DAS; while 60 DAS, the northern wheatgrass had the highest (Table 4.13). The larger seed size of the two wheatgrasses may have resulted in increased development as compared to the switchgrass and green needlegrass. Seed size has been shown to be correlated to seedling vigour, that is, with germination and seedling growth (Duebbert et al., 1981; Hill et al., 1985; McGinnies, 1960; Squires and Elliott, 1975).

Development of three or more leaves is desirable to reduce the risk of winterkill and to maximize regrowth the next season (White, 1984; Section 3.3.6.1). This limit was achieved at both sites by the sod-seeded switchgrass, northern wheatgrass and tall wheatgrass when chemical suppression occurred (Tables 4.12 and 4.13). However, it was not achieved by the sod-seeded green needlegrass, even when the resident vegetation was chemical suppressed.

Of the grasses tested, green needlegrass appeared to be the least adapted to sod-seeding, as it had the lowest plant development. Frank and Hofmann (1989) found that green needlegrass developed four leaves on a native mixed prairie site in North Dakota that had been grazed in previous years. In our study, green needlegrass only developed four leaves in the tillage treatments (Tables 4.12 and 4.13). Although the difference in the number of leaves between green needlegrass and other grasses was not great (Tables 4.12 and 4.13), it is known (White, 1984) that a difference of one or two leaves can result in twice the regrowth following a winter dormancy.

The number of leaves per plant in the fall tillage treatments at Gladstone were higher than those at Portage in 1992 (Tables 4.12 and 4.13). Once the competition from the resident vegetation was decreased, plants may have been able to benefit from the greater amount of available NO_3-N, P and K found at Gladstone as compared to Portage, allowing for greater growth and development of the plant (Appendix 1, Table A1.1). As well, early season conditions were very dry in 1992 at Portage, which may have limited grass development (Table 3.3).

4.4.4.2 Plant Height

Due to a similarity of results with the Haun measurement, only the plant height measurement from the end of the season will be discussed. The complete plant height dataset can be found in Appendix 5.

4.4.4.2.1 Controlled Environment Study

Significant sod x grass species interactions and soil type effects occurring with the Portage and Gladstone soils indicated that grasses attained greater heights when grown in bare soil than when in sod. At the end of the season, the switchgrass in the sod treatment was significantly shorter than other grasses in the sod treatment with both soils (Table 4.14). The green needlegrass and tall wheatgrass were taller than other grasses in the soil treatment at Gladstone, while differences in height in the soil treatment did not occur at Portage.

4.4.4.2.2 Field Study

A significant main plot x subplot interaction occurring at the end of the season at Gladstone in 1992 indicated that green needlegrass and tall wheatgrass were taller in the tillage treatment, with northern wheatgrass being shortest, while there was no significant difference between the grasses

Table 4.14 Influence of soil type and grass species on plant height (cm)* in controlled environment studies using the Portage La Prairie and Gladstone soils.

SOIL TYPE	SPECIES	DAYS AFTER SEEDING Portage 60	DAYS AFTER SEEDING Gladstone 45
SOD	SWITCHGRASS	8.2	6.2
SOD	GREEN NEEDLEGRASS	13.0	13.2
SOD	TALL WHEATGRASS	17.0	16.3
SOD	NORTHERN WHEATGRASS	14.4	13.0
SOIL	SWITCHGRASS	25.3	21.2
SOIL	GREEN NEEDLEGRASS	30.5	37.6
SOIL	TALL WHEATGRASS	24.1	35.5
SOIL	NORTHERN WHEATGRASS	26.1	30.2
	Mean	19.8	21.7
$L.S.D._{(0.10)}$		4.4	3.5
SOIL TYPE		*	*
SPECIES		*	*
INTERACTION		*	*

* significant at p=0.10

in the chemically suppressed and unsuppressed treatments (Table 4.15). The increased competition reduced the differences between grasses at this site. The grass heights increased significantly with increased sod-suppression at both sites (ie., tillage > chemical suppression > control) (Table 4.15). Thus, the competition reduction provided by chemical suppression enhanced plant height above that in unsuppressed plots, however plant height in the chemically suppressed plots

Table 4.15 Influence of suppression treatment and grass species on plant height (cm)* in field studies at Portage La Prairie and Gladstone, MB in 1992.

		DAYS AFTER SEEDING	
		Portage	Gladstone
SUPPRESSION	SPECIES	97	103
CONTROL	SWITCHGRASS	6.1	4.4
CONTROL	GREEN NEEDLEGRASS	8.7	7.2
CONTROL	TALL WHEATGRASS	10.4	6.6
CONTROL	NORTHERN WHEATGRASS	8.1	6.7
CHEMICAL	SWITCHGRASS	14.5	16.8
CHEMICAL	GREEN NEEDLEGRASS	16.5	19.1
CHEMICAL	TALL WHEATGRASS	20.8	22.9
CHEMICAL	NORTHERN WHEATGRASS	20.2	21.7
TILLAGE	SWITCHGRASS	29.2	50.2
TILLAGE	GREEN NEEDLEGRASS	26.6	65.0
TILLAGE	TALL WHEATGRASS	28.1	62.8
TILLAGE	NORTHERN WHEATGRASS	27.8	41.4
	Mean	18.1	27.1
$L.S.D._{(0.10)}$		6.1	7.0
MP		*	*
SP		ns	*
MP x SP		ns	*

* significant at p=0.10

was not as great as in the tilled plots.

Correlations between plant height measured at the end of the season and the corresponding resident vegetation light interception and dry matter measurements indicated significant negative relationships in all four trials (Tables 4.6 to 4.9). These results indicated that as the degree of competition from the resident vegetation increased, plant height was reduced.

4.4.5 Grass Aerial Dry Matter Accumulation

4.4.5.1 Controlled Environment Study

Aerial dry matter production of sod-seeded grasses was assessed at the end of the study period. Results with the Portage and Gladstone soils in the indoor study indicated that all four grass species produced much more dry matter in the bare soil treatment (Table 4.16). There was no significant sod x species interactions or grass species effects with the Portage soil, indicating that all species responded the same to the sod treatment (Table 4.16).

A significant sod x species interaction with the Gladstone soil was attributed to the fact that all grasses except switchgrass responded positively to the bare soil treatment (Table 4.16). Because switchgrass is a warm season grass and given that day/night temperatures in the growth room were 21°C/16°C, dry matter accumulation in switchgrass may have been limited more by temperature than resident vegetation type while the other grasses in the study may have responded more to reduced competition.

Table 4.16 Influence of soil type on aerial dry matter accumulation of four grass species (g plant^{-1})* in controlled environment studies using the Portage La Prairie and Gladstone soils.

		DAYS AFTER SEEDING	
		Portage	Gladstone
SOIL TYPE	SPECIES	62	48
SOD	SWITCHGRASS	0.01	0.01
SOD	GREEN NEEDLEGRASS	0.01	0.01
SOD	TALL WHEATGRASS	0.02	0.02
SOD	NORTHERN WHEATGRASS	0.02	0.01
SOIL	SWITCHGRASS	0.09	0.08
SOIL	GREEN NEEDLEGRASS	0.16	0.39
SOIL	TALL WHEATGRASS	0.17	0.40
SOIL	NORTHERN WHEATGRASS	0.16	0.50
	Mean	0.08	0.18
L.S.D.$_{(0.10)}$		0.05	0.10
SOIL TYPE		*	*
SPECIES		ns	*
INTERACTION		ns	*

* significant at p=0.10

4.4.5.2 Field Study

Significant main plot x subplot interactions occurred at Portage and Gladstone in 1992. At Portage, tall wheatgrass had greater dry matter accumulation than other grasses in the tillage treatment, while this was not so for the other seedbed preparation treatments. Thus, the increased productivity of tall wheatgrass was expressed only in the tillage treatment. At Gladstone, tall wheatgrass yields in the chemically suppressed plots were significantly greater than the unsuppressed plots, while other species were unaffected by seedbed preparation technique (Table 4.17). There was a significant increase in dry matter accumulation for tall wheatgrass with each increment in competition reduction, while other grasses required maximum competition reduction, that is, tillage, to get a significant increase in dry matter per plant at this site.

All species had the greatest dry matter accumulations under the tillage treatment (Table 4.17). In fact, there were no significant differences between yields in chemically suppressed and unsuppressed plots at Portage, indicating that sufficient suppression did not occur to increase growth above the unsuppressed control. At Portage, tillage (maximum competition reduction) was required to get a significant increases in dry matter accumulation per plant. At both sites, the greatest yields were obtained by tall wheatgrass under the tillage treatments. Favourable tall wheatgrass yields under conventional seedbed preparation practises were reported by other researchers (Lawrence, 1978; Lawrence and Warder, 1979), while Bowes and Zentner (1992) reported greater

Table 4.17 Influence of suppression treatment on aerial dry matter accumulation of four grass species (g plant^{-1})* in field studies at Portage La Prairie and Gladstone, MB in 1992.

		DAYS AFTER SEEDING	
		Portage	Gladstone
SUPPRESSION	SPECIES	109	113
CONTROL	SWITCHGRASS	0.02	0.01
CONTROL	GREEN NEEDLEGRASS	0.01	0.00
CONTROL	TALL WHEATGRASS	0.07	0.01
CONTROL	NORTHERN WHEATGRASS	0.03	0.00
CHEMICAL	SWITCHGRASS	0.29	0.10
CHEMICAL	GREEN NEEDLEGRASS	0.11	0.60
CHEMICAL	TALL WHEATGRASS	0.52	2.40
CHEMICAL	NORTHERN WHEATGRASS	0.36	0.67
TILLAGE	SWITCHGRASS	2.15	2.98
TILLAGE	GREEN.NEEDLEGRASS	1.85	5.42
TILLAGE	TALL WHEATGRASS	4.36	9.00
TILLAGE	NORTHERN WHEATGRASS	2.56	3.14
	Mean	1.03	2.03
L.S.D.$_{(0.10)}$		1.26	1.42
MP		*	*
SP		*	*
MP x SP		*	*

* significant at p=0.10

smooth bromegrass yields in areas where the resident vegetation had been suppressed using herbicide or rotovation than in those which had not undergone suppression.

In this study, higher dry matter yields in the tillage treatments were attributed to a reduced degree of competition from the resident vegetation compared to the unsuppressed treatments (Figures 4.2 and 4.3b). Plant dry matter accumulation was negatively correlated with resident vegetation light interception and dry matter accumulation at all four sites (Tables 4.6 to 4.9).

Lower yields in the chemical suppression compared with the tillage treatments could be due to such constraints as the physical impedance of the trash layer and possible herbicide residues and leachates from the trash causing allelopathy, competition with the resident vegetation and poorer seed-to-soil contact (King et al., 1989; Marshall and Naylor, 1984a).

Greater overall productivity at the Gladstone site (once the competition from the resident vegetation was decreased) was once again attributed to higher post-seeding precipitation in field trials and higher levels of soil nutrients in both indoor and field trials.

4.4.6 Root Development

The development of a root system is critical to the successful establishment of grasses (Plummer, 1943). For example, Hyder et al. (1971) and Wilson and Briske (1979) found that blue grama seedlings lacking adventitious roots did not survive the growing season.

4.4.6 1 Controlled Environment Study

No significant sod x grass species interactions or soil type effects occurred in the indoor study with either soil type (Table 4.18). This indicates that even though resident vegetation decreased plant development and growth, it did not affect the number of plants with roots above the critical threshold of four. The lack of significance may have occurred due to the native grasses spending most of their energy on below-ground growth. Tall and northern wheatgrasses generally had the greatest frequency of plants with more than four roots, while switchgrass and green needlegrass generally had the lowest.

4.4.6.2 Field Study

A significant main plot x subplot interaction at Portage indicated that switchgrass, green needlegrass and northern wheatgrass had a lower percentage of plants with roots above the critical limit of four in the unsuppressed plots than in other treatments, whereas tall wheatgrass was unaffected by suppression method (Table 4.19). Thus, root development in

Table 4.18 Influence of soil type and grass species on root frequency (% of plants with greater than 4 roots)* in controlled environment studies using the Portage La Prairie and Gladstone soils.

		DAYS AFTER SEEDING	
		Portage	Gladstone
SOIL TYPE	SPECIES	62	48
SOD	SWITCHGRASS	77	71
SOD	GREEN NEEDLEGRASS	90	68
SOD	TALL WHEATGRASS	100	100
SOD	NORTHERN WHEATGRASS	93	95
SOIL	SWITCHGRASS	80	50
SOIL	GREEN NEEDLEGRASS	75	85
SOIL	TALL WHEATGRASS	100	100
SOIL	NORTHERN WHEATGRASS	94	100
	Mean	89	84
$L.S.D._{(0.10)}$		19	29
SOIL TYPE		ns	ns
SPECIES		*	*
INTERACTION		ns	ns

* significant at p=0.10

tall wheatgrass did not require early season suppression, while root development in other species did benefit. All grasses had the lowest percentage of plants with greater than 4 roots in the unsuppressed treatments at Gladstone in 1992 (Table 4.19). Tall wheatgrass had the greatest percentages in

Table 4.19 Influence of suppression treatment and grass species on root frequency (% of plants with greater than 4 roots)* in field studies at Portage La Prairie and Gladstone, MB in 1992.

		DAYS AFTER SEEDING	
		Portage	Gladstone
SUPPRESSION	SPECIES	109	113
CONTROL	SWITCHGRASS	50	13
CONTROL	GREEN NEEDLEGRASS	20	7
CONTROL	TALL WHEATGRASS	95	79
CONTROL	NORTHERN WHEATGRASS	50	43
CHEMICAL	SWITCHGRASS	100	95
CHEMICAL	GREEN NEEDLEGRASS	95	93
CHEMICAL	TALL WHEATGRASS	100	100
CHEMICAL	NORTHERN WHEATGRASS	100	98
TILLAGE	SWITCHGRASS	100	100
TILLAGE	GREEN NEEDLEGRASS	100	100
TILLAGE	TALL WHEATGRASS	100	100
TILLAGE	NORTHERN WHEATGRASS	100	100
	Mean	84	77
L.S.D.$_{(0.10)}$		19	11
MP		*	*
SP		*	*
MP x SP		*	*

* significant at p=0.10

the unsuppressed treatment at both sites. Green needlegrass had lower percentages than other grasses in the unsuppressed treatment at Portage, while both green needlegrass and switchgrass were significantly lower than both wheatgrasses at Gladstone. No significant differences between grasses existed in other treatments at Gladstone.

It is known that adventitious roots do not develop when the soil surface is dry (Wilson and Briske, 1979). The unsuppressed treatment had less soil moisture than the chemical suppression and the tillage treatments (Figure 4.1), and this may be one reason for less root development in these plants.

Under conditions of low sunlight, plants produce more top growth and less root growth (Cooper, 1967; Pritchett and Nelson, 1951; Watkins, 1940). In the present study, significant negative correlations between the percentage of plants with greater than 4 roots and resident vegetation dry matter and light interception were observed at both field trials (Tables 4.8 and 4.9) but not in the indoor studies (Tables 4.6 and 4.7).

The relationship between Haun stage measurements and root percentages was analyzed to determine if the plant development had an effect on the number of roots present. Newman and Moser (1988b) found that the stage of adventitious root development of nine cool-season and nine warm-season grasses was not found to be related to the stage of leaf development of the plant as much as it was related to seedling age or genetic differences amongst species. In the present study, no significant relationship was found in the indoor study (Tables 4.6 and 4.7). Significant positive correlations were, however, observed at the Portage and Gladstone field trials (Tables 4.8 and 4.9). These results indicate that, unlike observations by Newman and Moser (1988b), the number of roots was positively related to the number of leaves per plant.

4.4.7 In-Season Plant Survival Rates

Measurements of plant survival between sampling dates indicated that the greatest loss of plants occurred early in the season (Tables 4.20 and 4.21). However, some differences in species response to seedbed preparation system were observed. For example, a significant main plot x subplot interaction occurred 19-26 DAS at Portage in 1992. Lower in-season survival rates of green needlegrass and the two wheatgrasses occurred in the tillage treatments than the chemical suppression and unsuppressed treatments (Table 4.20). Switchgrass was unaffected by seedbed preparation method.

Significant suppression treatment effects occurred with the 0-26 and 39-67 DAS measurements. The fall tillage treatments had the lowest survival rates 26 DAS. Sixty-seven

DAS, the chemical suppression treatments generally resulted in the highest survival rates, while the fall tillage treatments had the lowest. The increased competition with weeds in tillage plots may be one reason for the reduced in-season survival in these plots. There were no significant grass

Table 4.20 Influence of suppression treatment and grass species on in-season survival (%)* in a field study at Portage La Prairie, MB in 1992.

SUPPRESSION	SPECIES	DAYS AFTER SEEDING 19-26	26-39	39-67	67-97
CONTROL	SWITCHGRASS	88	100	95	92
CONTROL	GREEN NEEDLEGRASS	100	88	89	82
CONTROL	TALL WHEATGRASS	97	69	86	92
CONTROL	NORTHERN WHEATGRASS	80	92	77	85
CHEMICAL	SWITCHGRASS	99	96	96	97
CHEMICAL	GREEN NEEDLEGRASS	100	89	91	94
CHEMICAL	TALL WHEATGRASS	90	92	94	98
CHEMICAL	NORTHERN WHEATGRASS	87	92	84	90
TILLAGE	SWITCHGRASS	97	82	76	97
TILLAGE	GREEN NEEDLEGRASS	42	72	84	91
TILLAGE	TALL WHEATGRASS	57	76	88	95
TILLAGE	NORTHERN WHEATGRASS	57	63	76	100
	Mean	83	84	86	93
$L.S.D._{(0.10)}$		21	23	14	11
MP		*	ns	*	ns
SP		ns	ns	ns	ns
MP x SP		*	ns	ns	ns

* significant at p=0.10

species effects (Table 4.20).

A significant main plot x subplot interaction occurred 32-60 DAS at Gladstone in 1992, with the switchgrass, and tall and northern wheatgrasses having lower in-season survival rates in the unsuppressed treatment, while no significant

Table 4.21 Influence of suppression treatment and grass species on in-season survival (%)* in a field study at Gladstone, MB in 1992.

SUPPRESSION	SPECIES	DAYS AFTER SEEDING 18-32	32-60	60-74	74-103
CONTROL	SWITCHGRASS	92	75	98	96
CONTROL	GREEN NEEDLEGRASS	45	85	95	82
CONTROL	TALL WHEATGRASS	39	56	96	73
CONTROL	NORTHERN WHEATGRASS	22	45	91	72
CHEMICAL	SWITCHGRASS	92	93	99	98
CHEMICAL	GREEN NEEDLEGRASS	60	94	100	93
CHEMICAL	TALL WHEATGRASS	73	95	99	94
CHEMICAL	NORTHERN WHEATGRASS	84	95	98	96
TILLAGE	SWITCHGRASS	88	97	100	94
TILLAGE	GREEN NEEDLEGRASS	96	88	96	99
TILLAGE	TALL WHEATGRASS	86	98	100	98
TILLAGE	NORTHERN WHEATGRASS	79	90	100	98
	Mean	71	84	98	91
$L.S.D._{(0.10)}$		27	17	6	11
MP		*	*	*	*
SP		*	*	ns	ns
MP x SP		ns	*	ns	ns

* significant at p=0.10

difference occurred between the tillage and chemical suppression treatments (Table 4.21). Green needlegrass was unaffected by seedbed preparation method. Significant suppression treatment effects occurred throughout the season, indicating that the unsuppressed treatment had the lowest survival rates. Significant grass species effects occurred with the 18-32 and 32-60 DAS measurements (Table 4.21). The switchgrass had the greatest in-season survival between 18-32 DAS. The switchgrass and green needlegrass generally had the greatest survival rates between 32-60 DAS, while the northern wheatgrass generally had the lowest.

It would appear that maximum competition reduction provided by tillage was unnecessary for successful in-season survival of sod-seeded grass seedlings. The competition reduction provided by glyphosate was sufficient for adequate survival.

Correlations were calculated between the Haun stage measurement and the percent in-season survival in 1992 to determine if plant development affected plant survival (Table 4.22). The scatter diagrams of the data points indicated that the data in the fall tillage treatments was grouped separately from the data in the chemical suppression and unsuppressed treatments. Correlations were not significant at Portage, however, they were significant at all dates at Gladstone. At this site, as the plant development increased, the survival increased.

Correlations were computed between the percentage of plants with greater than 4 roots and the in-season survival measured at the end of the season at both sites in 1992 (Table 4.23). The correlation analysis was positively significant at Portage, but not at Gladstone. The extent of root development has been stated to be more important to grass seedling survival than the plant's ability to harden to drought (Frischknecht, 1951).

Table 4.22 Correlation coefficients* between in-season survival and Haun stage in field studies at Portage La Prairie and Gladstone, MB in 1992.

		Date 1[z] Haun Stage	Date 2[y] Haun Stage	Date 3[x] Haun Stage
Portage	Survival	-0.422	-0.463	-0.366
Gladstone	Survival	0.679*	0.543*	0.566*

* significant at p=0.10
[z] Portage = 26 DAS Gladstone = 32 DAS
[y] Portage = 39 DAS Gladstone = 60 DAS
[x] Portage = 67 DAS Gladstone = 74 DAS

Table 4.23 Correlation coefficients* between root frequency (% of plants with greater than 4 roots) and in-season survival in field studies at Portage La Prairie and Gladstone, MB in 1992.

		Root Number[z]
Portage	Survival 97 DAS	0.794*
Gladstone	Survival 103 DAS	0.486

* significant at p=0.10
[z] Portage = 109 DAS Gladstone = 113 DAS

4.5 Conclusions

The tillage treatment generally resulted in the greatest establishment and development of the sod-seeded grasses tested in this study. Chemical suppression of the resident vegetation improved establishment, development and survival over that in the unsuppressed control. It would appear that under the conditions found in the study, sod-seeding is a feasible seedbed preparation technique to provide dense nesting cover for waterfowl, provided that the resident vegetation is suppressed.

Of the grasses studied, tall and northern wheatgrasses were the most conducive to sod-seeding, while switchgrass and green needlegrass were the most difficult grasses to establish. The smaller seed size of the latter two grasses as compared to the wheatgrasses may be a factor affecting seedling vigour. Seed reserves in the small-seeded crops may have affected seedling growth and survival under the competitive conditions that exist with sod-seeding.

5.0 SUMMARY AND CONCLUSIONS

5.1 Evaluation of Sod-Suppression Techniques

At Portage, where the indigenous vegetation was timothy, results indicated that chemical suppression of the resident vegetation did not enhance plant population density, in-season survival during the year of establishment, overwinter survival or plant population densities the year after establishment. However, effective chemical suppression did enhance leaf development. Scarification also increased plant development at Portage, but had no effect on plant establishment or survival.

Results at Gladstone differed from those at Portage. For example, treatments that effectively suppressed the resident vegetation consistently increased tall wheatgrass densities. Chemical suppression also increased morphological development, in-season survival and overwinter survival. Round-up was the most effective of the herbicide treatments, resulting in the greatest number of leaves per plant, the greatest plant heights and the greatest in-season and overwinter survival rates. The highest plant densities were achieved by Poast in 1991 and Gramoxone in 1992. Scarification did not affect establishment or overwinter survival, but increased plant development and in-season survival rates.

At the Gladstone site, only Round-up and Gramoxone under scarification (1992 establishment year) produced anything close to an acceptable plant population density the year after establishment. All other treatments resulted in densities less than 10 plants m^{-2}. Scarification increased plant density the year after establishment. These results suggest that where competition from the resident vegetation is intense (ie., the Gladstone site), only superior suppression of the resident vegetation will allow for acceptable tall wheatgrass establishment.

The differences in response of tall wheatgrass at Portage and Gladstone indicate the influence of environment on grass establishment. Greater tall wheatgrass morphological development (greater height and Haun stage measurements) and in-season survival rates occurred at Portage as compared to Gladstone. In the harsher environment found at Gladstone, with rhizomatous grasses providing more intense competition, chemical suppression enhanced the success of establishment and the vigour of the plant.

This study clearly demonstrated that tall wheatgrass plants must reach a critical leaf number of three leaves by the end of the first growing season for maximum overwinter survival. This critical stage was achieved in both years at Portage, however, tall wheatgrass plants at Gladstone, especially in 1992, often did not achieve this stage. At

Gladstone in 1992, the treatment of Round-up under scarification was the only treatment to result in plants with three leaves or greater.

5.2 Evaluation of Sod-Seeded Grasses

In the indoor trial, switchgrass generally had the lowest population densities, lowest yield and lowest frequency of plants with more than 4 roots. Temperature may have been one factor limiting the growth and yield of switchgrass in the growth room experiments. The two wheatgrasses, tall and northern wheatgrass, generally had the highest population densities and root frequency. As well, northern wheatgrass had the highest Haun stage values throughout both experiments. Green needlegrass had root frequencies similar to switchgrass (ie., often less than four roots per plant). Results of the controlled environment study suggest that, of the grasses studied, switchgrass would be the most difficult grass to establish under sod-seeding, while the two wheatgrasses would be the most conducive to this seeding method.

Results of the field trials support those from the controlled environment studies. For example, at Portage in 1992, green needlegrass had the lowest densities of all grasses throughout the establishment season, possibly attributable to dormancy. This may restrict its use for sod-seeded dense nesting cover if dense stands of cover are required in the year following seeding. If dormancy is the problem, green needlegrass may be at a disadvantage because resident vegetation would regrow, thereby creating greater competition for the second-year seedlings.

Northern wheatgrass generally had the greatest number of leaves per plant at Portage and had greater root development than switchgrass or green needlegrass at Gladstone. Green needlegrass generally had the lowest number of leaves per plant and root development at Portage. Tall wheatgrass had the greatest yields and greatest root development at both sites. Thus, as in the controlled environment studies, the two wheatgrasses have the greatest establishment under sod-seeding conditions.

At Portage in 1992, greater establishment in the chemical suppression compared with the tillage and unsuppressed treatments was attributed to higher levels of soil moisture and reduced competition. At Gladstone, tillage was required for maximum northern wheatgrass and green needlegrass establishment. However, switchgrass establishment at Gladstone was as successful when the resident vegetation was suppressed by glyphosate as when tillage was used. The chemical suppression treatment resulted in greater Haun stage values than the unsuppressed control for all grasses at Gladstone, and for the two wheatgrasses at Portage (but not for the switchgrass and green needlegrass at this site). All grasses at both sites had as successful root development in the chemically suppressed treatments as in the tillage treatments. However, tillage treatments generally resulted in the greatest plant development (Haun stage and height) and dry matter accumulation of all grasses. Tillage thus resulted in the greatest establishment, however, establishment was increased with chemical suppression as compared to unsuppressed treatments.

5.3 Conclusions

Results of the study indicate that the type of environment in which grasses are to be sod-seeded is a major determining factor as to the level of management required for successful grass establishment, development and survival.

Mowing did not successfully increase plant establishment, development or survival of tall wheatgrass at either site in either year. Although scarification generally did not influence the resident vegetation, plant development and survival of the sod-seeded tall wheatgrass was enhanced by scarification, possibly due to early changes in the soil microclimate.

One goal of Experiment 1 was to enhance grass establishment, development and survival, and not necessarily to increase grass productivity. Plant development at the end of the first growing season and overwinter survival are thus very important parameters in this study. Based on the results of this study, the following conclusions can be made. In a situation where resident vegetation is highly competitive, such as at Gladstone, chemical suppression using glyphosate, or even paraquat, along with scarification is recommended. Without effective suppression, sod-seeding tall wheatgrass would not be possible. In a situation where the resident vegetation is less competitive, such as at Portage, scarification may not greatly improve plant stands, although it did increase year-after-establishment plant population densities in one out of two years. For maximum development and dense stands, chemical suppression along with scarification is again recommended. Glyphosate was the most successful herbicide studied at both sites.

Of the grasses studied, the tall and northern wheatgrasses were the most conducive to sod-seeding, while switchgrass and green needlegrass were the most difficult grasses to establish successfully under sod-seeding. The smaller seed size of the latter two grasses as compared to the wheatgrasses may be a factor. Seed reserves in the small-seeded plants are lower, and this could reduce growth and survival under the competitive conditions that exist with sod-seeding. Dormancy may also be a factor involved with green needlegrass. However, all grasses had similar densities at the end of the season to the more successful treatments in the tall wheatgrass experiment. This suggests that even switchgrass and green needlegrass may be sod-seeded, provided some degree of suppression of the resident vegetation occurs. None of the grasses could be sod-seeded successfully without chemical suppression of the resident vegetation.

Results indicate that it is possible to sod-seed tall and northern wheatgrasses and achieve satisfactory establishment, development and survival when chemical suppression of the resident vegetation is practised. Under these conditions, switchgrass and green needlegrass involve greater risk. Utilizing these grasses in a mixture under sod-seeding conditions may be preferable. Other grasses with less risk involved could be sod-seeded, yet species diversity would be increased by including these grasses.

6.0 FUTURE RESEARCH

Areas of future research include:

- The evaluation of small- vs. large-seeded grasses could determine if, in fact, all small-seeded grasses should be planted in mixtures due to the greater risk involved.

- Sod-seeding switchgrass and green needlegrass in mixtures should be studied to determine if this is possible, or if the competition would limit successful switchgrass and green needlegrass establishment.

- Other grasses could be evaluated, both alone and in mixtures, for their competitive ability, to determine their potential for sod-seeding.

- The biodiversity of the stand could be increased, thereby increasing the stand attractiveness to wildlife, by sod-seeding forbs and shrubs into these grass stands. Management practises that would increase the establishment of sod-seeded forbs, such as burning the grass stand with/without additional chemical suppression, need to be developed.

- Studies on seed-placing fertilizer, especially phosphorus, could be conducted to determine if establishment is increased, without increasing the competition from the resident vegetation to the point that grass establishment is decreased.

- It should be determined if sod-seeding grasses at different times of the year, specifically in the fall, would increase establishment compared to spring seedings.

- Fall applications of glyphosate with/without a subsequent spring application could be evaluated to determine if the control of the resident vegetation is increased.

- Post-establishment management practises, such as the use of fire, to increase the spread of established sod-seeded seedlings would be the next step in this study.

- The long-term establishment, development and survival of these sod-seeded grasses could be evaluated by following the development of the established trials over several years.

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Appendix 1
Environmental Conditions

Table A1.1 Soil test results at Portage La Prairie and Gladstone, MB in 1991 and 1992.

Location	Year	Depth (cm)	Texture	Available Nutrients (kg ha^{1}) NO_3-N	P	K	SO_4-S
Portage	1991	0-15	clay	2.3	11.1	597.0	36.0
		15-60	clay	7.2	-	-	126.0
Gladstone	1991	0-15	clay	11.6	3.5	938.3	28.2
		15-60	clay	22.9	-	-	112.1
Portage	1992	0-15	clay	7.9	20.0	783.0	36.0
		15-60	clay	19.0	-	-	126.0
Gladstone	1992	0-15	VFSCL[z]	22.4	42.6	985.0	30.2
		15-60	VFSC[y]	21.0	-	-	42.0

[z] Very Fine Sandy Clay Loam
[y] Very Fine Sandy Clay

Table A1.2 Monthly mean air temperature and precipitation at Portage La Prairie, MB in 1991 and 1992 (Environment Canada).

	Temperature (°C)		Precipitation (mm)	
	1991	1992	1991	1992
January	-18.4	-11.7	19.5	20.4
February	-8.9	-10.3	16.0	26.3
March	-6.0	-4.0	32.0	15.3
April	6.1	2.0	63.5	28.4
May	13.8	11.4	65.3	13.6
June	18.6	15.0	82.4	46.1
July	19.5	15.6	100.2	111.3
August	20.1	16.0	15.0	41.5
September	11.9	11.2	71.8	51.9
October	1.7	4.6	54.9	2.9
November	-8.1	-4.2	30.5	30.0
December	-11.3	-16.8	44.0	51.5

Table A1.3 Monthly mean air temperature and precipitation at Gladstone, MB in 1991 and 1992 (Environment Canada).

	Temperature (°C)		Precipitation (mm)	
	1991	1992	1991	1992
January	-18.1	-11.5	8.4	17.0
February	-7.7	-9.6	18.4	21.2
March	-5.5	-3.0	36.2	16.4
April	6.4	2.4	52.2	35.6
May	13.8	12.3	45.4	25.6
June	18.4	15.1	146.6	74.8
July	19.6	16.2	104.4	83.8
August	20.0	16.2	15.6	44.2
September	12.2	10.9	74.8	71.0
October	2.0	4.9	52.9	7.6
November	-7.9	-3.6	30.0	25.2
December	-11.4	-16.7	33.4	27.5

Table A1.4 Mean air temperature and precipitation at Portage La Prairie and Gladstone, MB in 1993 (Environment Canada).

	Temperature (°C)		Precipitation (mm)	
	Portage	Gladstone	Portage	Gladstone
January	-14.8	-15.6	16.0	14.8
February	-13.9	-12.2	Trace	Trace
March	-4.0	-2.5	19.0	10.6
April	4.0	4.0	41.0	19.1

Appendix 2
Evaluation of Sod Suppression Techniques - Analysis of Variance

Table A2.1 Mean square values for light interception (%) at Portage in 1991.

Source	df	Days After Seeding			
		23	27	93	128
Rep	3	36.48	111.05	1973.38*	667.66*
Scarification (MP)	1	3327.20*	1917.61*	2.79	88.92
Error a	3	216.65*	140.53	56.43	103.59
Treatment (SP)	5	1298.83*	1637.59*	1724.57*	2950.05*
MP x SP	5	253.10*	170.15*	14.48	107.10
Error b	30	64.52	64.18	115.44	137.61

Table A2.2 Mean square values for light interception (%) at Gladstone in 1991.

Source	df	Days After Seeding				
		20	28	35	89	112
Rep	3	29.22	53.16	121.28*	516.27*	570.28*
Scarification (MP)	1	8.13	3.61	214.9	521.27*	757.32
Error a	3	57.24*	34.36	131.01*	11.13	257.80*
Treatment (SP)	5	75.43*	19.91	72.60*	309.57*	664.31*
MP x SP	5	16.84	15.43	52.66	33.67	87.17
Error b	30	15.99	31.47	31.51	142.4	65.44

Table A2.3 Mean square values for light interception (%) at Portage in 1992.

Source	df	Days After Seeding					
		36	42	68	76	92	99
Rep	3	36.80	63.46*	111.39	277.08*	192.47	124.59
Scarification (MP)	1	115.51	17.28	652.02*	318.22*	126.88	103.84
Error a	3	28.25	29.00	19.71	30.18	52.66	211.20
Treatment (SP)	5	833.25*	85.43*	3004.35*	2494.92*	1862.85*	1510.30*
MP x SP	5	53.92	14.30	72.41	51.52	67.12	113.92
Error b	30	42.66	14.64	90.63	51.87	95.81	136.52

Table A2.4 Mean square values for light interception (%) at Gladstone in 1992.

Source	df	Days After Seeding					
		26	51	71	79	93	104
Rep	3	60.24	52.14	154.17	1560.36*	56.41	247.87
Scarification (MP)	1	798.78*	16.52	7.95	12.03	1.91	91.44
Error a	3	53.82	58.70	78.72	167.34	64.09	115.1
Treatment (SP)	5	1492.81*	1254.03*	651.12*	216.14	189.94	334.34*
MP x SP	5	188.42*	292.46	143.8	138.82	124.26	93.75
Error b	30	67.68	148.16	106.36	140.85	157.43	98.06

Table A2.5 Mean square values for dry matter accumulation of the resident vegetation (kg/ha).

Source	df	Portage		Gladstone	
		1991	1992	1991	1992
Rep	3	1252155.87*	441318.89*	1134190.17*	198029.80
Scarification (MP)	1	1319635.36*	15899.52	1704492.56	819645.87
Error a	3	102366.04	60576.44	446634.15*	180480.01
Treatment (SP)	5	4074947.07*	4548123.69*	773538.08*	1207981.82*
MP x SP	5	714461.68*	251801.60*	66515.46	815819.80*
Error b	30	249175.29	116993.38	134099.91	245802.45

Table A2.6 Mean square values for plant density (plants/m2) at Portage in 1991.

Source	df	Days After Seeding			
		36	69	92	128
Rep	3	422.74	342.36*	257.47*	175.52
Scarification (MP)	1	13.02	52.08	0.52	275.52
Error a	3	446.35	203.47	54.69	343.58*
Treatment (SP)	5	389.27	226.25	144.27	179.27
MP x SP	5	229.27	177.08	104.27	64.27
Error b	30	294.55	124.17	100.66	145.38

Table A2.7 Mean square values for plant density (plants/m2) at Gladstone in 1991.

Source	df	Days After Seeding		
		63	87	112
Rep	3	471.35*	101.39	116.67
Scarification (MP)	1	63.02	8.33	2.08
Error a	3	175.52	40.28	74.31
Treatment (SP)	5	374.27	153.33	118.33*
MP x SP	5	259.27	23.33	19.58
Error b	30	195.94	82.50	55.07

Table A2.8 Mean square values for plant density (plants/m2) at Portage in 1992.

Source	df	Days After Seeding			
		27	40	68	99
Rep	3	1668.06*	1017.19	593.58	633.85
Scarification (MP)	1	1200.00*	567.19	500.52	500.52
Error a	3	168.06	211.63	374.13	397.74
Treatment (SP)	5	321.25	556.77	496.77	360.94
MP x SP	5	311.25	383.44	224.27	176.77
Error b	30	534.31	493.99	458.85	380.80

Table A2.9 Mean square values for plant density (plants/m2) at Gladstone in 1992.

Source	df	Days After Seeding			
		36	58	76	106
Rep	3	851.39*	417.19*	354.69*	197.74
Scarification (MP)	1	2002.08	3250.52	3250.52*	2929.69*
Error a	3	809.03*	772.74*	431.08*	492.19*
Treatment (SP)	5	952.08*	963.44*	818.02*	674.27*
MP x SP	5	313.33	326.77*	388.02*	360.94*
Error b	30	196.04	140.38	144.97	103.72

Table A2.10 Mean square values of covariate analysis of plant density (plants/m2) at Portage in 1992.

Source	df	Days After Seeding
		27
Rep	3	1678.41*
Scarification (MP)	1	843.95
Treatment (SP)	5	324.14
MP x SP	5	311.19
Soil Moisture (27 DAS)	1	96.36
Residual error	32	513.66

Table A2.11 Mean square values for Haun stage at Portage in 1991.

Source	df	Days After Seeding			
		36	69	92	128
Rep	3	0.36*	4.15*	10.65*	5.69*
Scarification (MP)	1	0.55*	6.20	2.51	12.16*
Error a	3	0.05	2.02*	3.65*	0.21
Treatment (SP)	5	0.19*	0.52	9.10*	16.95*
MP x SP	5	0.03	0.55	2.80	2.34
Error b	30	0.07	0.31	1.58	1.31

Table A2.12 Mean square values for Haun stage at Gladstone in 1991.

Source	df	Days After Seeding		
		63	87	112
Rep	3	0.10	1.32*	1.70
Scarification (MP)	1	1.12*	0.01	1.58
Error a	3	0.14	0.09	2.37*
Treatment (SP)	5	0.47*	0.63*	0.90
MP x SP	5	0.33*	0.13	1.07
Error b	30	0.13	0.18	0.90

Table A2.13 Mean square values for Haun stage at Portage in 1992.

Source	df	Days After Seeding			
		27	40	68	99
Rep	3	0.02	0.03	0.09	0.59
Scarification (MP)	1	0.48*	1.57*	13.72*	8.34
Error a	3	0.05*	0.27*	2.34*	9.75*
Treatment (SP)	5	0.02	0.27*	5.41*	47.33*
MP x SP	5	0.01	0.01	0.58	1.87
Error b	30	0.01	0.05	0.42	2.72

Table A2.14 Mean square values for Haun stage at Gladstone in 1992.

Source	df	Days After Seeding			
		36	58	76	106
Rep	3	0.23*	0.85*	1.07	2.53*
Scarification (MP)	1	0.44*	3.49*	9.24*	4.69
Error a	3	0.08*	0.47	0.54	1.51
Treatment (SP)	5	0.60*	3.16*	9.44*	10.55*
MP x SP	5	0.05	1.41*	4.29*	3.18*
Error b	30	0.03	0.31	0.85	0.96

Table A2.15 Mean square values for plant height (cm) at Portage in 1991.

Source	df	Days After Seeding			
		36	69	92	128
Rep	3	6.71*	80.10*	94.56*	46.44*
Scarification (MP)	1	5.84	207.83*	109.68*	85.41*
Error a	3	2.05	6.64	8.52	2.06
Treatment (SP)	5	3.54	11.84	47.07*	54.68*
MP x SP	5	0.57	35.10*	22.18	42.50*
Error b	30	2.19	15.92	18.71	10.10

Table A2.16 Mean square values for plant height (cm) at Gladstone in 1991.

Source	df	Days After Seeding		
		63	87	112
Rep	3	7.34	1.55	34.98*
Scarification (MP)	1	63.34*	44.33*	8.70
Error a	3	8.48	2.81	13.19
Treatment (SP)	5	6.83	4.01	6.71
MP x SP	5	4.00	2.17	23.28
Error b	30	4.34	5.23	12.92

Table A2.17 Mean square values for plant height (cm) at Portage in 1992.

Source	df	Days After Seeding			
		27	40	68	99
Rep	3	7.99*	7.51*	13.29*	24.51*
Scarification (MP)	1	0.27	0.80	9.16	19.15
Error a	3	4.12*	3.68*	17.19*	54.36*
Treatment (SP)	5	1.21	4.24*	9.59*	92.06*
MP x SP	5	0.85	0.40	5.88	15.56
Error b	30	1.08	1.41	3.00	10.04

Table A2.18 Mean square values for plant height (cm) at Gladstone in 1992.

Source	df	Days After Seeding			
		36	58	76	106
Rep	3	0.75	11.18*	14.20	27.27
Scarification (MP)	1	30.69*	56.40*	180.89*	129.10*
Error a	3	3.76*	3.56	7.56	20.69
Treatment (SP)	5	8.16*	40.46*	119.66*	240.27*
MP x SP	5	1.94	9.89*	33.04*	75.30*
Error b	30	1.46	1.72	7.45	17.11

Table A2.19 Mean square values for plant survival (%) at Portage in 1992.

Source	df	Days After Seeding		
		40	68	99
Rep	3	97.63	38.41	49.08
Scarification (MP)	1	234.83	87.35	25.55
Error a	3	95.75	65.19	66.64
Treatment (SP)	5	52.38	50.86	45.54
MP x SP	5	80.52	22.75	45.74
Error b	30	81.20	88.07	45.73

Table A2.20 Mean square values for plant survival (%) at Gladstone in 1992.

Source	df	Days After Seeding		
		58	76	106
Rep	3	411.55	203.64	479.63
Scarification (MP)	1	4256.20*	1328.26*	1910.16
Error a	3	449.51	65.52	387.14
Treatment (SP)	5	1434.75*	293.31	1860.75*
MP x SP	5	465.25	139.81	136.55
Error b	30	246.05	200.11	217.67

Table A2.21 Mean square values for overwinter survival (%) at Portage and Gladstone in 1993.

Source	df	Portage	Gladstone
		Days After Seeding	
		379	398
Rep	3	0.68	668.84
Scarification (MP)	1	406.06	4488.23
Error a	3	87.46	1387.13*
Treatment (SP)	5	140.06	2324.05*
MP x SP	5	170.72	440.76
Error b	30	92.37	497.36

Table A2.22 Mean square values for plant density (plants/m2) at Portage in 1992 and 1993.

		1992	1993
		Days After Seeding	
Source	df	364	379
Rep	3	6.25	563.19
Scarification (MP)	1	75.00	533.33*
Error a	3	443.06*	69.44
Treatment (SP)	5	35.83	209.58
MP x SP	5	76.25	390.83
Error b	30	75.49	382.15

Table A2.23 Mean square values for plant density (plants/m2) at Gladstone in 1993.

		Days After Seeding
Source	df	398
Rep	3	16.67
Scarification (MP)	1	918.75*
Error a	3	96.53*
Treatment (SP)	5	365.83*
MP x SP	5	271.25*
Error b	30	34.10

Table A2.24 Mean square values for Haun stage measurements at Portage in 1992 and 1993.

Source	df	1992	1993
		Days After Seeding	
		364	379
Rep	3	1.53	0.54
Scarification (MP)	1	1.18	30.18
Error a	3	16.24*	10.18
Treatment (SP)	5	14.54*	19.88*
MP x SP	5	2.58	6.97
Error b	30	5.35	5.12

Table A2.25 Mean square values for Haun stage measurements at Gladstone in 1993.

Source	df	Days After Seeding
		398
Rep	3	1.78
Scarification (MP)	1	4.66
Error a	3	2.61
Treatment (SP)	5	3.35
MP x SP	5	2.57
Error b	30	1.96

Table A2.26 Mean square values for plant height (cm) at Portage in 1992 and 1993.

Source	df	1992	1993
		Days After Seeding	
		364	379
Rep	3	34.17	33.10
Scarification (MP)	1	18.11	170.52
Error a	3	39.30	62.08
Treatment (SP)	5	68.67*	70.53*
MP x SP	5	8.17	21.20
Error b	30	25.30	14.78

Table A2.27 Mean square values for plant height (cm) at Gladstone in 1993.

Source	df	Days After Seeding 398
Rep	3	88.10*
Scarification (MP)	1	24.60
Error a	3	79.79*
Treatment (SP)	5	89.44*
MP x SP	5	27.69*
Error b	30	11.39

Table A2.28 Mean square values for Robel pole measurements at Portage in 1992.

Source	df	Average
Rep	3	17.06*
Scarification (MP)	1	2.59
Error a	3	0.71
Treatment (SP)	5	28.90*
MP x SP	5	1.95
Error b	30	1.09

Appendix 3
Evaluation of Sod-Seeded Grasses - Analysis of Variance Controlled Environment Study

Table A3.1 Mean square values for aerial dry matter accumulation of the resident vegetation (g/pot).

Source	df	Portage	Gladstone
Rep	3	0.23	0.12
Sod	1	43.54*	29.13*
Species (Sp)	3	0.25	0.03
Sod x Sp	3	0.25	0.03
Error	21	0.76	0.09

Table A3.2 Mean square values for plant density (plants/pot) at Portage.

		Days After Seeding					
Source	df	6	12	23	33	47	60
Rep	3	1.28	4.11	3.79	2.25	1.53	0.61
Sod	1	0.78	0.28	0.00	0.13	0.28	0.03
Species (Sp)	3	64.11*	41.44*	37.54*	39.75*	40.36*	38.61*
Sod x Sp	3	0.36	0.20	0.42	0.38	0.53	1.86
Error	21	2.28	2.38	2.46	2.32	2.58	2.69

Table A3.3 Mean square values for plant density (plants/pot) at Gladstone.

		Days After Seeding						
Source	df	4	6	9	12	20	30	45
Rep	3	6.42*	0.71	1.88	1.92	1.79	3.38	3.13
Sod	1	8.00*	1.13	3.13	2.00	0.00	0.50	0.50
Species (Sp)	3	77.58*	81.21*	32.04*	27.25*	34.13*	27.21*	25.21*
Sod x Sp	3	7.25*	3.54	1.21	0.08	1.00	0.92	1.08
Error	21	2.58	2.54	1.30	1.35	1.72	1.85	2.05

Table A3.4 Mean square values for plant Haun stage at Portage.

		Days After Seeding				
Source	df	12	23	33	47	60
Rep	3	0.01	0.10	0.21	0.41	0.08
Sod	1	0.25*	2.76*	13.48*	39.12*	48.36*
Species (Sp)	3	1.21*	1.45*	3.12*	4.85*	5.73*
Sod x Sp	3	0.04	0.24	0.14	0.35	1.23*
Error	21	0.06	0.13	0.16	0.30	0.14

Table A3.5 Mean square values for Haun stage at Gladstone.

		Days After Seeding				
Source	df	9	12	20	30	45
Rep	3	0.00	0.01	0.05	0.07	0.11
Sod	1	0.02*	0.51*	2.25*	22.82*	50.28*
Species (Sp)	3	0.03*	0.46*	0.40*	1.60*	3.01*
Sod x Sp	3	0.01*	0.04*	0.12*	0.30*	0.37*
Error	21	0.00	0.01	0.03	0.03	0.10

Table A3.6 Mean square values for plant height (cm) at Portage.

		Days After Seeding					
Source	df	6	12	23	33	47	60
Rep	3	0.16	1.73*	1.58	0.17	5.09	9.61
Sod	1	0.29	0.01	4.08	47.97*	624.19*	1381.41*
Species (Sp)	3	35.78*	96.35*	142.04*	200.90*	150.06*	35.88*
Sod x Sp	3	0.60*	1.13	4.49	11.46*	2.56	48.84*
Error	21	0.18	0.69	3.83	3.70	6.87	12.88

Table A3.7 Mean square values for plant height (cm) at Glatdstone.

		Days After Seeding						
Source	df	4	6	9	12	20	30	45
Rep	3	0.11	0.57	2.04	2.67	3.80*	9.06*	19.27
Sod	1	0.67*	0.99*	0.37	0.68	195.53*	827.23*	2878.32*
Species (Sp)	3	1.51*	18.55*	69.80*	105.22*	218.30*	355.08*	255.25*
Sod x Sp	3	0.65*	1.01*	1.26	0.78	17.05*	44.90*	32.02*
Error	21	0.07	0.27	0.93	1.24	1.31	1.56	8.43

Table A3.8 Mean square values for grass aerial dry matter accumulation (grams/plant).

Source	df	Portage	Gladstone
Rep	3	0.00	0.01
Sod	1	0.13*	0.88*
Species (Sp)	3	0.00	0.07*
Sod x Sp	3	0.00	0.06*
Error	21	0.00	0.01

Table A3.9 Mean square values for root frequency above the critical limit of four.

Source	df	Portage	Gladstone
Rep	3	1690.37*	3309.11*
Sod	1	22.91	0.78
Species (Sp)	3	730.10*	2784.11*
Sod x Sp	3	162.85	521.61
Error	21	236.37	555.54

Appendix 4
Evaluation of Sod-Seeded Grasses - Analysis of Variance Field Study

Table A4.1 Mean square values for light interception (%) of the resident vegetation at Portage.

		Days After Seeding			
Source	df	68	76	92	112
Rep	3	336.43*	811.28*	496.16*	667.16*
Suppression (MP)	2	6939.30*	9591.47*	4617.36*	7759.15*
Error a	6	428.67*	545.63*	715.89*	473.01*
Species (SP)	3	63.77	59.17	27.72	72.00
MP x SP	6	58.79	12.14	80.98	41.48
Error b	27	54.01	75.55	99.59	44.56

Table A4.2 Mean square values for light interception (%) of the resident vegetation at Gladstone.

		Days After Seeding					
Source	df	25	60	70	78	92	113
Rep	3	40.34	289.64*	154.83	155.97*	287.40	116.38
Suppression (MP)	2	4477.66*	2032.19	167.72	207.88	226.85*	14.46
Error a	6	31.64	440.73*	72.94	56.54	5.95	33.10
Species (SP)	3	94.55*	28.16	164.91	33.92	84.95	85.92
MP x SP	6	83.07	67.06	113.84	56.20	50.26	127.70
Error b	27	36.33	95.34	115.90	54.99	148.31	57.62

Table A4.3 Mean square values for aerial dry matter accumulation of the resident vegetation (kg/ha) in 1992.

Source	df	Portage	Gladstone
Rep	3	882945.51*	104005.20
Suppression (MP)	2	21635011.17*	21093997.27*
Error a	6	613893.97*	69266.31
Species (SP)	3	176717.24	28302.44
MP x SP	6	130651.06	129218.72
Error b	27	203527.75	186178.69

Table A4.4 Mean square values for plant density (plants/m2) at Portage.

		Days After Seeding				
Source	df	19	26	39	67	97
Rep	3	1036.81*	360.24	279.17	1054.69	531.08
Suppression (MP)	2	1413.02*	1038.02	1748.44	3722.40*	4363.02*
Error a	6	406.08	576.91	929.69	795.31	664.41
Species (SP)	3	3140.97*	3299.13*	4743.06*	3667.19*	3393.58*
MP x SP	6	576.91	955.38*	866.49	597.40	472.74
Error b	27	329.28	410.71	479.98	640.57	519.04

Table A4.5 Mean square values for plant density (plants/m2) at Gladstone.

		Days After Seeding				
Source	df	18	32	60	74	103
Rep	3	2542.19*	4134.03*	5103.47*	4223.61*	3586.63*
Suppression (MP)	2	32459.90*	34932.81*	35654.69*	35397.40*	37108.33*
Error a	6	3428.65*	1943.92	2768.58	3000.17	2811.11
Species (SP)	3	7382.47*	9325.69*	15503.47*	15351.39*	15585.24*
MP x SP	6	3281.42*	3535.59*	3768.58*	3255.03*	3665.97*
Error b	27	1021.59	1633.68	1415.86	1569.10	1414.99

Table A4.6 Mean square values for Haun stage at Portage.

		Days After Seeding			
Source	df	19	26	39	67
Rep	3	0.00	0.04	0.18*	1.30
Suppression (MP)	2	0.01*	0.40*	4.77*	86.94*
Error a	6	0.00	0.03	0.10	1.66*
Species (SP)	3	0.01	0.26*	0.69*	5.93*
MP x SP	6	0.00	0.04	0.20*	1.54*
Error b	27	0.00	0.02	0.05	0.57

Table A4.7 Mean square values for Haun stage at Gladstone.

		Days After Seeding			
Source	df	18	32	60	74
Rep	3	0.00	0.60*	2.03	0.55
Suppression (MP)	2	0.01	8.36*	146.32*	214.95*
Error a	6	0.00	0.32*	1.88*	2.15
Species (SP)	3	0.01	0.33*	4.59*	7.54*
MP x SP	6	0.01	0.11	2.18*	1.94
Error b	27	0.01	0.08	0.90	1.28

Table A4.8 Mean square values for plant height (cm) at Portage.

		Days After Seeding				
Source	df	19	26	39	67	97
Rep	3	0.12	3.26	0.56	0.09	32.74*
Suppression (MP)	2	1.93	5.49	37.62*	178.20*	1533.19*
Error a	6	0.99	1.18	1.53*	6.13	55.02*
Species (SP)	3	33.77*	51.14*	54.93*	70.96*	24.04
MP x SP	6	0.81	0.27	3.09*	8.74*	14.47
Error b	27	0.58	1.98	0.65	4.33	10.52

Table A4.9 Mean square values for plant height (cm) at Gladstone.

		Days After Seeding				
Source	df	18	32	60	74	103
Rep	3	0.14	4.23	21.59*	55.41*	65.70
Suppression (MP)	2	22.62*	120.15*	1545.63*	3299.17*	10022.96*
Error a	6	0.26	4.07*	8.65*	24.66	13.60
Species (SP)	3	23.99*	59.08*	189.70*	151.08*	201.03*
MP x SP	6	5.26*	10.04*	49.62*	44.07*	163.57*
Error b	27	0.36	1.93	3.85	13.52	38.80

Table A4.10 Mean square values for grass aerial dry matter accumulation (grams/plant) in 1992.

Source	df	Portage	Gladstone
Rep	3	2.57*	2.55*
Suppression (MP)	2	35.17*	119.35*
Error a	6	2.99*	2.42*
Species (SP)	3	2.28*	18.85*
MP x SP	6	35.17*	8.34*
Error b	27	0.15	0.83

Table A4.11 Mean square values for root frequency above the critical limit of four.

Source	df	Portage	Gladstone
Rep	3	460.02*	75.81
Suppression (MP)	2	11077.94*	21011.08*
Error a	6	401.27*	97.64
Species (SP)	3	1432.80*	1726.81*
MP x SP	6	1207.38*	1314.64*
Error b	27	153.08	64.68

Table A4.12 Mean square values for plant survival (%) at Portage.

		Days After Seeding			
Source	df	26	39	67	97
Rep	3	210.40	181.55	221.17	66.11
Suppression (MP)	2	4269.04*	1264.67	401.99*	300.36
Error a	6	255.16	588.25*	98.96	89.35
Species (SP)	3	577.79	411.96	294.26	108.46
MP x SP	6	808.80*	331.51	95.71	50.33
Error b	27	294.49	230.66	129.34	64.37

Table A4.13 Mean square values for plant survival (%) at Gladstone.

		Days After Seeding			
Source	df	32	60	74	103
Rep	3	575.72	141.84	18.09	51.76
Suppression (MP)	2	5309.07*	4326.10*	88.16*	1324.01*
Error a	6	634.24	339.25*	14.12	27.76
Species (SP)	3	1221.64*	396.89*	15.94	159.30
MP x SP	6	740.62	504.79*	15.40	194.57
Error b	27	398.35	119.65	29.63	107.44

Appendix 5
Sod-Seeded Grass Heights

Table A5.1 Influence of soil type and grass species on plant height (cm)* in a controlled environment study using the Portage La Prairie soil.

		DAYS AFTER SEEDING					
SOIL TYPE	SPECIES	6	12	23	33	47	60
SOD	SWITCHGRASS	0.6	1.1	2.7	4.0	4.9	8.2
SOD	GREEN NEEDLEGRASS	2.9	6.6	8.9	11.3	12.8	13.0
SOD	TALL WHEATGRASS	5.9	10.0	12.3	14.2	15.0	17.0
SOD	NORTHERN WHEATGRASS	4.4	6.6	10.6	11.1	12.7	14.4
SOIL	SWITCHGRASS	0.5	1.3	3.7	5.4	13.8	25.3
SOIL	GREEN NEEDLEGRASS	3.2	6.8	10.3	10.9	21.2	30.5
SOIL	TALL WHEATGRASS	4.9	8.9	14.3	19.2	22.7	24.1
SOIL	NORTHERN WHEATGRASS	4.4	7.3	9.1	14.8	23.0	26.1
	Mean	3.4	6.1	9.0	11.4	15.8	19.8
$L.S.D._{(0.10)}$		0.5	1.0	2.4	2.3	3.2	4.4
SOIL TYPE		ns	ns	ns	*	*	*
SPECIES		*	*	*	*	*	*
INTERACTION		*	ns	ns	*	ns	*

* significant at p=0.10

Table A5.2 Influence of soil type and grass species on plant height (cm)* in a controlled environment study using the Gladstone soil.

		DAYS AFTER SEEDING						
SOIL TYPE	SPECIES	4	6	9	12	20	30	45
SOD	SWITCHGRASS	0.2	0.2	1.1	1.3	2.5	5.1	6.2
SOD	GREEN NEEDLEGRASS	1.1	2.7	4.7	6.1	8.0	11.5	13.2
SOD	TALL WHEATGRASS	2.2	4.5	8.5	10.1	11.4	15.5	16.3
SOD	NORTHERN WHEATGRASS	1.5	3.7	6.6	7.4	10.8	11.9	13.0
SOIL	SWITCHGRASS	0.2	0.4	0.9	1.4	3.9	8.3	21.2
SOIL	GREEN NEEDLEGRASS	1.0	2.5	5.6	7.3	14.6	24.0	37.6
SOIL	TALL WHEATGRASS	1.0	3.1	7.4	9.9	19.3	29.3	35.5
SOIL	NORTHERN WHEATGRASS	1.4	3.5	6.2	7.6	14.5	23.2	30.2
	Mean	1.1	2.6	5.1	6.4	10.6	16.1	21.7
$L.S.D._{(0.10)}$		0.3	0.6	1.2	1.4	1.4	1.5	3.5
SOIL TYPE		*	*	ns	ns	*	*	*
SPECIES		*	*	*	*	*	*	*
INTERACTION		*	*	ns	ns	*	*	*

* significant at p=0.10

Table A5.3 Influence of suppression treatment and grass species on plant height (cm)* in a field study at Portage La Prairie, MB in 1992.

SUPPRESSION	SPECIES	DAYS AFTER SEEDING 19	26	39	67	97
CONTROL	SWITCHGRASS	1.0	1.9	2.3	4.8	6.1
CONTROL	GREEN NEEDLEGRASS	3.0	3.3	4.5	5.7	8.7
CONTROL	TALL WHEATGRASS	4.2	5.6	5.3	8.4	10.4
CONTROL	NORTHERN WHEATGRASS	4.5	4.3	5.1	8.1	8.1
CHEMICAL	SWITCHGRASS	0.4	1.4	2.6	6.6	14.5
CHEMICAL	GREEN NEEDLEGRASS	3.9	4.3	6.0	11.0	16.5
CHEMICAL	TALL WHEATGRASS	5.8	7.1	8.9	14.6	20.8
CHEMICAL	NORTHERN WHEATGRASS	4.7	5.5	7.4	12.0	20.2
TILLAGE	SWITCHGRASS	0.9	1.5	3.7	9.5	29.2
TILLAGE	GREEN NEEDLEGRASS	3.4	4.3	8.7	14.0	26.6
TILLAGE	TALL WHEATGRASS	6.1	7.4	8.9	13.4	28.1
TILLAGE	NORTHERN WHEATGRASS	5.0	5.6	8.1	16.2	27.8
	Mean	3.6	4.3	6.0	10.4	18.1
$L.S.D._{(0.10)}$		1.0	1.7	1.2	2.8	6.1
MP		ns	ns	*	*	*
SP		*	*	*	*	ns
MP x SP		ns	ns	*	*	ns

* significant at p=0.10

Table A5.4 Influence of suppression treatment and grass species on plant height (cm)* in a field study at Gladstone, MB in 1992.

		DAYS AFTER SEEDING				
SUPPRESSION	SPECIES	18	32	60	74	103
CONTROL	SWITCHGRASS	1.4	1.9	3.0	4.3	4.4
CONTROL	GREEN NEEDLEGRASS	2.3	2.9	5.6	6.2	7.2
CONTROL	TALL WHEATGRASS	2.2	3.6	6.1	5.8	6.6
CONTROL	NORTHERN WHEATGRASS	2.0	3.5	5.9	6.6	6.7
CHEMICAL	SWITCHGRASS	0.7	2.5	7.8	10.8	16.8
CHEMICAL	GREEN NEEDLEGRASS	2.5	4.8	10.0	13.4	19.1
CHEMICAL	TALL WHEATGRASS	4.8	7.4	14.7	18.0	22.9
CHEMICAL	NORTHERN WHEATGRASS	3.2	5.8	14.5	18.9	21.7
TILLAGE	SWITCHGRASS	0.7	2.8	13.0	24.9	50.2
TILLAGE	GREEN NEEDLEGRASS	4.5	9.0	28.2	35.9	65.0
TILLAGE	TALL WHEATGRASS	7.3	11.7	28.1	40.7	62.8
TILLAGE	NORTHERN WHEATGRASS	6.2	10.1	28.6	34.3	41.4
	Mean	3.1	5.5	13.8	18.3	27.1
$L.S.D._{(0.10)}$		0.7	2.0	2.9	5.1	7.0
MP		*	*	*	*	*
SP		*	*	*	*	*
MP x SP		*	*	*	*	*

* significant at p=0.10