EVALUATION FOR
GRAZING TOLERANCE IN ALFALFA

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THESIS SUBMITTED TO THE
FACULTY OF GRADUATE STUDIES
UNIVERSITY OF MANITOBA

IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE, DEPARTMENT OF PLANT SCIENCE

0-612-41683-6

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University
of Manitoba in partial fulfillment of the requirements of the degree
of
Master of Science

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Abstract

Knowledge of plant characteristics that are associated with grazing tolerance of alfalfa (*Medicago sativa* L.) would help in the development of cultivars that are tolerant of close continuous grazing. The objectives of this study were to characterize a broad range of cultivars for tolerance to grazing and evaluate these cultivars for traits that have been associated with grazing tolerance within one grazing season. A series of 10 experiments were established from seed (Glenlea, MB; Brandon, MB) or from transplants (Portage la Prairie, MB) and were subjected to either close continuous grazing or rotational grazing with beef cattle. Cultivars were evaluated ground cover, stand density, stem production and decumbency, crown area, crown bud production, secondary root number, crown depth, nitrogen concentration and total nonstructural carbohydrates (TNC) during each grazing season. There were few differences between cultivars for stand persistence after one season of grazing at all locations. There was no ground cover correlation between continuous and rotational grazing in microplots ($r=0.03$, $p<0.82$) and a low correlation for large plots ($r=0.36$, $p<0.0003$). Cultivar differences were present for some plant traits (e.g. decumbency, crown bud production), but there was no consistent trend across traits or between experiments. The results suggest that in the short growing season that occurs in western Canada, more than one season of grazing is necessary for the evaluation of alfalfa persistence and plant traits using either seeded stands or transplants.

Abbreviations:

TNC - Total nonstructural carbohydrates

n.s. - Means do not differ significantly ($p \leq 0.05$)

Keywords: Alfalfa, root and crown morphology, total nonstructural carbohydrates, grazing tolerance, continuous grazing, rotational grazing, transplants

Evaluation of Techniques for Selection for Grazing Tolerance

1. Introduction

Grazing alfalfa (*Medicago sativa* L) on a continuous basis offers many advantages over the use of alfalfa either in a rotational grazing program or the use of grass-only pastures. The use of alfalfa under continuous grazing has a lower cost than under rotational grazing because of reduced fencing and labour expenditures. The primary benefit of grazing alfalfa is higher animal productivity through increased rate of gain due to higher protein and energy content. Alfalfa also provides higher dry matter production and better seasonal distribution of growth than most grasses which allows higher stocking densities to be maintained. Nitrogen fixation reduces the need for commercial fertilizer application. Alfalfa shows higher production than grasses under drought conditions because it's deep taproot allows for retrieval of water from further down in the soil profile. In the future, these benefits will have even greater significance with the development of low bloat and possibly bloat free alfalfa.

Currently recommended alfalfa cultivars in western Canada are either creeping rooted types or hay-types. Generally hay-type cultivars do not persist under grazing, or must be rotationally grazed. A hay-type alfalfa cultivar is one which was selected to yield when cut for hay several times per year. Creeping rooted cultivars have been selected for the creeping rooted trait. These cultivars produce new shoots from lateral roots that can extend some distance from the original plant crown. Therefore, they are able to "creep" or spread when planted in a pasture. These cultivars are winterhardy and tolerate grazing, but are also associated with lower productivity than hay-type cultivars. It is obvious that the development of cultivars that maintain the yield of hay-types combined with persistence under grazing would be desirable. This would create true "dual purpose" alfalfa cultivars.

The objectives of this study were to 1) evaluate a broad range of cultivars to characterize their tolerance to close continuous grazing and rotational grazing; 2) to evaluate these cultivars for characteristics that have been associated with grazing tolerance; 3) to determine if cultivar differences for grazing tolerance will be apparent after one season of grazing.

2. Literature Review

2.1 General Considerations for Grazing Tolerance

Alfalfa plants are capable of surviving grazing by livestock provided that there is a sufficient rest interval between grazing periods to allow the plant to restore root carbohydrate levels for regrowth. This rest period should be in excess of 35 days (Lodge 1991). However, cultivars can be developed which combine the higher yield of hay-types with the ability to persist under continuous grazing without requiring a rest period which will allow their use in continuously grazed pastures possible. The first cultivar of this type was developed and released from the University of Georgia as 'Alfagraze' (Bouton et al. 1991). The development of grazing tolerant alfalfas has traditionally been done using frequent clipping by mechanical means, but Alfagraze was developed using actual grazing animals. Animals induce a significantly greater stress on the plant by subjecting the plant to continuous daily harvesting, trampling of the plant crowns, pulling on the plants by the animals and subjecting the plants to waste excretion (Smith et al, 1989). These severe stresses quickly sorted out the grazing tolerant plants from the intolerant ones.

In Australia Lodge (1985) reported that the greatest stand loss in grazed alfalfa occurred after two years of grazing, but there were no differences between cultivars from different fall dormancy groups after four seasons of grazing. Reynolds (1971) showed that alfalfa in Tennessee stands declined severely even in one year when they were clipped eight times. Two year stands, clipped five or six times a season, were also severely reduced. Leach et al (1984) reported that grazing duration had a greater effect on species composition than the length of the rest interval. Matches (1968) in Missouri found that bromegrass disappeared from a mixture with alfalfa under rotational grazing by cattle or sheep, or with a mowing treatment indicating that alfalfa was more competitive under these conditions. Nuttall et al (1980) reported increases in the forage production of bromegrass in a mixture with alfalfa with the application of nitrogen fertilizer in the first year of grazing. The percentage of alfalfa in the mixture increased from the second through the fifth year of rotational grazing when no fertilizer or only phosphate was applied. No change in species composition occurred over this same time period when nitrogen was applied. Counce et al (1984) reported higher alfalfa plant mortality occurred under grazing compared to clipping in Georgia. Cultivar mortality differed after two years of grazing, but not after two years of clipping. The lack of difference between cultivars under mowing and no correlation between clipping and grazing mortality led these researchers to suggest that the methods of defoliation had different effects on alfalfa persistence.

2.2 Developing Grazing Tolerant Cultivars

Berdahl et al (1989) reported alfalfa cultivars that spread by creeping roots increased in number when inter-seeded into rangeland after 7 years, while hay-type alfalfa cultivars decreased. They noted that stand densities were more reliable when made 2 years after establishment than when taken after one year as the stand rapidly declined for all cultivars after the first year. Berdahl et al (1989) noted faster regrowth for hay type alfalfa cultivars and suggested that the slower regrowth of the more persistent cultivars may be a factor in the maintenance of root carbohydrate reserves. Berdahl et al (1986) also noted that alfalfa plants with rapid regrowth after harvesting tended to have low survival.

Heinrichs (1973) stated that alfalfa cultivars with higher genetic levels of *Medicago sativa* ssp. *falcata* (L.) resulted in greater winterhardiness and deeper crowns than *Medicago sativa* ssp. *sativa* (L.) cultivars. These traits are also important for survival in pastures in Western Canada. Falcata germplasm is characterized as having a slower growth rate than *Medicago sativa* ssp. *sativa* (L.), lower yield in the latter part of the growing season, and increased winterhardiness. The majority of cultivars used in Western Canada include both types of germplasm and are known as *Medicago sativa* ssp. *media*. This combines the higher growth rates of sativa and the positive attributes of falcata. Heinrichs and Morley (1960) found a positive correlation between winterhardiness and increased creeping root expression. Heinrichs (1973) spent much of his career developing creeping rooted cultivars that could be planted in pastures.

2.3 Stand Assessment

Under grazing conditions, alfalfa must maintain a sufficient plant population to remain productive. The development of grazing tolerant cultivars must include an evaluation of plant persistence under grazing or clipping stress. Lodge and Gleeson (1984) compared methods of assessing plant populations. They found that crown counts underestimated true plant numbers at higher populations due to the inability to accurately determine the number of adjacent plants. They concluded that the use of a wire grid (5 or 10 cm spacing) to estimate frequency was more reliable at higher populations than plant counts. Smith et al (1989) stated that stem density was a better measure of stand productivity than plant numbers. Smith et al (1992) reported higher plant numbers for Alfagraze and another grazing tolerant germplasm than for 'Apollo' and 'Spredor II' in both pure and mixed stands after one, two and three years of grazing. In stands of alfalfa mixed with tall fescue, plant survival was reduced over that occurring in pure stands. Assessing plant survival using a wire grid is faster and more accurate than plant counts. At high populations, plant counts will underestimate the actual plant number when several plants are growing closely together.

Bittman and McCartney (1994) used a 'mob' grazing system in northern Saskatchewan where large numbers of animals are placed into the test area for short periods of time. The frequency of grazing determines the grazing pressure. They found the ground cover of the hay-type cultivar 'Beaver' declined more than the creeping rooted cultivars 'Rambler', 'Rangelander' and 'Heinrichs', which are used for long term production. The falcata cultivar 'Anik' and falcata germplasm 'SCMF 3713', increased in ground cover after four years of grazing. The cultivars in this test differ greatly in winterhardiness, but under conventional cultivar yield evaluation experiments, which are managed to minimize winter injury, differences were not evident. The more persistent Anik and SCMF 3713 actually showed lower yields in these trial. When yield data at the end of the trials was examined, these cultivars compared more favourably. They also found a correlation between yield and ground cover under grazing, suggesting that ground cover can be used to evaluate alfalfa under grazing.

In Virginia, Allen et al (1996a) reported that plant density decreased in the third grazing season in plots grazed for six weeks when compared to a grazing duration of two or four weeks in each of year one and two respectively. Under a lower grazing pressure, differences were not evident for different grazing durations. In Georgia, Smith et al (1989) reported high plant reductions for hay-type cultivars, medium stand reductions for creeping rooted cultivars and a lower reduction for Alfagraze after three years of grazing. They reported the same differences for ground cover. Smith and Bouton (1993) reported higher plant densities for populations selected under grazing from each of Apollo, 'Florida 77', Spredor II and 'Travois' than for their parental cultivars after 2 years of grazing. There was no difference between Alfagraze and a population selected from it in the same trials.

Brummer and Bouton (1991) felt that more than one year of evaluation may be needed to differentiate between cultivars in the southern U.S. for grazing persistence. Smith and Bouton (1993) stated that two or more years under grazing may be required to differentiate between cultivars. In their comparisons of persistence under grazing, differences between cultivars were apparent after one season in one trial, but a second trial required two seasons for cultivar differences to appear.

2.4 Yield

Cuykendall and Marten (1968) found that in the second and subsequent growing seasons, yield of alfalfa was higher under grazing than when cut for hay. They felt that potassium deposited in the excreta from sheep was responsible for the higher yield. When high levels of potassium fertilizer were applied, the differences disappeared. Bittman et al (1991) found that in northern Saskatchewan mixed alfalfa/bromegrass (*Bromus inermis* Leyss) stands showed increased alfalfa yields when fertilized with phosphate while the yield of bromegrass remained the same. They felt that this was due to competition for nutrients between the grass and the alfalfa.

Wolf and Allen (1990) reported that spring grazing in Virginia had no effect on subsequent hay yields later in the season, or the next year. They found that summer grazing reduced hay production in the fall, but not during the following year. When examining the effects of clipping frequency in Wisconsin, Smith and Nelson (1967) found yields of alfalfa decreased as cutting frequency increased in the first year. They found that with three or four harvests, yields decreased if a higher cutting height was used, but with six harvests, yields were greater with a higher cutting height. Wolf and Smith (1963) reported higher yields when alfalfa-grass mixtures were cut three times rather than five. Reynolds reported optimum yields occurred with three or four harvests in the second season. Lodge (1985) reported higher yields under grazing for the less dormant cultivars under Australian conditions.

Before 1991, cultivars that were used in pastures were developed using clipping as the defoliation method. However, alfalfa reacts differently depending on whether it is grazed or clipped. The development of grazing tolerance in alfalfa should include stress from grazing. The creeping rooted trait and the use of *Medicago sativa* ssp. *falcata* (L.) have been used in the development of cultivars for use in pastures. However, these characteristics result in lower yield potential, especially later in the season. While the use of falcata germplasm increases winterhardiness which is required in western Canada, the development of cultivars that are higher yielding and have the ability to maintain productivity throughout the season and over many seasons is most desirable. The development of cultivars with these characteristics will require several seasons of evaluation under grazing.

2.5 Morphology

Various plant development characteristics have been associated with grazing tolerance in other studies. Morphological characteristics that correlate with grazing tolerance, but do not result in reduced yield, could be used in a selection procedure for the development of new cultivars. Selecting directly for these characteristics would reduce the time for the development of cultivars suitable for use under grazing.

2.5.1 Stem Density

Smith et al (1989) reported that stem density is highly correlated with percent ground cover, and that stem density is a determining factor in forage productivity. This holds promise in measuring productivity under continuous grazing where plants are not allowed to accumulate much above ground tissue. It has been reported that Alfagraze has high stem numbers which are associated with grazing tolerance (Brummer and Bouton, 1991). Brummer and Bouton found an initial increase in stem number during frequent clipping (used to simulate grazing), followed by a slight decrease later on in the season. They found differences between alfalfa entries, comparing both original cultivars and selected lines from these cultivars, early in the season, but these differences disappeared by the end of the season for both sets of plants. Smith et al (1989) found the grazing tolerant cultivar Alfagraze initially had a higher stem density than both hay-type and creeping rooted cultivars. Alfagraze and the creeping rooted cultivars had higher stem densities than the hay type after three seasons of grazing. Juan et al (1994) did not find differences for shoot numbers or for the relative proportion of crown and stubble shoots in five cultivars of different fall dormancy. Allen et al (1986a) reported that under high grazing pressure by sheep stem density decreased over time in the second year of spring grazing. This did not carryover into the third year when grazing did not occur. Allen et al (1986b) reported that when grazed in the summer, stem density in fall regrowth was decreased with increasing length of the grazing period in each of two successive years of grazing. Stem density taken immediately after grazing ended showed the same pattern after the first year of grazing, but not after the second.

2.5.2 Crown Characteristics

Crown size is also associated with grazing tolerance (Berdahl et al 1989; Daday 1968) where a larger size is associated with greater persistence. However, Brummer and Bouton (1991) did not find any differences in their study between either original cultivars or selections from these original cultivars by the end of one growing season. Smith et al (1992) did not find crown size differences between cultivars that differed in persistence under grazing. Also, crown depth (Teuber and Brick, 1988) has been reported to be important for grazing persistence. Brummer and Bouton (1991) found that Alfagraze produced the most crown buds at the end of the grazing season, but there was little difference between other cultivars in this study which included grazing tolerant cultivars and hay-type cultivars.

Brummer and Bouton (1991) reported that thin stems and decumbent growth were also associated with persistence under frequent mechanical harvests (used to simulate grazing). They found that with all five cultivars in their experiment, decumbency generally increased over the growing season. Interestingly, the most grazing tolerant cultivar, Alfagraze, showed an intermediate decumbency score between the two hay-type and the two creeping rooted cultivars. They also found that stems generally became thinner during the growing season, with the thickest stems being produced by the hay-type cultivars, the thinnest stems produced by the creeping rooted cultivars, and Alfagraze being intermediate to the two groups. This experiment suggests that a specific crown type or stem type is not required for tolerance to grazing in alfalfa.

Crown characteristics have been associated with persistence of alfalfa under grazing with larger, deeper crowns associated with plants that are more persistent (Berdahl et al, 1989). Crown bud production has been associated with increased tolerance to grazing. As more crown buds develop into stems, the size of the crown increases. Decumbency is a method of grazing avoidance where more prostrate stems are less likely to be removed. While helping to reduce plant mortality, it effectively reduces the yield of forage available to animals. Detailed measurement of crown characteristics is time consuming and, therefore, more expensive to evaluate than characteristics such as stem density and decumbency. Traits that can be evaluated rapidly are advantageous in developing cultivars that are grazing tolerant.

2.6 Ground Cover

Smith et al (1989) found much lower ground cover was present under continuous grazing conditions by hay-type alfalfa cultivars than creeping rooted cultivars, with Alfagraze ranking the highest. Ground cover is defined as the amount of plant material covering the soil surface. Therefore crown size, stem number and crown leaves are all factors that make up ground cover. Brummer and Bouton (1992), and Smith et al (1992) report that basal leaf retention is also important for grazing tolerance. Smith and Nelson (1967) reported that a leafy stubble was important for alfalfa survival when frequently harvested. This provides a carbohydrate supply during grazing which can be utilized for regrowth instead of relying on root carbohydrate storage (Smith and Nelson, 1967). Birdsfoot trefoil (*Lotus corniculatus* L.) is a species that has characteristic decumbent growth habit allowing it to maintain leaf area below grazing height. In alfalfa, decumbency could be important in avoiding consumption of the entire plant. Counce et al (1984) reported that grazing persistent upright cultivars grew more slowly than upright cultivars that were not persistent, therefore partitioning a higher level of photosynthate to restoring root reserves. Hodgkinson et al (1972) found that when partially defoliated, older leaves of alfalfa can increase their photosynthetic rate to the levels of new leaves.

2.7 Root Physiology

Alfalfa utilizes stored nutrients from the crown and root for regrowth in the spring, regrowth following herbage removal and to survive over winter. The greatest quantity of storage compounds are carbohydrates but nitrogenous compounds are also important. During the growing season, these are removed rapidly during the early stages of plant regrowth and then slowly replaced. Continual herbage removal and subsequent regrowth can result in the depletion of these crown and root reserves and eventual plant death. The development of cultivars that can withstand continual removal of herbage without depleting root reserves would be desirable for use under continuous grazing.

2.7.1 Root Carbohydrates

Nonstructural carbohydrates are all cellular carbohydrates that are not part of the cellular structure (ie - cellulose and hemicellulose) and include starches and sugars. Frankhauser and Volenec (1989) reported that plants with rapid shoot elongation rates had more total nonstructural carbohydrates (TNC) than those with slow shoot elongation rate stems. During the first two weeks of regrowth, TNC levels were similar, but by four weeks, plants with rapid shoot elongation rates had 54% higher TNC concentrations. Boyce and Volenec (1992) compared high and low starch alfalfa genotypes for regrowth and winter survival. They found that low starch plants had a higher shoot regrowth rate, but were affected more by winter stresses.

Allen et al (1986a) reported that TNC levels in alfalfa remained low during spring grazing, but increased rapidly after grazing ended. Allen et al (1986b) reported lower TNC levels after two, four, and six weeks of grazing compared to the starting levels after the first season of summer grazing, but not after the second season. In both years, the lowest TNC levels occurred after four weeks of grazing.

Brummer and Bouton (1992) reported that Florida 77, a grazing intolerant cultivar, and Alfagraze maintained high carbohydrate levels under infrequent clipping, but under frequent clipping, only Alfagraze maintained high levels. Travois, a creeping rooted cultivar, had low levels under both clipping programs.

Counce et al (1984) reported that grazing intolerant cultivars showed the greatest decrease in TNC levels during regrowth. The smallest decrease occurred for the creeping rooted types and an intermediate decrease occurred for the grazing tolerant upright type alfalfa cultivars.

They suggested that cultivars with faster regrowth rates allow for more frequent grazing, but that higher utilization of root TNCs for regrowth would lead to faster depletion of root reserves, and therefore, higher mortality rates. Juan et al (1994) reported increasing concentrations of TNC concentrations with decreasing fall dormancy in five alfalfa entries under two harvest regimes. Smith et al (1989) reported that the hay-type alfalfa cultivars Apollo and Florida 77 had the lowest TNC concentrations compared to the grazing tolerant Alfagraze and Travois, with Spredor II being intermediate after grazing ended. Smith et al (1992) stated that Alfagraze and a grazing tolerant germplasm maintained higher root TNC concentrations than Apollo and Spredor II in both pure and mixed stands.

Smith and Silva (1969) reported that at seven days after cutting, all of the new growth was produced from root reserves. By 42 days after harvest, 93% of the new growth was from photosynthate. Smith and Marten (1970) found that as regrowth progressed, an increasing proportion of the carbohydrates in the shoots were from photosynthate.

Nelson and Smith (1968), and Smith (1961) reported a cyclical pattern for carbohydrate root reserves with an initial decrease in the spring and after each harvest and a corresponding increase as foliage increased. Brown et al (1990) reported that root TNC concentrations increased in the fall even though harvesting was still being conducted. Jung and Smith (1961) reported that TNC concentration in roots peaked in September in Wisconsin at 57% TNC of the total dry weight, slowly decreased until February (42% TNC) and then a rapid decrease occurred so that by April

TNC levels were less than 10%. The largest proportion of the TNC was starch. Rong et al (1996) reported accumulation of starch through October in Indiana followed by a decrease over winter accompanied by an increase in ethanol soluble sugars. Kust and Smith (1961) found that higher levels of TNC in roots in the fall was associated with higher forage yields in the following year. More frequent harvesting tended to reduce TNC in the fall. Cooper and Watson (1968) found that total available carbohydrate in roots decreased to a lower level after each successive cutting under a four cut system in Montana. After the fourth cutting at the end of August, carbohydrate levels did not decrease from their preharvest level, only slowed in their increase. Feltner and Massengale (1965) reported that the time lapse from the initial TNC decrease after harvest to the initial increase was less in alfalfa plants cut less frequently.

Chatterton et al (1974) found that plants tolerant of frequent harvesting had lower crown weights than those not tolerant of frequent harvesting. Plants tolerant of frequent harvesting also had higher TNC concentrations than those that were intolerant, but due to lower crown weights, TNC weight per plant was lower. Plants that produced higher tiller numbers also produced higher crown weights, TNC concentrations and TNC weight per plant, and root dry weight than plants that produced fewer tillers. Clones of the clipping tolerant field plants grown indoors had higher TNC concentrations and TNC weight per plant than clones of plants intolerant of frequent harvesting at the beginning of flowering. Regrowth of plants intolerant of frequent harvesting was faster than that of tolerant plants. Reynolds (1971) reported higher concentrations of carbohydrate in the surviving plants from plots harvested eight times the previous year than from plants in plots harvested less frequently. Chatterton et al (1977) found that alfalfa plants tolerant of frequent harvests had higher concentrations of TNC and phosphorous in the roots and crowns than plants intolerant of frequent harvesting. They found that soluble carbohydrates were higher in high yielding plants as well.

Alfalfa must be able to survive with low TNC levels for extended periods of time when grazed continuously. Hay-type alfalfa cultivars do not have this ability, but this occurs in cultivars developed for use in pastures such as Alfagraze. As regrowth progresses the proportion of energy derived from photosynthesis increases in the new growth and root carbohydrate reserves are restored. Under continuous grazing, herbage is continually removed and the plant cannot restore carbohydrates to the roots. Traditional grazing tolerant cultivars regrow more slowly than hay-type cultivars.

2.7.2 Amylase Activity

Amylase enzymes are responsible for the breakdown of starch into glucose units. α-Amylase is responsible for degrading α-bonds between glucose units while β-amylase breaks apart β-bonds between glucose units. Volenec et al (1990) suggested that high total root amylase levels are not necessary for starch degradation in alfalfa roots. They reported that alpha-amylase closely followed, and was important to, starch degradation. Habben and Volenec (1991) reported that amylase activity was important for alfalfa regrowth by acting on starch to break it into glucose for use in regrowth. Volenec (personal communication) also felt that storage proteins were possibly more important for regrowth than root carbohydrate reserves. The storage proteins in alfalfa roots contain the amylases used for the breakdown of starch. Proteins are more expensive to synthesize than glucose units. By storing proteins in times of excess glucose production, more energy is available for regrowth. They felt that shoot regrowth rate was related to the rate of starch breakdown which are controlled by alpha and beta amylase. Habben and Volenec reported that beta-amylase was 800 times more active in roots than alpha-amylase, but that alpha-amylase activity was associated more closely with starch degradation trends. They also determined that both amylases had different isoforms that were not always present in all genotypes in the same combinations. Rong et al (1996) reported total amylase activity remained constant during starch degradation over winter, then decreased in spring during rapid shoot growth. They reported increases in root nitrogen and protein concentrations through the fall then decreases in the spring during regrowth. Volenec felt that total N may be an indicator of amylase concentration, but it would show less change than examination of the amylases themselves due to interference from non amylase associated nitrogen.

2.7.3 Nitrogen Concentration

Chatterton et al (1977) found ammonium concentration in alfalfa crowns and roots was much higher in high yielding plants than in low yielding plants. Plants that were tolerant of frequent harvests had higher ammonia concentrations in the crown and lower concentrations in the roots than plants intolerant of frequent harvests, indicating a higher nitrogen pool availability for regrowth. Smith and Silva (1969) reported that a smaller proportion of the root nitrogen was used for regrowth than of the TNC reserves. Hendershot and Volenec (1993a) reported rapid decreases in root nitrogen during early spring regrowth. Hendershot and Volenec (1993b) reported an increase in root nitrogen in the fall, maintenance during the winter and a rapid decrease in the spring. Jung and Smith (1961) reported total nitrogen concentration in roots and crowns increased through the fall, peaking in October, staying high through the winter and then decreasing rapidly in March. They noted that the concentration of the nonsoluble nitrogen fraction peaked in December, while the soluble protein fraction reached its maximum in October.

2.8 Summary

Grazing tolerance in alfalfa is not a single easily defined trait, but a complex group of plant traits. These morphological and physiological traits interact with each other, with soil characteristics, with environmental factors and with the grazing animal. The morphological traits that allow alfalfa to survive grazing include: stem density, crown size, depth of crown, crown bud production, and decumbency. The physiological traits include: TNC root reserves in the crown, the ability to withstand extended periods of low TNC reserves, nitrogen reserves in the crown, and amylase reserves in the crown. Alfalfa has been known for hundreds of years as an excellent source of hay, but research during the last 10 years has shown that cultivars can be developed that show excellent survival under grazing and still produce yields as high as hay-type cultivars.

3. Materials and Methods

This research project incorporated a series of experiments conducted at three locations in Manitoba, Canada (Portage la Prairie (50^0 Lat., 98.5^0 Long., 266 m altitude), Glenlea (49.7^0 Lat., 97.2^0 Long., 231 m altitude), and Brandon (49.9^0 Lat., 99.8^0 Long., 383 m altitude)) during 1992 and 1993. All experiments involved grazing alfalfa with beef cattle, but there were treatment variations at each location.

Four (Glenlea, MB) or two (Portage la Prairie, MB, Brandon, MB) experiments were conducted at each site. Identical experiments at each site were subjected either to close continuous grazing or rotational grazing. Where close continuous grazing was conducted, a sufficient number of animals were present to prevent herbage production occurring above four to five centimenters, the height that the cattle could graze down to. Rotational grazing involved placing sufficient numbers of cattle in the experimental area to remove all herbage to four to five centimetres height in a period of four to seven days.

The check cultivars used throughout all experiments were Alfagraze, Apollo and Spredor II. Alfagraze was developed in Georgia under conditions of close continuous grazing (Bouton et al., 1991). Spredor II is the most widely sold cultivar in the United States for use in pastures. It is a creeping rooted type alfalfa (Agriculture Canada, Description of Variety, 1983). Apollo is a hay type alfalfa that has been used as grazing intolerant check (Brummer and Bouton, 1991, Smith et al, 1989).

3.1 Glenlea Experiments

Plant survival was evaluated in experiments I, II, III and IV at Glenlea, MB in 1992. Ground cover, percent basal area interception and percent plant area interception were used to evaluate differences between cultivars for survival under two grazing intensities. Due to inundation with rainwater in 1993, large stand losses occurred and evaluation was discontinued.

3.1.1 Experiments I and II: Microplot

The alfalfa cultivars 'Alfagraze', 'Algonquin', 'Anik', 'Apollo', 'Arrow', 'Cimarron VR', 'Rangelander', 'Roamer', 'SCMF 3713', 'Spredor II', 'WL 317' and 'Wrangler' were hand broadcast at 15 kg ha^{-1} on 24 May 1991 (continuous) and 27 May 1991 (rotational) onto 1 m^2 plots in randomized complete block experiments with four replicates. Experiment I was subjected to continuous grazing and experiment II to rotational grazing by beef cattle. The continuous grazing trial had sufficient animals present in the experimental area at all times to restrict herbage production to four to five centimetres in height. The rotationally grazed trial was allowed time for herbage regrowth to occur between grazing periods. Phosphate was applied prior to sowing at a rate of 55 kg P_2O_5 ha^{-1}. Weeds were controlled throughout 1991 by clipping and handweeding.

Experiment I had two animals present at all times from 1 June until 5 September, 1992 with the exception of the periods of 19-23 June, and 4-6

July when the soil conditions were too wet for animals to remain in the experimental area. They had access to 0.49 ha of pasture. The experimental area was clipped on 3 August 1992 to remove excess growth. Forage on experiment II was removed by grazing with a sufficient number of animals to remove all forage to a grazing height of 4cm during the periods of 1-6 June, 28 June to 4 July, 26 July to 3 August and 1-5 September 1992. The experimental area was clipped on 3 August 1992 to remove excess growth.

Assessments were conducted bi-weekly from 8 July 1992 until the end of grazing. Percent ground cover was evaluated on each date by visually estimating the percentage of the ground that was covered by alfalfa within 0.25 m^2 frame placed over the center of each plot. Basal interception was determined by counting the number of times that a plant base or crown was present below intersecting wires on a point quadrat grid. The point quadrat grid had 10 wires running perpendicular to 10 more wires giving a total of 100 intersecting points (Smith et al 1992). This same quadrat was used to evaluate percent plant interception, where a hit was recorded anytime an alfalfa plant part (stem, leaf or base) occurred below two intersecting wires. For each assessment date, the center of the plot was used for the evaluations.

3.1.2 Experiments III and IV: Large Plot

Experimental design for both experiments was a randomized split plot with four replicates. The two main treatments were alfalfa planted with

Fleet meadow bromegrass (*Bromus riparius* Rehm) and alfalfa planted in a pure stand. Subplots consisted of the 12 alfalfa cultivars Alfagraze, Algonquin, Anik, Apollo, Arrow, Cimarron VR, Rangelander, Roamer SCMF 3713, Spredor II, WL 317, and Wrangler randomized within each main treatment. Alfalfa seed was hand broadcast on 24 May 1991 (Experiment III, continuous) and 27 May 1991 (Experiment IV, rotational) into subplots 1.5 x 6.1 m at 15 kg ha^{-1}. The meadow bromegrass was drilled on 28 May 1991 at 15 kg ha^{-1}. Phosphate was applied prior to sowing at a rate of 55 kg P_2O_5 ha^{-1}. Weeds were controlled throughout 1991 by clipping and handweeding.

Experiment III was subjected to continuous grazing, utilizing the same two animals present in experiment I, at all times from 1 June until 5 September 1992 with the exception of the periods of 19-23 June, and 4-6 July when the soil conditions were too wet for animals to remain in the experimental area. The total experimental area for experiments 1 and 3 was o.49 ha. The experimental area was clipped on 3 August 1992 to removes excess growth. Experiment IV was subjected to rotational grazing and forage was removed by grazing during the periods of 1-6 June, 28 June to 4 July, 26 July to 3 August and 1-5 September 1992. A sufficient number of animals were present during the grazing period to remove all herbage to a stubble height of four centimetres. The experimental area was clipped on 3 August 1992 to remove excess growth.

Stand assessments were conducted from before grazing started until after the end of grazing. Different estimation methods were conducted to compare their usefulness. Percent ground cover was evaluated by visually estimating the percentage of the soil surface that was covered by alfalfa over the whole plot. Basal interception was determined by counting the number of times that a plant base or crown occurred below two intersecting wires with the same point quadrat grid used in experiments I and II. Plant counts (the number of plants within 0.1 m^2) were taken on 8 August 1991 (the establishment year), after grazing commenced on 15 June 1992, and on 14 September 1992.

Ten alfalfa plants per subplot were randomly removed from selected cultivars in the fall of 1992 after grazing ended from the pure treatment and from subplots of all cultivars in the spring of 1993. These plants were frozen the day that they were removed for subsequent evaluation of root morphological and physiological characteristics.

3.2 Portage la Prairie Experiments

The use of alfalfa seedling transplants is widely utilized in the development process of alfalfa cultivars. The use of transplants may allow detection of cultivar differences with one year of grazing. Alfalfa plants from 11 cultivars were sown in early February, 1992 and late January 1993 into sandbeds in greenhouses. Plants were raised in the greenhouses until late May of each year at which point they were transplanted to the field. Phosphate was applied to the entire experimental area according to soil test recommendations (58 kg P_2O_5 ha^{-1} 1992, 72 kg P_2O_5 ha^{-1} 1993) prior to transplanting and incorporated with a field cultivator. Two experiments were established in each of 1992 (Experiment V and Experiment VI) and 1993 (Experiment VII and Experiment VIII) on a Gnadenthal loam soil. Experiments V and VII were subjected to continuous intense grazing with beef cattle. Experiments VI and VIII were subjected to a rotational grazing system where animals were allowed access to the trial initially at the same time as the start of grazing on experiments V and VII, and again four weeks later.

Experimental design for both experiments was a randomized split plot with four replicates. The two main treatments were alfalfa planted with 'Fleet' meadow bromegrass and alfalfa planted in a pure stand. Subplots consisted of the 11 alfalfa cultivars randomized within each main treatment. In 1992, plants were hand transplanted on 30 cm centers in a grid of five plants by five plants. In 1993, alfalfa plants were mechanically transplanted into a grid of six plants in each of four rows using a John

Deere transplanter. The eleven cultivars included were Alfagraze, Algonquin, 'Algonquin Selected', Apollo, 'Cut'N'Graze', Arrow, 'Grimm', Rangelander, SCMF 3713, Spredor II and 'Spredor III'. Due to a shortage of plants, Cut'N'Graze was not included in the rotationally grazed experiment in 1992.

Weed control was achieved with diclofop-methyl applied at 709 g active ingredient (a.i.) ha^{-1} on 25 June 1992, and imazethapyr at 50 g a.i. ha^{-1} with Agral 90 at 0.25 % volume on 27 June 1993. Plots were also handweeded in July of each year. Grazing began on 28 July 1992 and on 13 August 1993 using a mob grazing method with 45 animals in 1992 and 55 animals in 1993. The composition of the herd was an equal number of 550 kg Angus cows, four month old calves and yearling stockers. Under the continuous grazing regiment (Experiments V, 1992 and VII, 1993), livestock had continuous access to the plot area and grazed for approximately 2 hours every other day for 8 weeks. This stocking density was sufficient to restrict the growth of alfalfa to a height of three to six centimetres throughout the duration of the experiment. Livestock had access to the rotationally grazed experiments (Experiments VI, 1992 and VIII, 1993) for 2 days at the same time as the initial grazing of the continuous experiment, and again for one day 4 weeks after the initial date. This period of grazing was sufficient to remove all vegetation to a level of three to six centimetres.

Assessments of decumbency, height and individual plant ground cover were determined immediately before grazing was initiated on 27 July

1992 and 11 August 1993; during the grazing season on 18 August, 3 September, 17 September 1992, and 25 August, 8 September, 22 September 1993; and following the end of grazing on 8 October 1992 and 6 October 1993. These assessments were taken on each of 10 plants per subplot in 1992 and 12 plants in 1993. The plants evaluated were the same ones each time and were used for root evaluations following the termination of grazing. In 1992, the total number of stems per plant was determined. This assessment was modified in 1993 to include the total number of axillary and crown stems per plant.

Decumbency was a visual assessment (subjective) of the angle of which the stems grew from the base of the plant. It was scored from 5 (all stems vertical) to 1 (all stems prostrate) (Brummer and Bouton, 1991). Scores of 2 through 4 were a result of stems at intermediate angles of growth or averages of stems growing at different angles on each plant. Height in cm was taken on each plant at the highest point. The mean decumbency score and height of all the plants measured in each subplot were used for statistical analysis so that an assessment of cultivar differences could be determined.

The number of actively growing stems was determined at a height of 4 cm above the soil surface and averaged over all plants within each subplot. Crown stems were defined as those that originate from the crown at or below the soil surface (Teuber and Brick, 1988). Axillary stems are those that develop from the nodes of other stems. The mean of all plants measured in each subplot was used for statistical analysis.

Ground cover was assessed on an individual plant basis. Visual estimation was made as a percentage of the soil surface that was covered by plant material within a 30 cm by 30 cm square cantered over each plant. Plant averages for each subplot were used for statistical analysis.

On three dates in each of 1992 and 1993, preselected plants were removed from the subplots for detailed root evaluations. Five (1992) or six (1993) alfalfa plants from each subplot were removed on 27 July 1992 and 12 August 1993 before the initiation of grazing. Five (1992) or six (1993) more plants were then removed four weeks after grazing started, and the remaining 15 (1992) or 12 (1993) plants were removed eight weeks after the start of grazing. The plants removed from the plots were frozen the day of digging for subsequent evaluation of root morphological and physiological characteristics.

3.3 Experiments IX and X: Brandon

One rotationally grazed and one continuously grazed experiment was established on 5 May 1992 on a Souris fine sandy loam soil in a split plot design with four replicates. Main treatments consisted of pure alfalfa and alfalfa with meadow bromegrass competition. The twelve cultivars randomized within each main treatment were Alfagraze, Apollo, Arrow, Beaver, 'Able', Rangelander, SCMF 3713, Spredor II, Spredor III, WL 227, Wrangler and 'Pioneer 5151'. Alfalfa was sown perpendicular to the direction of sowing the meadow bromegrass on a 15 cm spacing. Total experimental area was 0.96 ha for each experiment. Manure was applied and incorporated prior to establishment to improve soil organic matter. All plots received an additional 45 kg N, 48 kg P_2O_5, 66 kg K_2O and 39 kg SO_4 per hectare prior to establishment and incorporated. Weed control was accomplished in the first year by clipping twice during the growing season. An additional 41 kg N, 54 kg P_2O_5, 59 kg K_2O and 34 kg SO_4 per hectare was applied in April of 1993. Grazing began on 3 June, 1993 for both experiments. A minimum of 2 steers (320 kg) were present on the continuously grazed experiment IX until grazing ended on 7 September 1993. Mowing was conducted to even out the level of defoliation on 7 July and 30 August 1993. Eleven steers (400 kg) were used for grazing on the rotationally grazed experiment X on 3-6 June, 5-7 July, 5-6 August, and 2-4 September 1993. Ten plants were removed from each subplot on 22 October 1993 and frozen for subsequent evaluation of root morphological and physiological characteristics.

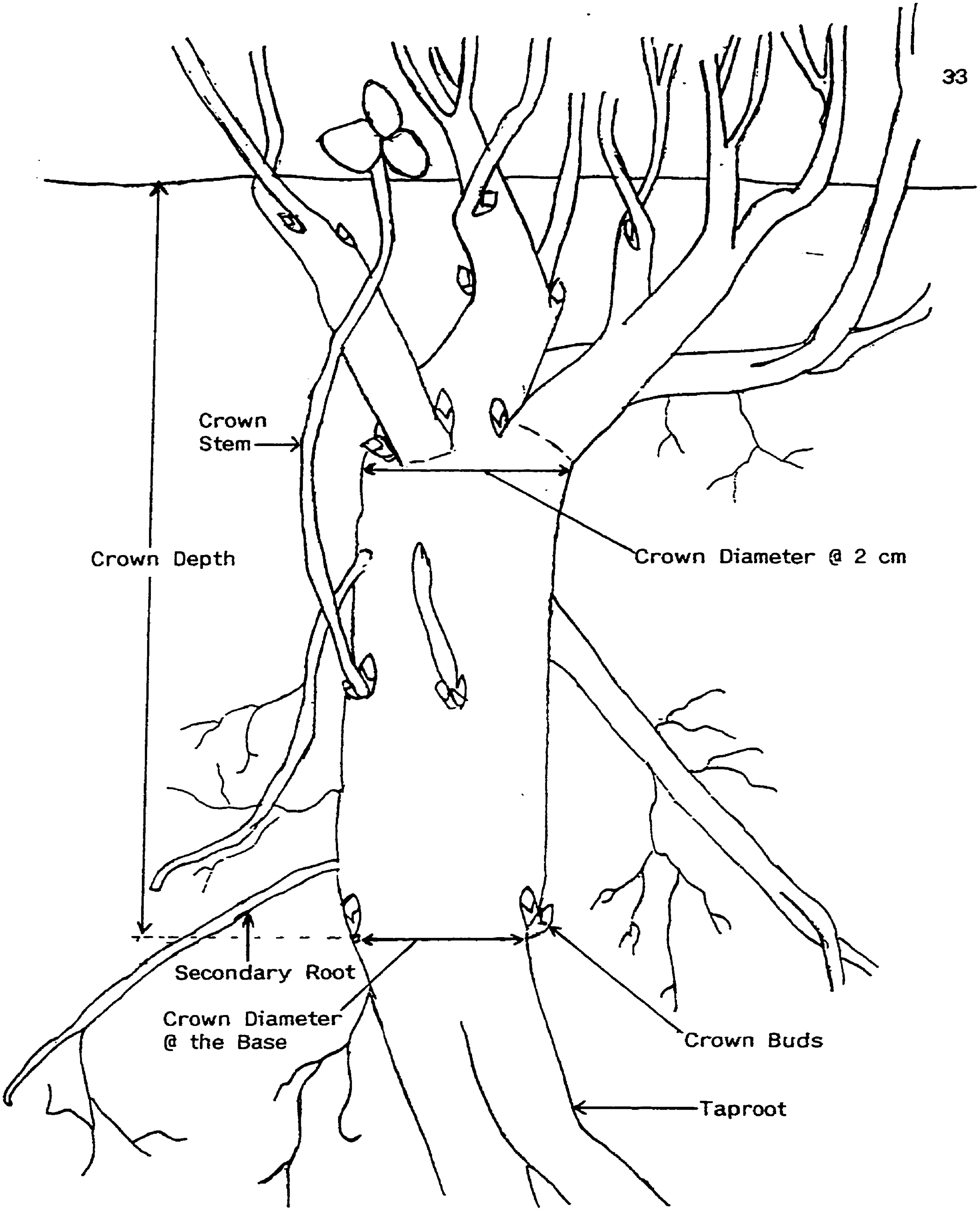
3.4 Morphological Root Measurements

Alfalfa plants removed from all grazing experiments in 1992 and 1993 were subjected to intensive measurements of root and crown morphological characteristics to determine their association with observed cultivar differences in grazing tolerance (Figure 1).

The crown of an alfalfa plant is the transition area between the root and shoots (Teuber and Brick, 1988). Over time the depth to the bottom of the crown and crown diameter increases as new shoots are produced. Crown area two cm below the soil surface was determined by measuring the diameter twice at perpendicular angles for all plants with the exception of the those removed from experiment V. Crown area was calculated from the average of these two measurements using the formula for the area of a circle (πr^2). Crown area at the base of the crown was also assessed for all plants removed from all experiments by measuring the diameter twice at perpendicular angles. The base of the crown is defined as being where the lowest unemerged bud or primordial bud was located. Crown area was calculated from the average of these two measurements using the formula for the area of a circle (πr^2) (Rapoport and Travis, 1984). Crown depth was measured from the soil surface to the base of the crown.

The number of crown buds that had not yet elongated (emerged from the soil surface) was counted. The number of secondary branch roots larger than one mm in diameter in the first 15 cm of the taproot were also counted.

Figure 1. Root and Crown Morphological Measurements.


Crown Stem
Crown Depth
Crown Diameter @ 2 cm
Secondary Root
Crown Diameter @ the Base
Crown Buds
Taproot

3.5 Physiological Measurements

The cultivars Alfagraze, Apollo and Spredor II were selected for detailed examination of root nitrogen and carbohydrate reserves. Plants of these cultivars were removed from the field after the completion of grazing (experiments III and IV: 18 September 1992; V and VI: 21 September 1992; VII and VIII: 7 October 1993; IX and X: 22 October 1993). Plants from both the pure and mixed stands were used from experiments V through X, but only from pure stands in experiments III and IV in 1992.

3.5.1 Total Nitrogen Analysis

The crowns and upper 15 cm of the taproot from 10 alfalfa plants per subplot were lyophilized then ground through a Wiley mill using a 2 mm screen. Subsamples from a composited sample of the 10 plants within a subplot were analyzed using for total nitrogen by a dry combustion method using a LECO N Detorminator (Model FT428; Leco Corp., Mississauga, Ontario). The Leco N Detorminator was calibrated using wheat flour.

3.5.2 Carbohydrate Extraction

The crowns and upper 15 cm of the taproot from 10 alfalfa plants per subplot were lyophilized then ground through a Wiley mill using a 2mm screen. Preparation of samples was adapted from the procedure used by Vikman and Vessey (1993). 50 mg subsamples of a composited sample from the 10 plants within a subplot were used for the extraction process. To each subsample 5 ml of hot 80% ethanol (65-70^{0}C) was added and mixed thoroughly. This mixture was centrifuged and the supernatant was collected. The process was repeated for a total of three washings with ethanol. The supernatant contained the soluble sugars. The ethanol was removed from the supernatant by evaporation until the sample was completely dry. The residue was resuspended in six ml of distilled water. These samples were then frozen until the chromatograph analysis was conducted.

The material remaining after washing with ethanol was then resuspended in 5 ml of distilled water and heated to 95^{0}C for two hours to gelatinize the starch. A water bath was used for this procedure. The solution was cooled to 37^0 C before the enzyme solution was added. Six hundred twenty five mm^3 of enzyme solution was added to each sample and incubated for two hours at 37^0 C. The enzyme mixture that was used contained 5 units of amyloglucosidase cm^{-3} (Sigma Chemical Co., St. Louis, USA) and 5 units of alpha-amylase (Sigma Chemical Co., St. Louis, USA) cm^{-3} in a 0.1M 2[N-morpholino]ethanesulphonic acid [MES] solution adjusted to a pH of 5 using KOH. The samples were then decanted into storage vials and frozen until analysis was conducted. These solutions contained predominantly glucose units.

Immediately before analysis, all samples were filtered through Millipore 0.45 or 0.8 micron filter to remove particulate matter. Carbohydrate analysis was conducted on a Dionex 4500i ion exchange chromatograph using pulse amperometric detection with CarboPac guard (PA) and separation (PA1) columns. The standard used contained 0.005 g Glucose, 0.041 g Sucrose and 0.086 g Fructose in either 2 L (S1) or 4 L (S2) (Sigma Chemical Co., St. Louis, USA).

3.6 Statistical Analysis

Due to differences in cultivar entries, establishment method and management evaluations between experimental locations data was not pooled. As there was no interaction between pure alfalfa stands and mixed stands with meadow bromegrass cultivar measurements were combined for all traits. Subplot means of plant crown morphological and physiological measurements were transformed prior to analysis of variance (ANOVA) using $x^{1/2}$ because the distributions were not normal. The square root transformation was chosen because the values were small with the variance was similar to the mean (Poisson distribution) (Steel and Torrie, 1980). Reported values were the actual plot means. Analysis of variance was conducted on plot means of all measurements for experiments I and II using the Statistical Analysis Systems (SAS, 1988) with cultivars and meadow bromegrass competition considered as random effects. Analysis of variance over dates was conducted to determine if any interactions were present for experiments III and IV. Analysis of covariance was conducted for experiments III and IV using the first measurement date of the grazing season as the covariate. Cultivar comparisons were conducted using Fisher's protected least significant difference procedure. Rank correlations between experiments I and II, and between III and IV were conducted by ranking each plot from highest to lowest within each replication and performing a correlation analysis between experiments for each given date of an assessment.

3.7 ALFALFA CULTIVARS USED FOR GRAZING TOLERANCE COMPARISONS

Cultivars are scored (1-9) for fall dormancy based on their fall growth. More dormant cultivars, those with a lower score, have less growth, partitioning more energy into root carbohydrate reserves (McKenzie et al, 1988). Non dormant cultivars continue to grow as they do during the spring and summer. Winterhardiness is associated with fall dormancy where the more dormant alfalfa cultivars are more winterhardy, but tend to yield less forage late in the season.

Alfagraze was selected for grazing tolerance and high productivity and released in 1991 by the University of Georgia (Bouton et al 1991). It is a synthetic cultivar with 34 parental plants selected after 2 cycles of grazing (cycle 1 had 3 years of grazing, cycle 2 had 2 years). Alfagraze has resistance to fusarium wilt and is moderately resistance to bacterial wilt and anthracnose. Alfagraze shows low resistance to phytophthora root rot. Alfagraze has a fall dormancy score of 2. It is most suited for the east central and southeastern United States where it shows better persistence under grazing with yields similar to hay type alfalfa cultivars. It is actively marketed in Canada by Pickseed and has shown winterhardiness equivalent to the standard hay-type cultivar Arrow.

Algonquin-original (O) is a hay-type cultivar common in Canada with low levels of disease resistance (Alfalfa Variety Description 121.33, 1973). Algonquin O was developed by Agriculture Canada at the Ottawa Research Station, and registered in 1973. It is a 24 clone synthetic classified as *Medicago media*. It has shown excellent winter survival in Western Canada. Yield is slightly higher than the check cultivars, Vernal and Iroquois.

Algonquin selected (S) was selected from the surviving plants from a 10 year old stand of Algonquin-O subjected to grazing at the Seven Sisters Grassland Project in Seven Sisters, Manitoba.

Anik is a *Medicago sativa* ssp. *falcata* L. of Siberian origin developed at Agriculture Canada, Beaverlodge, Alberta and released in 1975 (Pankiw and Siemens 1975). Evaluation in Northern Alberta showed Anik to be very winter hardy, high yielding and persistent. Anik frequently yielded higher than Beaver and Rambler in a one cut system. Regrowth after harvest is slower than these cultivars. Very little winterkill has been observed in standard cultivar testing where stands of Beaver and Rambler were reduced substantially. Anik showed good resistance to grazing at Melfort and at Mile 1019, Yukon territory. At Mile 1019, survival was good after 15 years, with the last 5 years subjected to intense grazing. Anik has proved to be more tolerant of brown root rot, snowmold and the crown root complex than Beaver and Rambler. Anik is not creeping rooted.

Apollo-original (O) was developed by North American Plant Breeders in 1971 from 1148 parental clones (Agriculture Canada Licence #1788, 1977). Approximately 75 % of the genetics are sources from northern winterhardy types (*M. sativa* ssp. *media L.*) with the remainder from flemish type alfalfa (*M. sativa* ssp. *sativa L.*). Apollo O is resistant to phytophthora root rot. Resistance to bacterial wilt is similar to Iroquois and Angus, but resistance to anthracnose and downy mildew is low. Apollo O is adapted to Eastern Canada, the southern areas of Western Canada and the Midwest of the United States. Roots are more branching than Vernal. Apollo O has been used as the grazing intolerant check in previous research and it has a fall dormancy of 4.

Cut'n'graze (formerly Apollo selected (S)) is a 90 parental clone synthetic selected from Apollo-O following two seasons of intense grazing conditions in Georgia (Bouton et al, 1993). Approximately 10% of the genetic background is of *M. sativa* ssp. *falcata* L. origin. Cut'N'graze has shown high resistance to fusarium wilt, resistance to bacterial wilt and phytophthora root rot, moderate resistance to anthracnose and low resistance to verticillium wilt and aphanomyces root rot. The area of adaptation is the North Central and Southern United States. Cut'N'graze shows lower survival than Alfagraze under intensive grazing.

Arrow was developed by Nickerson American Plant Breeders and registered in Canada in 1986 (Agriculture Canada Licence #2724, 1986). Arrow is a 66 clone synthetic with 38 % flemish (*M. sativa* ssp. *sativa* L.) and 7 % *M. sativa* ssp. *falcata* L., with the remainder of the germplasm from various different sources. It has early maturity and a fall dormancy of 3. Arrow is resistant to phytophthora and moderate resistance to bacterial wilt and verticillium wilt. Winter persistence is intermediate, similar to Saranac. Arrow is used primarily for hay and is widely sold in Canada with good winter hardiness.

Cimarron VR It is highly resistant to bacterial wilt, fusarium wilt and anthracnose (Certified Alfalfa Seed Council, 1993). Cimarron VR is resistant to verticillium wilt and phytophthora root rot. Cimarron VR has a fall dormancy of 4. Cimarron VR is a hay type in the U.S. with moderate levels of winter hardiness.

Grimm alfalfa originated in Germany and was brought to Minnesota in 1858 (Barnes et al). It is both winterhardy and resistant to drought. It is reported to have a branching root system. The seed used is from a locally adapted ecotype selected for persistence.

Rangelander was released in 1978 from Agriculture Canada, Swift Current (Agriculture Canada Licence #1806, 1978). Rangelander was developed from 15 parental plants exhibiting the creeping rooted trait which were selected after being grown with crested wheatgrass after 8 or more years. The parental plants are from breeding populations from Rambler, Roamer, Drylander and *M. sativa* ssp. *falcata* L. strains. Rangelander is very winterhardy and persists well when grown with other species. It is adapted to the dry areas of Western Canada and the northern Great Plains. After three years of growth over 80 % of plants show the creeping rooted trait. Plants have spread up to 6 meters in 10 years of growth. Persistence is greater than that of Rambler and Drylander, while yield is similar to Roamer and Drylander.

Roamer was released in 1966 from Agriculture Canada, Swift Current (Canada Department of Agriculture Licence #1029, 1966). Roamer is a synthetic cultivar composed of 7 genotypes selected at Saskatoon and Swift Current, Saskatchewan. It has a high level of *M. sativa* ssp. *falcata* L. germplasm. Recovery after harvest is slow. Winterhardiness is similar to Rambler and better than Beaver, Vernal and Grimm. It survives under drought very well, similar to Rambler. Roamer shows similar resistance as Beaver and Vernal to bacterial wilt. Approximately 65 % of plants show the creeping rooted trait. Roamer is used primarily in pasture.

SCMF 3713 is a *M. sativa* ssp. *falcata* L. that is winterhardy and has persistence under grazing when in mixtures, but has shown poor establishment (Bittman and McCartney, 1994).

Spredor II is the most commonly sold creeping rooted alfalfa in the US. It was developed by Northrup King and released in Canada in 1983 (Agriculture Canada, Description of Variety, 1983). It is made up of 43 parental plants selected primarily for the creeping rooted trait, but also for bacterial wilt resistance, persistence under frequent mechanical herbage removal, fast regrowth and seed set. Regrowth after harvest is still slow, however. Spredor II is highly resistant to bacterial wilt, but susceptible to phytophthora root rot, verticillium wilt, and anthracnose. It is moderately susceptible to fusarium wilt. Spredor II has a fall dormancy score of 1. It is strongly creeping rooted and is suitable for hay production and grazing.

Spredor III is the newest creeping rooted cultivar from Northrup King and marketed in Canada by Proven Seed.

WL 317 is similar to Arrow and Cimarron VR (Kugler et al, 1991). WL 317 has a fall dormancy of 3 and good winterhardiness. It is highly resistant to bacterial wilt, fusarium wilt and phytophthora root rot. WL 317 is resistant to verticillium wilt and anthracnose.

Wrangler was developed jointly by the USDA-ARS, and the Nebraska and Minnesota Agricultural Experiment stations and released in 1985 (Kehr et al 1985). Alfalfa plants from breeding lines developed in Nebraska were selected in Minnesota for winterhardiness and phytophthora root rot resistance. It shows resistance to bacterial wilt and fusarium wilt, moderate resistance to downy mildew, and low resistance to verticillium wilt and anthracnose. Approximately 5 % of the genetic background is *M. sativa* ssp. *falcata* L. Wrangler is not creeping rooted and has a fall dormancy score of 2.

4. RESULTS AND DISCUSSION

4.1 Alfalfa Persistence

Assessments of percent visual ground cover can be used to compare alfalfa stand density and potential growth (Smith and Bouton, 1993, Lodge and Gleeson, 1984). Cultivars with a lower visual ground cover may have reduced stands, lower yields and provide less competition to weeds than those cultivars that can maintain higher ground covers. The presence of other species also hinders the determination of alfalfa ground cover.

4.1.1 Glenlea Experiments I and II: Microplot

The microplot experiments were designed to determine the feasibility of evaluating different alfalfa cultivars in a small area. Rank correlations of cultivars were conducted between the continuous and rotational grazing systems to determine if cultivars performed differently with respect to each other under the different grazing systems. There was no significant correlation for cultivar response to grazing between the continuous and rotational grazing systems using any of the following persistence measurements: ground cover (Rank correlations: 8 July, $r = 0.25$, $P \leq 0.08$, $N = 48$ and 16 September, $r = 0.03$, $P \leq 0.82$, $N = 48$), percent plant interception (Rank correlations: July 8, $r = 0.03$, $P \leq 0.84$, $N = 48$ and September 16, $r = -0.03$, $P \leq 0.85$, $N = 48$). Because the rank correlations between cultivars under the two different grazing systems were not significantly correlated, the microplot experiments were analyzed separately. Since the microplots were only 1 m^2 they provided a good opportunity to compare the relationship between different persistence measurements. Rank correlations were conducted to compare visual percent ground cover estimates to the percent plant interception method utilizing a point quadrat within each grazing system. Correlations between these two measurements were highly significant with r values of 0.72 ($p = 0.0001$) and 0.86 ($p = 0.0001$) on 8 July and 16 September, when compared under continuous grazing, and r values of 0.76 ($p = 0.0001$) and 0.43 ($p = 0.0023$) on 8 July and 16 September when compared under rotational grazing. The close association between these two methods of assessment suggests that either can be used for evaluating ground cover. The lower correlations on 16 September under rotational grazing were likely due to higher fall regrowth which increases the difficulty in making these evaluations. The visual evaluation is a much simpler and faster method than using a point quadrat.

4.1.1.1 Experiment I: Close Continuous Grazing

Cultivar differences for percent ground cover were observed at the 8 July, 1992 measurement date (Table 1), 5 weeks after the initiation of grazing. Alfagraze showed the highest numerical ground cover, but not significantly higher than SCMF 3713, Anik, Cimarron VR and Wrangler. On 16 September 1992, Alfagraze showed significantly greater ($p < 0.05$) visual percent cover values than all other cultivars. Alfagraze, Algonquin, and Arrow showed no loss of visual ground cover between 8 July, 1992 and 16 September, 1992 even under close continuous grazing indicating a superior ability to persist under grazing than the other cultivars in the test.

Moderate reductions in ground cover occurred for Apollo (14%), Roamer (25%), Spredor II (30%), WL 317 (28%) and Wrangler (24%). Reductions in visual ground cover were more severe for Anik (52%), Cimarron VR (45%) SCMF 3713 (41%) and Rangelander (74%).

Table 1. Percent visual ground cover of 12 alfalfa cultivars in microplot experiments (1 m^2) under continuous close grazing (Experiment I) and rotational grazing (Experiment II) at Glenlea, MB, 1992.

	Experiment I				Experiment II			
Cultivar	8 July		16 Sept		8 July		16 Sept	
Alfagraze	21.0	(1)†	23.8	(1)	21.0	(6)	18.3	(3)
Algonquin	11.3	(6)	11.5	(5)	19.3	(8)	17.8	(5.5)
Anik	13.5	(4)	6.5	(9)	23.0	(5)	12.3	(10)
Apollo	5.8	(11)	5.0	(10)	18.8	(10)	14.0	(9)
Arrow	10.3	(9)	12.3	(3)	14.5	(12)	11.0	(11)
Cimarron VR	12.3	(5)	6.8	(8)	19.0	(9)	9.3	(12)
Rangelander	9.8	(10)	2.5	(12)	24.5	(4)	21.5	(2)
Roamer	5.3	(12)	4.0	(11)	20.8	(7)	17.8	(5.5)
SCMF 3713	20.0	(2)	11.8	(4)	34.8	(1)	14.8	(7)
Spredor II	10.5	(8)	7.3	(7)	25.3	(3)	23.8	(1)
WL 317	10.8	(7)	7.8	(6)	27.5	(2)	14.5	(8)
Wrangler	16.5	(3)	12.5	(2)	18.0	(11)	18.0	(4)
$p \leq F$	0.037		0.047		0.18		0.0096	
LSD(0.05)	9.45		11.17		n.s.‡		7.22	
Mean	12.0		9.1		21.7		15.7	
Std. Dev.	7.4		8.7		9.6		6.4	
Mean Sq.	96.4		128.1		113.5		72	

† Cultivar ranking within each measurement date for each experiment is enclosed in parentheses.

‡ Means do not differ significantly ($P \leq 0.05$)

Assessments of percent plant interception (Table 2) showed no cultivar differences on 8 July, 1992, or on 16 September, 1992. On 16 September Alfagraze ranked the highest while the lowest ranking cultivar was Rangelander. Spredor II was near the top while Apollo ranked near the bottom.

The microplots were located close to the water source for the cattle and as such the trial site was grazed heavily. This resulted in greater grazing stress than occurred in the adjacent experiment III with the result that cultivars separated more. The grazing cultivars Alfagraze and Wrangler, which were developed under grazing and frequent defoliation, respectively, and Arrow, a hay type cultivar showed the highest persistence and ground cover under grazing conditions. The grazing intolerant Apollo and creeping rooted Spredor II showed moderate reductions in ground cover. None of the creeping rooted cultivars commonly used for grazing ranked very high with Rangelander showing the poorest persistence. This may be due to only one season of grazing evaluations where the creeping rooted cultivars did not have sufficient time to generate 'new' plants or were too stressed and were unable to partition sufficient resources into producing 'new' plants. The hay type cultivars, with the exception of Arrow, showed moderate to poor performance under grazing. This indicates that there is little advantage for using creeping rooted cultivars, rather than hay type cultivars, in pastures when grazed intensively.

Table 2. Percent plant interception (stems and leaves) using a point quadrat of 12 alfalfa cultivars in microplot experiments (1 m^2) plots under continuous close grazing (Experiment I) and rotational grazing (Experiment II) at Glenlea, MB, 1992.

	Experiment I		Experiment II	
Cultivar	8 July	16 Sept	8 July	16 Sept
Alfagraze	11.3 (1)†	23.8 (1)	10.5 (10)	40.0 (7.5)
Algonquin	4.8 (8.5)	12.5 (8)	12.0 (9)	37.5 (9)
Anik	6.0 (6)	11.8 (7.5)	12.5 (7.5)	20.0 (12)
Apollo	2.5 (9)	6.0 (10)	12.5 (7.5)	40.0 (7.5)
Arrow	5.8 (7)	12.3 (6)	5.8 (12)	47.5 (3)
Cimarron VR	7.5 (4)	9.3 (9)	9.8 (11)	35.0 (10.5)
Rangelander	4.3 (10)	4.0 (12)	18.8 (3)	50.0 (1.5)
Roamer	1.8 (11)	5.5 (11)	15.8 (5)	42.5 (5)
SCMF 3713	9.3 (2)	17.5 (2)	28.8 (1)	35.0 (10.5)
Spredor II	8.8 (3)	15.8 (3)	22.5 (2)	42.5 (5)
WL 317	4.8 (8.5)	11.8 (7.5)	16.3 (4)	42.5 (5)
Wrangler	6.3 (5)	15.0 (4)	13.8 (6)	50.0 (1.5)
$p \leq F$	0.27	0.30	0.0094	0.0001
LSD (0.05)	n.s.‡	n.s.	10.47	7.73
Mean	5.9	11.8	14.6	39.4
Std. Dev.	5.1	10.2	8.9	11.8

† Cultivar ranking within each measurement date for each experiment is enclosed in parentheses.

‡ Means do not differ significantly ($P \leq 0.05$)

4.1.1.2 Experiment II: Rotational Grazing

There were no significant differences between cultivars for visual ground cover on 8 July, 1992, immediately following the second period of rotational grazing (Table 1). By the end of the first grazing season Spredor II ranked first and had significantly higher cover estimates than all other cultivars with the exception of Rangelander, Alfagraze, Wrangler, Algonquin and Roamer. These cultivars all had over 85% ground cover on 16 September, 1992 compared to the first assessment date (8 July, 1992). The lowest ranking cultivar was Cimarron VR which was less than all other cultivars except for Arrow, Anik, Apollo, WL 317, and SCMF 3713.

Percent plant interception (Table 2) measurements revealed significant differences on both measurement dates. On 16 September, 1992, Rangelander and Wrangler had higher values than all other cultivars with the exception of Arrow, Roamer, Spredor II and WL 317. Apollo and Alfagraze ranked near the lower end of the cultivars, only greater than Anik.

Under rotational grazing the creeping rooted cultivars Rangelander, Roamer and Spredor II performed better than under continuous grazing. Wrangler showed a similar cultivar ranking for both rotational and continuous grazing while Alfagraze did not perform as well as the creeping rooted cultivars under rotational grazing. By the end of the first season of grazing, Apollo ranked lower than most cultivars under either grazing management system. Cimmaron VR and the *M. falcata* cultivars Anik and

SCMF 3713 showed poor persistence with low plant interception values under rotational grazing. The upright growth habit of Cimmaron VR may have been a disadvantage with a measurement like plant interception.

Microplots may have merit in the evaluation of alfalfa cultivars and experimental lines for grazing tolerance, especially in breeding programs. Due to their small size, seed requirements for their establishment are low. This allows for a greater number of total experiments to be established with the limited amount of seed that is frequently available in the early stages of cultivar development. A greater number of entries may be evaluated within each experiment as the area required is much less, with the additional advantage of reduced spatial variability. As the size of a plot is reduced, fewer plants are evaluated and the variability may increase, especially within a highly variable species such as alfalfa. This may necessitate a higher number of replications than would normally be used for cultivar evaluation. By increasing the number of replications in an experiment the number of degrees of freedom available for detecting experimental error will be increased, and the precision of the experiment will be increased.

4.1.2 Glenlea Experiments III and IV

4.1.2.1 Visual Ground Cover

Initial alfalfa visual ground cover was similar for both pure and mixed stands in September, 1991 when plants were subjected to continuous grazing in 1992 (Table 4). In May 1992 visual ground cover provided by alfalfa, 57.6%, tended ($p \leq 0.06$) to be higher in pure stands than in mixed stands with meadow bromegrass, 38.2%. In the rotationally grazed site the alfalfa plants in the pure stand provided higher ground cover than those in the mixed stand in the establishment year (1991), and prior to grazing in 1992. There were no differences between treatments during the grazing season. With less frequent defoliation the meadow bromegrass showed increased competition with the alfalfa. The growth of meadow bromegrass was greatest in the spring (May and June) and therefore competition was greatest during this period. Alfalfa has the competitive edge during summer. There were no interactions between pure and mixed stands at any sampling date (Table 3, Table 4) except on 15 June 1992 in experiment IV, therefore cultivar means were combined.

Table 3. Analysis of variance over time for Experiment III (close continuous grazing) and Experiment IV (Rotational grazing) at Glenlea, MB.

	Experiment III		Experiment IV	
Source	MS	F value	MS	F Value
	Visual percent ground cover			
Treatment	11 270	n.s.	26 388	21.4^{*}
Cultivar	13	13.0^{****}	3 383	11.8^{****}
Treatment x Cultivar	1	n.s.	124	n.s.
Date	29 000	647.9^{****}	26 522	267.6^{****}
Date x Treatment	1 947	43.5^{****}	1 396	14.1^{****}
Date x Cultivar	117	2.6^{****}	303	3.1^{****}
Date x Treatment x Cultivar	23	n.s.	94	n.s.
	Plants per 0.1 m^2			
Treatment	638	n.s.	7 588	60.0^{**}
Cultivar	348	5.0^{****}	280	4.1^{****}
Treatment x Cultivar	130	n.s.	51	n.s.
Date	108	n.s.	423	8.1^{**}
Date x Treatment	1 018	9.8^{**}	119	n.s.
Date x Cultivar	58	n.s.	15	n.s.
Date x Treatment x Cultivar	50	n.s.	23	n.s.
	Percent basal area interception			
Treatment	62	33.1^{*}	82	10.9^{*}
Cultivar	4	2.2^{*}	8	4.4^{****}
Treatment x Cultivar	2	n.s.	2	n.s.
Date	576	328.2^{****}	539	196.0^{****}
Date x Treatment	24	13.7^{***}	16	5.6^{*}
Date x Cultivar	2	n.s.	6	2.3^{*}
Date x Treatment x Cultivar	1	n.s.	3	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

Analysis of variance over dates (Table 3) for percent ground cover showed differences between cultivars and between dates but not between treatments for experiment III. The interaction between date and treatment can be expected as the rate of growth of meadow bromegrass is higher in spring and summer, with slower growth occurring in the latter part of the grazing season. This provides increased competition in the spring and therefore constitutes a higher proportion of the herbage during this period. The interaction between date and cultivar can also be expected as the cultivars entered in the experiments have differing fall dormancy. Less dormant cultivars start growth earlier in the spring and produce more growth in the fall than the more dormant cultivars. Differences between treatments in Exp. IV are due to the increased time between grazings which allowed for more regrowth for the meadow bromegrass.

Figure 2a. Percent visual ground cover for selected cultivars in Experiment III (continuous grazing) over the grazing season. Least significant differences (LSD) are from the analysis of all cultivars within the experimental date.

Experiment III

Percent Ground Cover

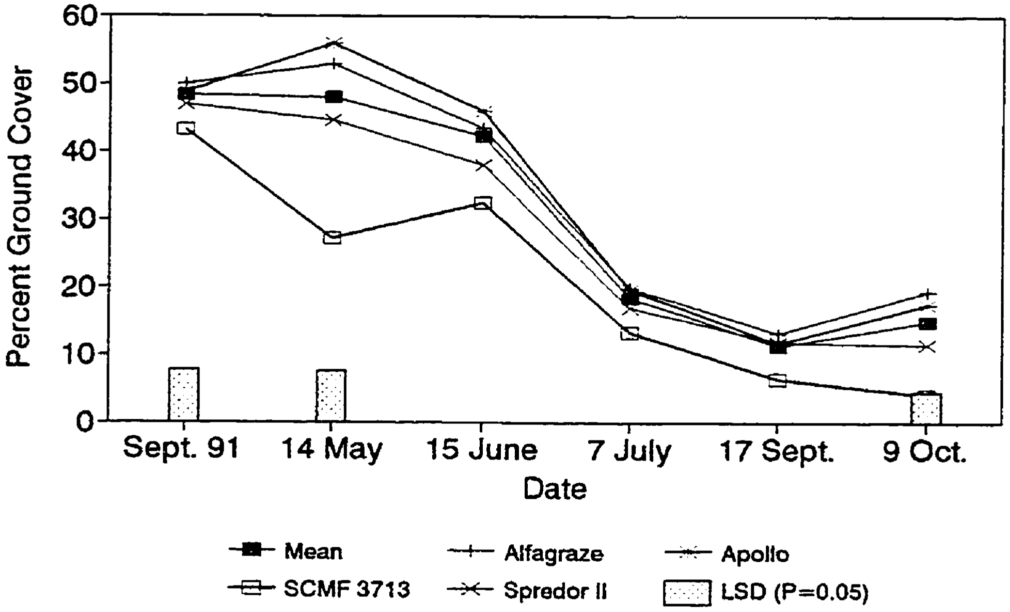
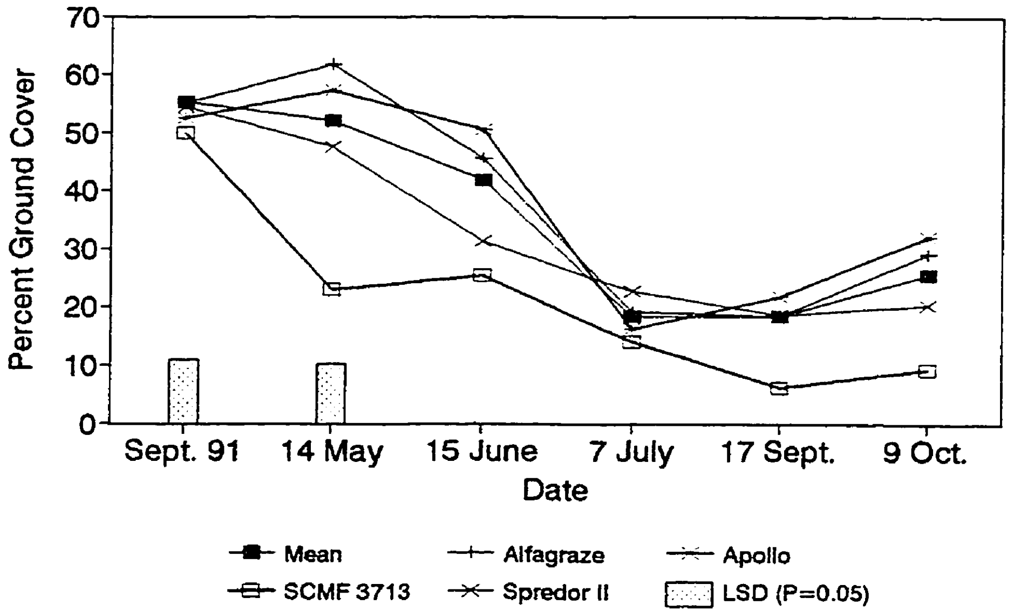


Figure 2b. Percent visual ground cover for selected cultivars in Experiment IV (rotational grazing) over the grazing season. Least significant differences (LSD) are from the analysis of all cultivars within the experimental date.

Experiment IV
Percent Ground Cover



Selected cultivars from experiments III and IV were plotted over the grazing season (Figures 2a, 2b) to look at date by cultivar interactions (Table 3). In experiment III (Figure 2a) the creeping rooted Spredor II and *M. falcata* cultivar SCMF 3713 tended to provide lower ground cover early in the grazing season (14 May) and late in the season (9 October). There were no differences between cultivars on 15 June, 7 July and 17 September, 1992. The cultivars tended to show similar rankings at the start and at the end of the grazing season. Apollo had the highest ground cover on 14 May 1992 but on 9 October 1992 Alfagraze ranked higher. Differences between cultivars on 9 October 1992 are partially due to varying levels of fall dormancy. These same cultivars showed similar tendencies in experiment IV (Figure 2b). There were no differences between cultivars during the grazing season or after. SCMF 3713 tended to rank lower than the other cultivars while Alfagraze and Apollo provided more ground cover on 14 May 1992 and tended to be higher after grazing ended (9 October 1992). In both experiments Apollo provided similar ground cover to that of Alfagraze. This is partly due to Apollo being a high yielding hay type cultivar with rapid growth. The ability of Apollo to maintain this growth over several years of continuous grazing is not as good as that of cultivars such as Alfagraze or Spredor II.

When analysis of covariance was performed using data from the 14 May 1992 as the covariate (Table 4), no differences between cultivars were evident during the grazing season in either experiment III or IV. Any differences between cultivars during the grazing season that were detected using analysis of variance on individual dates were likely due to differences that were present before grazing occurred.

Cultivar differences were not present for alfalfa ground cover on all dates during the grazing period in the continuously grazed experiment III (Table 5). Anik and SCMF 3712 had the lowest visual ground cover estimates taken in August 1991 of the establishment year. On 14 May, 1992 (before grazing was initiated), ground cover provided by Arrow was greater than the creeping rooted cultivars Rangelander, Roamer, Spredor II and Wrangler, and the *M. falcata* cultivars Anik and SCMF 3713. Assessments made on 17 September, after the end of grazing showed no differences between cultivars. Arrow had the greatest ground cover while Cimarron VR showed the greatest decrease in ground cover. Alfagraze ranked near the highest for ground cover provided. Spredor II and Apollo were intermediate in providing ground cover.

Under rotational grazing (experiment IV) decreases in ground cover in 1992 were similar among all cultivars with the exception of Anik and Roamer. Because Anik and Roamer are slower to start growth in spring they showed less of a decrease. The *M. falcata* cultivars SCMF 3713 and Anik showed very slow growth in the spring in comparison to the higher yielding hay cultivars. SCMF 3713 produced similar ground cover under both grazing management regiments both prior to and after grazing. After grazing ended, Roamer provided more ground cover than Anik and SCMF.

Rank correlations between Experiments III and IV indicated significant association for these experiments on all dates. The correlation between these rotational and continuous grazing experiments was moderate (Rank correlations between experiments III and IV: September, 1991, $r = 0.24$, $P \leq 0.017$, $N = 96$, 14 May 1992, $r = 0.58$, $P \leq 0.0001$, $N = 96$, and 17 September 1992, $r = 0.36$, $P \leq 0.0003$, $N = 96$. The experiments had been treated similarly until this time. After grazing had ended in September 1992 the correlation between these two experiments had decreased. After one season of grazing the alfalfa cultivars were beginning to differentiate in their response to the grazing management system indicating that development for cultivars that persist under close continuous grazing will need to be evaluated under conditions of close intensive grazing.

Table 4. Analysis of covariance for percent visual ground cover at Glenlea, MB under close continuous grazing (Experiment III) and rotational grazing (Experiment IV) using 14 May 1992 as the covariate for 15 June, 7 July, 17 September and 9 October 1992. Data for September 1991 and 14 May 1992 are analysis of variance.

	Experiment III		Experiment IV	
Source	MS	F value	MS	F value
	September, 1991			
Treatment	987	n.s.	3 384	23.6*
Cultivar	129	2.2*	302	2.5*
Treatment x Cultivar	72	n.s.	113	n.s.
	14 May, 1992			
Treatment	9 058	n.s.	15 725	25.1*
Cultivar	1 104	19.5****	2 447	22.4****
Treatment x Cultivar	47	n.s.	82	n.s.
	15 June, 1992			
Treatment	426.20	n.s.	25.93	n.s.
Cultivar	27.05	n.s.	94.59	n.s.
Treatment x Cultivar	26.77	n.s.	186.30	2.88**
	7 July, 1992			
Treatment	91.63	n.s.	231.24	n.s.
Cultivar	16.68	n.s.	48.83	n.s.
Treatment x Cultivar	4.04	n.s.	67.48	n.s.
	17 September 1992			
Treatment	2.82	n.s.	35.60	n.s.
Cultivar	12.55	n.s.	75.85	n.s.
Treatment x Cultivar	19.46	n.s.	157.42	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

Table 5. Visual percent ground cover of 12 alfalfa cultivars under close continuous grazing (Experiments III) and rotational grazing (Experiments IV) at Glenlea, MB in 1991 prior to grazing and during the 1992 grazing season.

	Experiment III			Experiment IV		
Stand	Sept. 1991	14 May	17 Sept.¶	Sept. 1991	14 May	17 Sept.
			% Visual Ground Cover			
Pure	51.3	57.6	12.6	61.2	65.0	24.5
Mixed	45.1	38.2	9.7	49.3	39.4	12.5
$p \geq F$	0.21	0.058	0.65	0.017	0.015	0.49
LSD (0.05)	n.s.†	n.s.	n.s.	7.78	16.28	n.s.
Cultivar‡						
Alfagraze	50.0 (5)§	52.8 (6)	13.1 (3)	55.0 (7)	61.8 (4)	18.4 (10)
Algonquin	47.5 (8)	53.2 (5)	11.9 (5)	51.3 (10)	56.4 (8)	18.8 (8)
Anik	39.4 (12)	21.6 (12)	5.5 (12)	41.3 (12)	11.4 (12)	8.0 (11)
Apollo	48.8 (6)	55.8 (4)	11.6 (8)	52.5 (9)	57.3 (7)	21.9 (3)
Arrow	53.8 (1)	58.6 (1)	14.6 (1)	57.5 (5)	65.9 (2)	20.2 (5)
Cimarron	52.5 (2)	56.8 (2)	10.3 (10)	60.0 (3)	63.2 (3)	19.7 (6)
Rangelander	51.3 (3.5)	49.8 (8)	10.4 (9)	64.4 (1)	59.9 (5)	19.1 (7)
Roamer	48.1 (7)	48.5 (9)	12.7 (4)	55.6 (6)	51.9 (9)	25.8 (1)
SCMF 3713	43.1 (11)	27.0 (11)	6.4 (11)	50.0 (11)	23.1 (11)	6.3 (12)
Spredor II	46.9 (9)	44.5 (10)	11.8 (6.5)	54.4 (8)	47.6 (10)	18.6 (9)
WL 317	51.3 (3.5)	56.0 (3)	13.8 (2)	61.9 (2)	68.8 (1)	24.1 (2)
Wrangler	45.0 (10)	50.3 (7)	11.8 (6.5)	58.8 (4)	59.2 (6)	21.3 (4)
$p \leq F$	0.0007	0.0001	0.30	0.012	0.0001	0.77
LSD (0.05)	7.78	7.51	n.s.	11.03	10.44	n.s.
Mean	48.2	47.9	11.2	55.2	52.2	18.5
Std. Dev.	11.1	17.6	4.8	13.5	24.3	13.6

† Means do not differ significantly ($P \leq 0.05$)

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Cultivars ranking within each measurement date for each experiment is enclosed in parentheses.

¶ Data for 17 September 1992 analyzed using 14 May 1992 as a covariate.

4.1.2.2 Plant Counts

Plant counts are a useful and traditional method to evaluate survival of plants over time under different levels of stress. With repeated counts the rate of decline, and therefore relative persistence, can be determined for different cultivars under grazing. Alfalfa plants produce shoots from the crown at points above and below the soil surface. Shoots with a below ground origin lead to difficulty in determining the actual number of plants, especially when they are close together. Several plants, located sufficiently close together, may be counted as one. Over time individual plants die, but this may not reflect in the final plant counts because of inaccurate counts earlier in the season. This effect would be more pronounced early in the life of a stand and in stands with high plant densities.

Under rotational grazing (experiment IV) there was a decrease in plant numbers from 33.7 plants per 0.1 m2 to 30.8 plants per 0.1 m2 during the first season of grazing (Table 3, Table 7), but not under continuous grazing (experiment III). Analysis of covariance revealed that differences between cultivars detected at the end of grazing using analysis of variance were attributable to differences between cultivars that were present prior to the start of grazing in both experiments.

Experiment III showed a date by treatment interaction (Table 3) where there were significantly more alfalfa plants in the pure stand in comparison to the mixed stand on 15 June 1992 (Table 7) under continuous grazing (experiment III). After grazing ended (14 Sept 1992), differences were no longer present between these treatments. In the rotational grazing experiment (experiment IV) there were more alfalfa plants in the pure stand than in the mixed treatment early (15 June) in the 1992 grazing season and but no late (14 September) in the grazing season. Trends showed a greater decrease in the pure stand than in the mixed stand. Since there were no interactions between the pure and mixed stands at any measurement date (Table 3), cultivar measurements were combined across the main plot treatments.

Prior to the initiation of grazing, in Experiment III (14 September) Anik and SCMF 3713 showed the lowest plant numbers, but the other cultivars showed very little difference. The ability of an alfalfa stand to maintain plant numbers under stress conditions indicates the length of time the stand can remain productive. Cultivars that are more tolerant to a particular stress will maintain stand productivity for a longer period of time. After one season of close continuous grazing plant numbers decreased by more than 10% for Anik (34%), Arrow (11%), Cimarron VR (16%) and Rangelander (11%). The cultivars Alfagraze, Algonquin, SCMF 3713, Spredor II and Wrangler did not show any decrease in plant number over one season of grazing. There were cultivar differences under rotational grazing (experiment IV) on 15 June, 1992. Analysis of covariance of plant counts on 14 September showed no differences between cultivars in either experiment III or experiment IV.

Rank correlations for plant counts between Experiments III and IV were not significant either on 15 June or 14 September (15 June, $r = 0.19$, $P \leq 0.061$, $N = 96$ and 14 September, $r = 0.15$, $P \leq 0.16$, $N = 96$.). A correlation was possible on 15 June at $p \leq 0.06$ indicating little difference between cultivars within the two trials early in the season. The lack of correlation between cultivars following the application of the two different grazing management systems indicate that individual cultivars performed differently under different levels of the same type of stress. The evaluation of cultivars under one grazing regiment cannot be used to infer their performance under a different grazing intensity.

Table 6. Analysis of covariance for plants per 0.1 m^2 at Glenlea, MB under close continuous grazing (Experiment III) and rotational grazing (Experiment IV) using 15 June 1992 as the covariate for 14 September 1992. Data for 15 June 1992 is analysis of variance.

	Experiment III		Experiment IV	
Source	MS	F value	MS	F value
		15 June, 1992		
Treatment	1 634	11.1^{*}	4 803	12.2^{*}
Cultivar	118	4.2^{****}	163	3.6^{***}
Treatment x Cultivar	34	n.s.	45	n.s.
		14 September, 1992		
Treatment	1.84	n.s.	9.62	11.67^{*}
Cultivar	0.42	n.s.	0.82	n.s.
Treatment x Cultivar	0.10	n.s.	0.55	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

Table 7. Plants per 0.1 m^2 of 12 alfalfa cultivars under close continuous grazing (Experiments III) and rotational grazing (Experiments IV) at Glenlea, MB in 1992.

	Experiment III		Experiment IV	
Stand	15 June	14 Sept.¶	15 June	14 Sept.
		plants $0.1m^2$		
Pure	37.6	31.5	40.8	36.3
Mixed	29.3	32.4	26.6	25.3
$p \geq F$	0.045	0.51	0.040	0.61
LSD (0.05)	7.89	n.s.†	12.9	n.s.
Cultivar‡				
Alfagraze	34.3 (7.5)§	39.4 (2)	36.8 (4)	33.0 (4)
Algonquin	31.3 (10)	31.8 (7)	34.6 (7)	32.8 (5)
Anik	24.8 (12)	16.3 (12)	23.0 (12)	23.5 (11)
Apollo	35.0 (5)	32.4 (6)	33.6 (8)	30.6 (8)
Arrow	34.3 (7.5)	30.4 (10)	37.9 (1.5)	32.6 (6)
Cimarron VR	37.6 (2)	31.6 (8)	33.4 (9)	30.3 (10)
Rangelander	35.3 (4)	31.3 (9)	37.9 (1.5)	36.0 (1)
Roamer	34.5 (6)	33.1 (4)	34.8 (6)	33.4 (2.5)
SCMF 3713	28.3 (11)	29.6 (11)	27.5 (11)	22.1 (12)
Spredor II	32.4 (9)	32.9 (5)	31.5 (10)	30.5 (9)
WL 317	35.8 (3)	34.1 (3)	36.6 (5)	30.9 (7)
Wrangler	38.3 (1)	40.8 (1)	37.1 (3)	33.4 (2.5)
$p \leq F$	0.0001	0.065	0.0006	0.44
LSD (0.05)	5.3	n.s.	6.8	n.s.
Mean	33.5	32.0	33.7	30.8
Std. Dev.	9.7	11.7	11.1	9.8

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† Means do not differ significantly ($P \leq 0.05$)

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Cultivar ranking within each measurement date for each experiment is enclosed in parentheses.

¶ Data for 14 September 1992 analyzed using 15 June 1992 as a covariate.

4.1.2.3 Basal Area Cover

The basal area cover is used as a quantitative estimate of plant density. At low plant populations basal area cover may be less effective at deriving a true estimate of plant populations than plant counts. Multiple plants clustered together are counted as one plant. Basal area cover is ineffective at distinguishing between cultivars when the number of plants is low due to the low probability that a representative number of plant crowns will occur under the intersecting wires on a grid. Basal area cover is faster to conduct than plant counts.

Percent basal area cover using a point quadrat (Table 9) showed that meadow bromegrass competition with alfalfa decreased the size and or number of alfalfa crowns on 15 June but not on 28 August in experiment III. There were no differences between treatments on 12 June in experiment IV. However on 11 September there was a higher basal count in the pure stand. There were no interactions between stands and cultivars at any measurement date, therefore cultivar measurements were combined across these main plot treatments.

Cultivar differences were present on 15 June but not on 28 August in both Experiments III and IV. This indicated that under either close continuous grazing or rotational grazing initial basal cover differences between cultivars were no longer present at the end of the grazing season.

Rank correlations between Experiments III and IV did not show significance on either 15 June or 28 August (15-18 June, $r = 0.16$, $P \leq 0.12$, $N = 96$, and 28 August/ 11 September, $r = -0.09$, $P \leq 0.39$, $N = 96$.). The lack of cultivar differences with the percent basal area cover measurements and the presence of differences for both visual ground cover and plant counts indicate that basal area was not a reliable method of determining persistence, especially at low plant densities.

Table 8. Analysis of covariance for percent basal area interception at Glenlea, MB under close continuous grazing (Experiment III) and rotational grazing (Experiment IV) using 15 June 1992 as the covariate for 28 August 1992 (Experiment III) and 11 September 1992 (Experiment IV). Data for 15 June 1992 is analysis of variance.

	Experiment III		Experiment IV	
Source	MS	F value	MS	F value
	15 June, 1992			
Treatment	82	16.7^{*}	84	n.s.
Cultivar	6	2.0^{*}	14	4.3^{*}
Treatment x Cultivar	3	n.s.	5	n.s.
	28 August, 1992		11 September, 1992	
Treatment	1.8	n.s.	9.6	11.7^{*}
Cultivar	0.4	n.s.	0.6	n.s.
Treatment x Cultivar	0.5	n.s.	0.4	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

Table 9. Percent basal area interception using a point quadrat of 12 alfalfa cultivars under close continuous grazing (Experiments III) and rotational grazing (Experiments IV) at Glenlea, MB in 1991 and 1992.

	Experiment III		Experiment IV	
Stand	15 June	28 Aug.¶	12 June	11 Sept¶
	% Basal Area Interception			
Pure	5.5	1.3	5.7	1.8
Mixed	3.7	0.9	3.8	1.0
p≥F	0.027	0.09	0.11	0.042
LSD	1.44	n.s.†	n.s.	0.59
Cultivar‡				
Alfagraze	4.8 (6)§	1.2 (5.5)	5.2 (4.5)	1.5 (6.5)
Algonquin	5.5 (2)	1.1 (7.5)	6.3 (2)	1.3 (8.5)
Anik	3.0 (12)	0.5 (12)	2.2 (12)	1.1 (11)
Apollo	4.4 (7.5)	1.1 (7.5)	5.0 (6)	1.6 (3.5)
Arrow	5.4 (3)	1.2 (5.5)	6.0 (3)	1.2 (10)
Cimarron VR	4.0 (10)	0.9 (11)	4.1 (8.5)	1.8 (1)
Rangelander	4.9 (4.5)	1.3 (3.5)	4.9 (7)	1.3 (8.5)
Roamer	6.0 (1)	1.0 (9.5)	4.1 (8.5)	1.6 (3.5)
SCMF 3713	3.5 (11)	1.0 (9.5)	3.6 (11)	0.8 (12)
Spredor II	4.4 (7.5)	1.4 (1.5)	3.7 (10)	1.5 (6.5)
WL 317	4.3 (9)	1.4 (1.5)	7.0 (1)	1.6 (3.5)
Wrangler	4.9 (4.5)	1.3 (3.5)	5.2 (4.5)	1.6 (3.5)
p≤f	0.040	0.39	0.0001	0.48
LSD (0.05)	1.65	n.s.	1.79	n.s.
Mean	4.6	1.1	4.8	1.4
Std. Dev.	2.1	0.6	2.6	0.8

† Means do not differ significantly ($P \leq 0.05$)

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Cultivar ranking within each measurement date for each experiment is enclosed in parentheses.

¶ Data for 28 August and 11 September analyzed using 15 June 1992 as a covariate.

4.1.3 Conclusions

Continuous close grazing exerts a higher level of stress on alfalfa plants when compared to rotational grazing since plants are able to regrow and store root carbohydrate reserves between defoliations, similar to what occurs under hay production (Nelson and Smith, 1968, and Smith, 1961). Stand density assessments made on microplot Experiments I and II did not show rank correlations across cultivars between the two different management systems. Likewise, rank correlations across cultivars were not present between Experiments III and IV for plant counts and basal area cover, but were weakly correlated for ground cover.

Since continuous grazing results in high plant stress, stand losses between and within cultivars in a selection experiment will occur more quickly than under rotational grazing system (Counce et al, 1984). Because plants react differently under the two grazing systems, grazing tolerance evaluations should be conducted under continuous grazing to insure that cultivars are sufficiently tolerant to grazing.

Although alfalfa is not usually grown in pure stands for pasture, evaluation of pure alfalfa stands is easier than when it is grown with a grass species. Herbicide products available for pure alfalfa are more numerous than those that are compatible with one or more grass species. Results from these trials did not show any interaction between cultivars with and without the presence of meadow bromegrass, suggesting that evaluation without companion species can be effective.

Evaluation of alfalfa in micro plots (1 m^2) has the potential to offer several benefits. In a breeding program, small quantities of seed are often all that is available. With microplots the area required for evaluation is also reduced, decreasing spatial variability within an experiment and reducing land costs. Reducing spatial variability is extremely important in a breeding program because hundreds of lines may require evaluation.

In these experiments, there were no differences between cultivars during the grazing season for percent ground cover (Table 4), or at the end of the grazing season for either plants per 0.1 m^2 (Table 6) or percent basal area interception (Table 8). Analysis of covariance using the first date of each measurement of the grazing season removed cultivar differences that occurred when each date was analyzed individually. This indicates that cultivar differences within the first grazing season are a factor of differences that were present prior to the start of grazing, and not a result of the grazing stress itself.

With the relatively short growing season available in Western Canada, it is expected that two or more years of grazing will be required for sufficient segregation to occur for cultivar or breeding lines to be identified as grazing tolerant or intolerant. In Georgia, Smith and Bouton (1993) suggest that two or more years of grazing may be required to determine different grazing tolerance between cultivars.

4.2 Plant Characteristics

4.2.1 Experiments V - VIII: Portage la Prairie Field Evaluations

Alfalfa plants at Portage la Prairie were transplanted as 4 month old seedlings from the greenhouse in May of each year. Transplants are often used in breeding programs to reduce cultivar development time. If alfalfa transplants can be utilized for grazing experiments, then the plants would be larger throughout the first year allowing for grazing to occur earlier in the year of establishment.

4.2.1.1 Alfalfa Stem Production

Alfalfa stem production at Portage la Prairie was unaffected by competition with meadow bromegrass regardless of whether stems had an axillary or crown origin (Table 10). Since there was no interaction present between pure alfalfa stands and mixed stands with competition from meadow bromegrass, stem results were combined across alfalfa cultivars with and without grass competition. Under continuous grazing, total stem number between cultivars did not differ in 1992, nor did the number of axillary stems in 1993. The number of crown stems differed between cultivars in 1993. When grazed rotationally, cultivars differed in the production of total stems in 1992 and crown stems in 1993, but not axillary stems in 1993. This indicated that assessment of crown stem production may be more useful for determining differences between cultivars than total stem number. Cultivar differences under continuous grazing in 1992 may have been masked due to the inclusion of axillary stems in the assessments.

Separation between cultivars after one season of grazing was small with little difference between the majority of cultivars (Table 10). Where differences did occur, SCMF 3713, which performed well in experiments I-IV at Glenlea, had the fewest stems. Additionally, SCMF 3713 had the lowest ranking for total stem number in 1992 under continuous grazing (significant at the 10% level). In 1993, Spredor II had the second lowest number of crown stems under both grazing intensities. The selected populations from Algonquin (Algonquin-S) and Apollo (Cut'N'Graze) did not differ from their parental cultivars but had lower rank means than their parental populations. This indicates that selection can be made for increased grazing tolerance without necessarily decreasing the potential for forage production.

Mean rankings across total stems and crown stems revealed that Grimm, Rangelander and Apollo had the highest average rank while SCMF 3713, Spredor II and Alfagraze had the lowest average rank for stem number (data not shown). Both Alfagraze and SCMF 3713 performed well under close continuous grazing while Rangelander ranked near the bottom for the persistence measurements evaluated.

Interestingly, in these experiments the grazing tolerant cultivars produced fewer stems than the grazing intolerant cultivars. The hay type cultivars tended to rank highest for stem number. Higher stem density has been associated with increased forage yield of alfalfa (Smith et al 1989). Other research (Smith et al 1992) showed higher plant stem numbers for more grazing tolerant cultivars on established alfalfa stands. Crown stems are the primary source of new growth after defoliation has occurred. Due to the difficulty in measuring productivity under close continuous grazing crown stem numbers might be a good indicator of potential productivity.

Table 10. Stem counts taken at 2.5 cm above the soil surface for Experiments V (17 September 1992, continuous grazing), VII (22 September 1993, continuous grazing), VI (18 September 1992, rotational grazing), VIII (22 September 1993, rotational grazing) on alfalfa transplants at Portage la Prairie, MB.

	Exp. V	Exp. VII		Exp. VI	Exp. VIII	
Stand	Total Stems	Axillary Stems	Crown Stems	Total Stems	Axillary Stems	Crown Stems
	- - - - - - - - - -	- - - - - Number of	Stems Plant^{-1}	- - - - -	- - - - -	- - - - -
Pure	5.34†	2.80	4.30	6.6	4.7	6.05
Mixed	4.08	3.27	4.54	5.9	3.5	6.21
p≥f	0.12	0.058	0.51	0.076	0.37	0.59
Cultivar‡						
Alfagraze	5.2	3.1	4.4ab§	5.1bc	3.8	6.3ab
Algonquin	4.2	3.4	5.3a	7.5a	4.8	5.7ab
Algonquin-S	5.2	3.0	4.8ab	6.0ab	4.7	5.8ab
Apollo	5.2	2.5	4.5ab	5.5bc	3.8	7.2a
Cut'N'Graze	4.3	3.6	4.4ab	---	4.6	7.0a
Arrow	4.8	2.7	4.5ab	7.2a	3.7	6.1ab
Grimm	5.4	3.6	4.6ab	7.3a	4.3	6.5ab
Rangelander	5.5	2.8	4.4ab	7.2a	3.9	7.0ab
SCMF 3713	3.6	2.7	3.1c	4.5c	3.8	4.0c
Spredor II	4.3	3.1	3.7bc	6.1ab	3.9	5.3bc
Spredor III	4.1	2.8	5.0a	6.1ab	4.2	6.7ab
p≥f	0.095	0.47	0.040	0.0013	0.62	0.0067
Mean	4.7	3.0	4.4	6.2	4.1	6.1
Std. Dev.	1.8	1.1	1.3	1.8	4.4	1.9

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean stem numbers.
‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.
§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

4.2.1.2 Alfalfa Growth Habit

Decumbency is a characteristic of grazing avoidance where more prostrate plants are less likely to be grazed. Therefore plants that are more decumbent in growth will survive better under grazing, but will have a lower harvestable yield. Alfalfa plant decumbency was unaffected by the presence or absence of meadow bromegrass competition (Table 11). Since no interaction was present between pure alfalfa stands and stands with meadow bromegrass competition, the data was combined for alfalfa plants with and without competition.

Cultivars differed in growth habit in 1992 under continuous grazing (experiment V) and in both 1992 and 1993 under rotational grazing (experiments VII and VIII) (Table 11). Under continuous grazing, the creeping rooted cultivars (Rangelander, Spredor II, Spredor III) and *M. sativa* ssp *falcata* alfalfa cultivar (SCMF 3713) were more prostrate than the hay-type cultivars (Apollo, Arrow, Algonquin). Although not significant, trends for the 1993 continuous grazing experiment (VI) showed that the creeping rooted types were more prostrate than the hay-type alfalfas. Alfagraze tended to be intermediate in decumbency when compared to Apollo and Spredor II. This characteristic was also reported by Brummer and Bouton (1991). The evaluation of the continuously grazed plants is biased to a degree by the fact that upright stems are continuously removed by grazing more often than those that are more close to the ground.

In contrast, under rotational grazing, plants have time to regrow after grazing and the upright stems are not removed as frequently as in continuous grazing. Under rotational grazing, cultivars showed marked differences in both years. The creeping rooted cultivars Rangelander and Spredor III and the *M. falcata* entry SCMF 3713 ranked as more prostrate over both years than the hay-type Apollo, the least decumbent. Spredor II ranked higher under rotational grazing than under continuous grazing. Alfagraze ranked less decumbent in 1992 (experiment VI) than Spredor II, but more decumbent in 1993 (experiment VIII).

Over time, all alfalfa plants tended to become more prostrate under grazing (Figure 3). Alfalfa plants were upright prior to grazing in 1993 so assessments were not made. Plants tended to be less decumbent under rotational than under continuous grazing in both years (Table 11). Plants under continuous grazing became more prostrate at each successive assessment. Under rotational grazing in 1992, plants became more prostrate after each grazing period. In 1993, the alfalfa plants continued to become more prostrate through the second grazing, then became less prostrate. At the end of each grazing season the rotationally grazed plants were less prostrate than the continuously grazed plants.

Decumbency is a method of grazing avoidance utilized by alfalfa plants. By reducing the amount of defoliation, plants are able to synthesize carbohydrates and reduce the reliance on stored root carbohydrates for regrowth. This prevents the depletion of root reserves and increases the long term survival of alfalfa plants. Under grazing, plants become more prostrate as the grazing season progresses (Brummer and Bouton, 1991). Where differences existed the selected populations of Apollo (Cut'N'Graze) and Algonquin (Algonquin-S) tended to be more prostrate than their parental populations. This indicates that selection for grazing tolerance may produce populations that use grazing avoidance to increase survival. This allows plants to maintain adequate root storage reserves for winter survival and regrowth the following year.

Figure 3. Mean decumbency scores combined for cultivars and treatments over time for experiments Exp V (1992 continuous grazing), VII (1993 continuous grazing), VI (1992 rotational grazing), VIII (1993 rotational grazing). Grazing began immediately after assessments at week 0 and continued through to week 8 for continuous grazing. Rotational grazing occurred immediately after assessments were taken at week 0 and week 4. Vertical lines show the standard deviation for each individual experimental date.

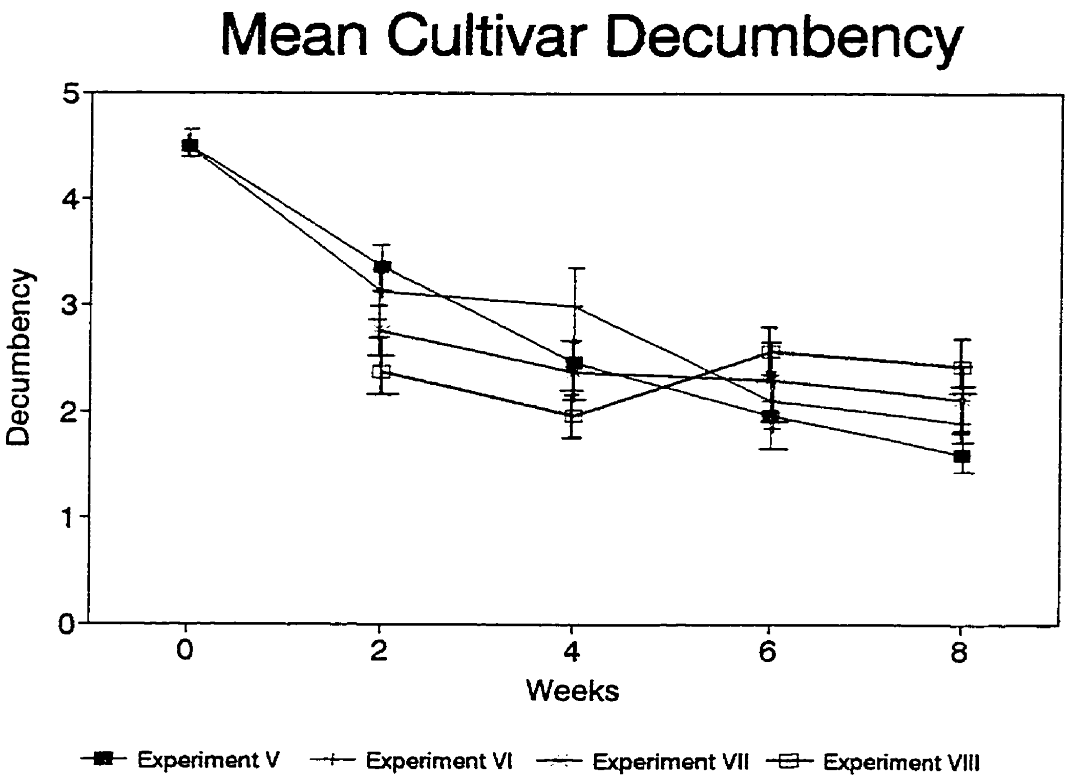
Mean Cultivar Decumbency
Decumbency
0
1
2
3
4
5
0
2
4
6
8
Weeks
Experiment V
Experiment VI
Experiment VII
Experiment VIII

Table 11. Mean decumbency scores (1 – prostrate, 5 – vertical) for Experiments V (17 September 1992, continuous grazing), VII (22 September 1993, continuous grazing), VI (18 September 1992, rotational grazing), VIII (22 September 1993, rotational grazing) on alfalfa transplants at Portage la Prairie, MB.

Stand	Exp. V	Exp. VII	Exp. VI	Exp. VIII
	- - - - - - - - -	1 to 5	- - - - - - - - -	
Pure	1.77†	2.5	1.9	2.5
Mixed	2.14	2.2	2.3	2.7
$p \geq f$	0.20	0.31	0.12	0.45
Cultivar‡				
Alfagraze	2.1a-c§	2.4	2.2b-d	2.7a-c
Algonquin	2.2ab	2.2	2.2a-c	2.7a-c
Algonquin-S	1.8a-c	2.8	1.9cd	2.3cd
Apollo	2.5a	2.7	2.9a	3.1a
Cut'N'Graze	2.0a-c	2.6	---	2.7a-c
Arrow	2.4a	2.6	2.7ab	2.5b-d
Grimm	1.9a-d	2.5	2.2bc	2.5b-d
Rangelander	1.6b-d	1.7	1.6e	2.3cd
SCMF 3713	1.4d	1.9	1.6de	2.0d
Spredor II	1.9a-d	1.9	2.0c-e	3.0ab
Spredor III	1.7cd	2.1	1.9c-e	2.5b-d
$p \geq f$	0.02	0.38	0.0002	0.005
Mean	2.0	2.3	2.1	2.6
Std. Dev.	0.7	1.1	0.8	0.8

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean decumbency scores.
‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.
§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

4.2.1.3 Alfalfa Ground Cover

The ability of an alfalfa plant to provide ground cover is a factor in weed competition. The higher the percent ground cover, the more that weed seedlings are shaded. Species other than alfalfa which are more competitive will reduce the growth of alfalfa, and over time increase in percentage of the stand, thereby reducing the productive life of the alfalfa. In these experiments meadow bromegrass planted in 1992 established well and was very competitive. Alfalfa ground cover was reduced when in competition with meadow bromegrass compared to when it was grown alone both under continuous and rotational grazing (Table 12). The meadow bromegrass planted in 1993 was less vigorous than in 1992, resulting in a lack of ground cover differences between the pure alfalfa stands and mixtures with meadow bromegrass. Under continuous grazing, alfalfa cultivars did not differ in the percentage of ground cover provided after eight weeks of grazing. In 1992, trends indicated that SCMF 3713, a *M. falcata* which typically has slower regrowth than sativa germplasm, had less ground cover than the other cultivars. In 1992, Alfagraze tended to provide less ground cover than Apollo and Spredor II but was very similar in 1993.

The lack of differences between cultivars was an indication of the uniformity of grazing pressure across the experiments and between years. Uniformity of grazing is important because livestock are forced to graze less palatable plants to the same degree as those that may be more palatable. This removes bias by the livestock and permits evaluation of other characteristics independent of palatability. The fact that the plants were young and the grazing season short also contributed to a lack of differences in the experiments.

Under rotational grazing, cultivars differed in ground cover four weeks after the second grazing period in 1992, but not in 1993 (Table 12). In 1992, SCMF 3713 had a lower ground cover than the other cultivars which did not differ from each other. A lack of differentiation under rotational grazing can be attributed to the lateness of the season, when plants were preparing for winter by reducing growth and accumulating root reserves. A later fall in 1992 than in 1993 allowed for some differentiation. Less dormant cultivars would normally show more fall growth than the most dormant. SCMF 3713 is a *M. falcata* type alfalfa with slower regrowth than *M. sativa* alfalfa, which is the predominate genetic background in most cultivars available on the market today.

Table 12. Individual plant ground cover assessment expressed as the percent of a 30 cm square area occupied by each plant for Experiments V (1 October 1992, continuous grazing), VII (6 October 1993, continuous grazing), VI (2 October 1992, rotational grazing), VIII (6 October 1993, rotational grazing) on alfalfa transplants at Portage la Prairie, MB.

Stand	Exp. V	Exp. VII	Exp. VI	Exp. VIII
	- - - - - - - - -	- - - %	- - - - - -	- - - - - -
pure	8.4†	6.8	10.3	6.92
mixed	4.1	6.2	7.2	7.98
$p \geq f$	0.02	0.75	0.021	0.13
Cultivar‡				
Alfagraze	5.3	5.3	9.4a§	9.4
Algonquin	5.4	9.0	9.6a	7.7
Algonquin-S	5.4	8.0	8.3a	7.0
Apollo	7.5	5.2	8.6a	7.0
Cut'N'Graze	6.1	5.5	---	7.3
Arrow	6.7	5.5	10.1a	7.2
Grimm	6.7	6.3	10.2a	6.9
Rangelander	7.9	5.7	8.5a	9.4
SCMF 3713	4.2	6.1	5.4b	7.0
Spredor II	7.6	5.7	9.4a	6.8
Spredor III	6.1	9.4	8.7a	6.2
$p \geq f$	0.07	0.31	0.046	0.31
Mean	6.3	6.5	8.8	7.5
Std. Dev.	3.6	3.9	3.8	4.4

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean individual plant ground cover.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

4.2.2 Alfalfa Crown and Root Morphology

4.2.2.1 Crown Area

Larger crown areas have been associated with increased persistence under grazing. Larger crowns have the capacity to store higher levels of root carbohydrates which are used for regrowth and winter survival and provide more potential sites for crown buds for regrowth. While significantly different only in experiment V, alfalfa plants in pure stands in experiments VI to X tended to have larger crowns than plants grown in competition with meadow bromegrass after one season of grazing (Tables 13 and 14). Meadow bromegrass competes with alfalfa for nutrients, water and light. Grass competition reduces the growth of alfalfa (Mooso and Wedin, 1990), reducing the synthesis of root reserves during regrowth. This would indicate that competition can reduce the ability of alfalfa to survive, especially when constant herbage removal is occurring. Rotationally grazed alfalfa plants tended to develop larger crowns than continuously grazed alfalfa plants due to an increase in the time available for accumulation of root reserves between defoliation periods (Tables 13 and 14).

Under continuous grazing, differentiation between cultivars did not occur at any location at the 5% significance level (Table 13). Differences occurred between cultivars at the 10% significance level at Portage la Prairie in 1993. The hay-type cultivar Arrow had a smaller crown area than Rangelander (a creeping rooted cultivar), Grimm (locally adapted seed source), and Algonquin-S and Cut'N'Graze (selected for grazing tolerance). The falcata entry and the other creeping rooted cultivars, SCMF 3713, Spredor II and Spredor III, respectively did not differ from the cultivars with the largest crowns. Apollo tended to have larger crowns than either Alfagraze or Spredor II. Cut'N'Graze and Algonquin-S tended to have larger crowns than their parental populations indicating selection for grazing tolerance may have resulted in plants with larger crowns.

Constant defoliation under grazing may have reduced plant growth and development, preventing differentiation between cultivars after only one season of grazing. In measuring individual plants, there appeared to be a larger variation within cultivars than between which would further reduce the ability to separate cultivars. In subsequent experiments, crown measurements should be taken on older plants that are subjected to grazing stress over a longer period of time.

With rotational grazing, cultivars showed crown area differences after grazing at Brandon, MB in 1993, after grazing at Portage la Prairie in both 1992 and 1993, and prior to grazing at Portage la Prairie in 1993 at the 5% significance level (Table 14). Cultivars also differed at Glenlea in the spring following the first grazing season at the 6% significance level, and prior to grazing at Portage in 1992 at the 10% significance level. In both years after grazing at Portage SCMF 3713 had a smaller crown area than the other cultivars and ranked the lowest at Glenlea. Cut'N'Graze had a smaller crown area than Apollo in 1992, and Algonquin-S had a smaller crown area than Algonquin in 1993. Apollo tended to have larger crowns than either Alfagraze or Spredor II which were similar. As in the continuously grazed plants, there appeared to be a larger variation within cultivars than between.

Cut'N'Graze and Algonquin-S performed differently than their respective parental populations under the continuous and rotational grazing regimes. While they appear more adapted under continuous grazing, they may be less adapted to a hay type defoliation regiment such as rotational grazing.

Table 13. Cross sectional area (mm^2) of the plant crown located 2 cm below the soil surface of 11 alfalfa cultivars under continuous grazing for Experiments III (Glenlea, MB, 1993) VII (Portage la Prairie, MB 1993) and IX (Brandon, MB 1993), and at the base of the crown for Experiment V (Portage la Prairie, MB 1992). Alfalfa roots from Experiment III were removed in the spring following one season of grazing.

	Exp. V		Exp. III	Exp. VII		Exp. IX
Stand	27 July	21 Sept.	12 May	12 Aug.	7 Oct.	22 Oct.
			mm^2			
Pure	6.5†	19.3	31.3	35.1	60.4	41.1
Mixed	5.5	9.2	21.7	33.7	57.6	29.8
p$\geq$f	0.57	0.028	0.060	0.90	0.83	0.13
Cultivar‡						
Alfagraze	6.1	17.6	25.4	33.3	43.2	37.4
Algonquin	5.4	10.4	36.6	40.6	60.4	---
Algonquin-S	5.2	11.4	---	34.2	65.0	---
Apollo	8.6	19.3	29.8	37.0	55.7	48.9
Cut'N'Graze	6.2	13.3	---	31.5	78.0	---
Arrow	4.7	15.2	23.5	39.8	37.9	33.2
Grimm	6.5	17.0	---	42.8	66.6	---
Rangelander	8.0	14.2	23.3	30.0	75.4	31.1
SCMF 3713	5.1	10.8	20.3	25.0	55.8	31.5
Spredor II	6.7	13.8	20.1	32.2	53.3	37.3
Spredor III	3.6	12.1	---	31.8	57.3	27.4
p$\geq$f	0.09	0.13	0.32	0.31	0.052	0.13
Mean	6.0	14.2	24.7	34.4	59.0	35.5
Std. Dev.	3.9	8.5	10.1	15.1	26.2	16.8

† Analysis of variance and cultivar mean comparison based on transformed data ($x^{1/2}$), but reported values were the actual mean plant crown areas.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

Table 14. Cross sectional area (mm^2) of the plant crown located 2 cm below the soil surface of 11 alfalfa cultivars under rotational grazing for Experiments VI (Portage la Prairie, MB 1992), IV (Glenlea, MB 1993), VIII (Portage la Prairie, MB 1993) and X (Brandon, MB 1993). Alfalfa roots from Exp. VI were removed in the spring following one season of grazing.

	Exp. VI		Exp. IV	Exp. VIII		Exp. X
Stand	27 July	21 Sept.	12 May	12 Aug.	7 Oct.	22 Oct.
	– – – – – – – – – – – – – – mm^2 – – – – – – – – – – – – –					
Pure	7.45†	42.1	61.1	35.6	74.1	67.4
Mixed	6.74	34.0	36.7	31.7	70.6	44.7
p≥f	0.81	0.44	0.15	0.54	0.53	0.13
<u>Cultivar‡</u>						
Alfagraze	8.6	42.6_{ab}§	33.2	$28.6b_{c}$	68.2_{ab}	51.6_{b}
Algonquin	7.1	45.1_{ab}	36.6	35.2_{ab}	91.4_{a}	---
Algonquin-S	7.2	39.4_{ab}	---	28.4_{bc}	58.8_{b}	---
Apollo	6.9	56.6_{a}	48.8	49.1_{a}	87.1_{ab}	125.0_{a}
Cut'N'Graze	---	30.7_{b}	---	38.8_{ab}	81.6_{ab}	---
Arrow	8.5	32.5_{ab}	53.2	33.4_{ab}	78.5_{ab}	35.5_{b}
Grimm	8.4	39.7_{ab}	---	36.2_{ab}	87.9_{ab}	---
Rangelander	8.2	34.7_{ab}	70.3	41.8_{ab}	79.2_{ab}	36.6_{b}
SCMF 3713	3.4	12.1_{c}	27.2	18.6_{c}	29.1_{c}	55.6_{b}
Spredor II	6.2	41.9_{ab}	73.0	26.8_{bc}	60.8_{ab}	56.2_{b}
Spredor III	6.3	41.3_{ab}	---	33.1_{b}	73.6_{ab}	31.7_{b}
p≥f	0.094	0.014	0.057	0.014	0.0022	0.011
Mean	7.1	37.9	48.9	33.6	72.4	56.0
Std. Dev.	3.8	25.5	42.1	20.1	37.8	60.3

† Analysis of variance and cultivar mean comparison based on transformed data ($x^{1/2}$), but reported values were the actual mean plant crown areas.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

4.2.2.2 Crown Depth

Crown depth has been associated with persistence under grazing. Deeper crowns are more protected from grazing damage such as trampling than plants that have shallow crowns. Buds are produced further under the soil surface when crowns are deeper, affording more protection from grazing damage. After one season of grazing there were no apparent crown depth differences between cultivars or other treatments at any site (Appendix A1, Tables A1.1 and A1.2).

4.2.2.4 Number of Crown Buds

An increased production of crown buds has been associated with cultivars that are more grazing tolerant (Brummer and Bouton, 1991). Higher numbers of crown buds provide for more potential stems for regrowth after forage removal. Emergence of crown buds was discussed previously under the section of crown and axillary stems. Data from Glenlea was not included in this analysis because plants were removed in the spring after growth had started and the majority of the crown buds had broken dormancy and were actively growing.

Under continuous grazing (Table 15) at Portage la Prairie in 1992, the plants from the pure alfalfa stands had significantly more crown buds than in the mixed meadow bromegrass treatment after grazing, but there were no crown bud differences between these treatments at any other location or date. Cultivars showed no differences either before grazing started or after grazing ended at Portage la Prairie in 1992. In 1993, cultivar differences were present after one season of grazing at both Portage la Prairie and Brandon and prior to grazing at Portage la Prairie. Comparisons made between locations in 1993 showed SCMF 3713 and Rangelander to have the most crown buds (Brummer and Bouton, 1991), while Arrow and Alfagraze had the lowest number. Alfagraze has been reported elsewhere to produce large numbers of buds under grazing, while Arrow is a typical hay-type alfalfa. Rangelander is a creeping rooted alfalfa and SCMF 3713 is a falcata type and both have been reported to have good tolerance to grazing, but lower forage yields. While not significantly different, Cut'N'Graze had a higher average number of crown buds than its parental cultivar, Apollo. Spredor II tended to have an average number of crown buds. Apollo tended to rank slightly lower than Spredor II but higher than Alfagraze.

Under rotational grazing (Table 16), there were no crown bud differences between pure alfalfa and mixed meadow bromegrass treatments. There were cultivar differences after grazing ended at Portage in both years and before grazing started in 1992 at Portage. Rangelander, Algonquin, Grimm, SCMF 3713 and Algonquin-S ranked at or near the top for bud counts at Portage in 1992, while in 1993 Spredor III, Rangelander, Grimm, Cut'N'Graze, Algonquin and Algonquin-S had the highest rankings. Alfagraze, Apollo and Arrow had ranked at or near the bottom in both years. These cultivars performed similarly under both grazing management regiments. Algonquin-S and Cut'N'Graze did not differ from their parental cultivars. Rangelander had the most buds under both rotational and continuous grazing while Alfagraze and Arrow had the fewest.

In these experiments Algonquin (hay-type), Rangelander, Spredor III (creeping rooted) cultivars, and SCMF 3713 (falcata) produced more crown buds than the hay-type cultivars Apollo and Arrow and the grazing tolerant cultivar Alfagraze. The older grazing tolerant cultivars appeared to produce more crown buds than the newer hay-type and grazing tolerant cultivars. Crown buds have also been associated with superior winterhardiness and the cultivars with the highest crown bud numbers in these experiments were also some of the most winterhardy.

Table 15. Number of unemerged crown buds of 11 alfalfa cultivars under continuous grazing for Experiments V (Portage la Prairie, MB, 1992), VII (Portage la Prairie, MB, 1993) and IX (Brandon, MB, 1993).

	Exp. V		Exp. VII		Exp. IX
Stand	27 July	21 Sept.	12 Aug.	7 Oct.	Oct. 22
	- - - - - - - Crown Buds Plant^{-1} - - - - - - -				
Pure	0.36†	2.37	2.02	1.41	1.59
Mixed	0.19	1.01	4.53	1.43	1.13
$p \geq f$	0.26	0.011	0.39	0.74	0.47
Cultivar‡					
Alfagraze	0.0	0.9	4.2_{ab}§	0.8_{de}	1.1_{bc}
Algonquin	0.2	1.4	7.2_{a}	1.7_{a-c}	---
Algonquin-S	0.4	3.0	5.9_{a}	1.4_{a-d}	---
Apollo	0.2	1.1	1.5_{b}	1.0_{d-e}	1.4_{bc}
Cut'N'Graze	0.6	1.1	3.9_{ab}	1.6_{a-d}	---
Arrow	0.3	1.5	1.2_{b}	0.7_{e}	0.5_{c}
Grimm	0.2	1.8	2.0_{b}	1.7_{a-d}	---
Rangelander	0.2	2.3	2.5_{ab}	2.2_{a}	2.1_{ab}
SCMF 3713	0.2	1.7	2.3_{b}	1.9_{ab}	3.0_{a}
Spredor II	0.5	2.0	1.6_{b}	1.0_{b-e}	1.6_{b}
Spredor III	0.3	1.5	4.0_{ab}	1.7_{a-c}	1.1_{bc}
$p \geq f$	0.24	0.75	0.037	0.013	0.0032
Mean	0.3	1.7	3.3	1.4	1.5
Std. Dev.	0.5	1.9	5.8	0.9	1.3

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean crown bud numbers.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

Table 16. Number of unemerged crown buds of 11 alfalfa cultivars under rotational grazing for Experiments VI (Portage la Prairie, MB, 1992), VIII (Portage la Prairie, MB, 1993) and X (Brandon, MB, 1993).

	Exp. VI		Exp. VIII		Exp. X
Stand	27 July	21 Sept.	12 Aug.	7 Oct.	22 Oct.
	Crown Buds Plant^{-1}				
Pure	0.68†	3.15	1.53	2.18	1.74
Mixed	0.66	2.79	1.33	2.25	1.71
p≥f	0.88	0.24	0.67	0.58	0.80
Cultivar‡					
Alfagraze	1.1_{a}§	2.6_{b-d}	1.8	1.4_{cd}	1.6
Algonquin	0.9_{a}	3.9_{ab}	1.5	2.6_{a-c}	---
Algonquin-S	0.5_{a-d}	3.4_{a-c}	2.0	3.4_{a}	---
Apollo	0.9_{a}	2.4_{b-d}	1.1	1.5_{cd}	2.0
Cut'N'Graze	---	2.2_{cd}	1.2	2.6_{a-d}	---
Arrow	0.9_{ab}	1.4_{d}	1.0	2.0_{b-d}	1.1
Grimm	0.8_{a-c}	3.8_{ab}	0.9	2.4_{a-d}	---
Rangelander	0.9_{ab}	4.7_{a}	1.7	3.0_{ab}	1.7
SCMF 3713	0.1_{d}	3.1_{a-c}	1.6	1.6_{d}	2.0
Spredor II	$.03_{b-d}$	2.9_{bc}	1.3	1.8_{cd}	2.0
Spredor III	0.3_{cd}	2.1_{cd}	1.6	2.2_{a-d}	1.7
p≥f	0.028	0.0021	0.73	0.013	0.69
Mean	0.7	3.0	1.4	2.2	1.7
Std. Dev.	0.7	1.8	1.1	1.4	1.1

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean crown bud numbers.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

4.2.2.4 Number of Secondary Roots

Secondary roots help to anchor plants in the soil, resisting being pulled out during grazing and improving winter survival by resisting heaving during freezing and thawing. They also serve the main purpose of collecting water and nutrients from the soil.

Under continuous grazing (Table 17) there were more secondary roots on alfalfa plants grown in pure stands at the end of the grazing season at Glenlea in 1992 and Brandon in 1993. At Portage la Prairie in 1992, there tended to be more roots on the pure stand plants. In 1993 at Portage la Prairie ($p \leq 0.05$) the alfalfa plants competing with meadow bromegrass had more secondary roots prior to grazing, but this difference disappeared by the time grazing ended. The increased competition for nutrients by the meadow bromegrass, which tended to reduce foliar growth of the alfalfa, may be responsible for fewer number secondary roots under continuous grazing. In mixed stands the priority for photosynthate and protein partitioning for alfalfa would be to maintain and increase aboveground biomass so as to compete with the meadow bromegrass for the available sunlight. There were no differences between cultivars at any site in either year under continuous grazing. Where the alfalfa was sown from seed at Glenlea and Brandon, alfalfa plants were competing with each other, and appeared to have fewer secondary roots than the transplanted space plants at Portage la Prairie which had more area per plant. While not significant, the cultivars Apollo and Rangelander ranked near the top both at Portage la Prairie in both years and Brandon. Rangelander is creeping rooted where new plants can develop from lateral roots. Alfagraze and Spredor II tended to have slightly fewer secondary roots than Apollo.

There were no secondary root differences under rotational grazing for alfalfa with and without meadow bromegrass competition (Table 18). This may be due to increased availability of energy for storage and root growth since defoliation occurred less often and the energy requirement for regrowth was less frequent. Cultivars differed at Portage la Prairie in 1992 after grazing at the 5% significance level, and prior to grazing at Portage la Prairie in 1992 and after grazing at Portage la Prairie in 1993 at the 10% significance level. After grazing in 1992 at Portage la Prairie, SCMF 3713 had fewer secondary roots than all other cultivars with the exception of Cut'N'Graze, while Algonquin-S had more secondary roots than both SCMF 3713 and Cut'N'Graze. At Portage la Prairie in 1993, Spredor III and Apollo had more secondary roots than did SCMF 3713 and Algonquin-S at the 10% significance level. While not significant, Apollo ranked the highest at both Glenlea and Brandon after grazing ended. Under rotational grazing, the cultivars with faster regrowth such as Apollo may reach a level of above ground biomass where energy is diverted back to the roots for storage and growth sooner than cultivars with slower regrowth, allowing for increased root growth. Apollo also had a high ranking under close continuous grazing.

Table 17. Number of secondary roots larger than 1 mm in diameter in the upper 15 cm of the tap root of 11 alfalfa cultivars under continuous grazing for Experiments V (Portage la Prairie, MB 1992) III (Glenlea MB, 1993) VII (Portage la Prairie, MB 1993) and IX (Brandon, MB 1993). Alfalfa roots from Exp. III were removed in the spring following one season of grazing.

	Exp. V		Exp. III	Exp. VII		Exp. IX
Stand	27 July	21 Sept.	12 May	12 Aug.	7 Oct.	22 Oct.
	- - - - - - - - Number of Secondary Roots - - - - - - -					
Pure	0.72†	6.2	1.9	7.4	9.32	4.03
Mixed	0.69	2.5	0.8	9.9	9.59	2.27
p≥f	0.87	0.052	0.044	0.014	0.44	0.0057
Cultivar‡						
Alfagraze	0.3	4.1	1.0	7.0	8.6	2.4
Algonquin	0.3	2.5	1.5	13.4	9.5	---
Algonquin-S	0.4	3.6	---	10.1	9.1	---
Apollo	1.2	5.1	1.4	7.6	10.4	3.9
Cut'N'Graze	0.8	2.7	---	7.4	9.9	---
Arrow	0.6	7.2	0.7	7.8	8.9	2.2
Grimm	0.8	3.9	---	9.3	9.2	---
Rangelander	1.2	5.7	1.8	7.6	10.7	4.1
SCMF 3713	0.6	3.6	1.6	7.3	9.3	3.4
Spredor II	1.1	4.5	1.6	10.0	7.9	3.4
Spredor III	0.4	3.6	---	7.5	10.5	2.5
p≥f	0.25	0.27	0.32	0.40	0.51	0.55
Mean	0.7	4.3	1.4	8.6	9.5	3.2
Std. Dev.	1.2	3.8	1.3	5.6	2.6	2.3

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean number of secondary roots.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

Table 18. Number of secondary roots larger than 1 mm in diameter in the upper 15 cm of the tap root of 11 alfalfa cultivars under rotational grazing for Experiments VI (Portage la Prairie, MB 1992), IV (Glenlea, MB 1993), VIII (Portage la Prairie, MB 1993) and X (Brandon, MB 1993). Alfalfa roots from Exp. IV were removed in the spring following one season of grazing.

	Exp. VI		Exp. IV	Exp. VIII		Exp. X
Stand	27 July	21 Sept.	12 May	12 Aug.	7 Oct.	22 Oct.
	- - - - - - -	Number of	Secondary	Roots - - - - - - -		
Pure	2.50†	8.0	3.8	8.45	9.64	4.0
Mixed	2.28	6.1	2.0	8.34	9.77	3.5
$p \geq f$	0.39	0.44	0.21	0.92	0.69	0.59
Cultivar‡						
Alfagraze	2.0	6.0_{ab}§	1.9	7.5	10.2	3.6
Algonquin	2.0	7.2_{ab}	1.8	9.4	9.8	---
Algonquin-S	2.8	10.1_{a}	---	8.2	8.6	---
Apollo	1.9	8.7_{ab}	5.1	8.6	11.0	4.3
Cut'N'Graze	---	5.1_{bc}	---	9.4	10.4	---
Arrow	4.8	6.3_{ab}	2.2	10.4	10.1	3.3
Grimm	4.7	9.1_{ab}	---	8.1	8.8	---
Rangelander	1.5	6.3_{ab}	3.1	7.8	9.2	3.8
SCMF 3713	0.6	3.1_{c}	2.3	7.7	7.4	4.2
Spredor II	1.7	8.6_{ab}	4.1	8.5	9.8	3.5
Spredor III	1.3	6.7_{ab}	---	7.0	11.6	3.5
$p \geq f$	0.080	0.015	0.22	0.16	0.092	0.82
Mean	2.4	7.0	2.9	8.4	9.7	3.8
Std. Dev.	3.4	4.9	3.7	2.6	2.7	2.0

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean number of secondary roots.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

4.2.2.5 Alfalfa Crown Physiology

Storage proteins, measured as nitrogen, may be an important factor in regrowth (Volenec, personal communication). Protein is an energy expensive component for a regrowing plant to synthesize. If stored proteins are utilized, more of the initial energy available to the plant can be used for growth. Evaluation of crowns from the cultivars Alfagraze, Apollo and Spredor II showed no differences for total nitrogen content (Appendix A1, Table A1.3). Hendershot and Volenec (1993-2) examined total N, soluble proteins and NH_2-N. Smith and Silva (1969) found total N followed cyclical pattern similar to total nonstructural carbohydrates.

Total nonstructural carbohydrates are the energy source used for winter survival and the initiation of new growth. They are comprised of all carbohydrates that are stored for later use and are not part of the actual cellular structure. Carbohydrate components of harvested roots were analyzed for glucose, fructose, sucrose and starch (Tables 19a and 19b). The largest component in alfalfa roots is starch, the primary storage carbohydrate used for regrowth in spring, after forage removal, and for survival over winter. The second largest carbohydrate component in these roots is sucrose. Starch levels did not differ between cultivars or between alfalfa plants alone or with meadow bromegrass competition at any site with the exception of continuous grazing at Brandon. At Brandon, plants without competition from meadow bromegrass accumulated a higher concentration of starch than those with competition. Alfagraze accumulated a higher concentration of starch than did Apollo and Spredor II. Total nonstructural carbohydrates, the sum of starch and soluble sugars, mirror that of starch, due to the high percentage of the total comprised of starch. Trends for starch show that under continuous grazing, Alfagraze has a higher concentration than Apollo in all four experiments, and has a higher concentration than Spredor II in three experiments. Results were more erratic under rotational grazing, where plants have more time to accumulate root reserves. A higher percentage of the TNC was comprised of soluble sugars under rotational grazing. This is similar to the results of Smith et al (1989) in Georgia.

In Tennessee Reynolds (1971) found TNC root concentration in one year old plants decreased from an initial level of 30% to 20% when the first clipping occurred in mid June, with a smaller decrease after the second clipping. When clipped eight times starting in mid April TNC decreased from 20% to 3%. The level of TNC did not rise above 10% until prior to the fifth clipping in early July then slowly increased to 15% at the time of the eighth clipping in early September. Brummer and Bouton (1992) found a range of 200 g kg^{-1} to 425 g kg^{-1} for Alfagraze under frequent harvesting in two experiments in Georgia. Counce et al (1984) found similar patterns of TNC depletion following harvest for cultivars that were classified as either non-persistent upright, persistent upright, or persistent creeping rooted. The non-persistent upright cultivars decreased from 475 g kg_{-1} to 225 g kg^{-1} before reaccumulating, while the persistent upright and persistent creeping rooted cultivars decreased from 375 g kg^{-1} and 310 g kg^{-1}, respectively, to 140 g kg-1 before increasing. In Minnesota Juan et al (1994) found TNC concentration was related to dormancy when measured at the bud and bloom stages of alfalfa (*Medicago sativa* L.) development. They reported that more dormant cultivars had lower TNC concentrations than did less dormant cultivars.

Table 19a. Starch and Total Non-structural Carbohydrate (TNC) levels for alfalfa crowns after one season of continuous grazing for Experiments V (Portage la Prairie, MB, 21 September 1992), III (Glenlea, MB, 18 September 1992), VII (Portage la Prairie, MB, 7 October 1993), IX (Brandon, MB, 22 October 1993).

	Starch				TNC			
	Continuously Grazed							
Exp.	V	III	VII	IX	V	III	VII	IX
	- - - - - - - - - - - mg kg^{-1} - - - - - - - - - - -							
pure	103.0†	---	53.0	73.2	109.9	---	71.7	89.5
mixed	113.2	---	75.5	50.6	120.9	---	96.3	66.8
$p \geq f$	0.15	---	0.48	0.043	0.18	---	0.58	0.045
Cultivar‡								
Alfagraze	118.1	97.7	68.9	83.7	124.1	108.7	87.9	99.7
Apollo	111.9	72.5	60.1	57.2	119.3	83.7	80.7	72.7
Spredor II	97.3	68.8	69.9	44.8	105.7	80.4	90.5	62.1
$p \geq f$	0.85	0.68	0.53	0.0010	0.80	0.74	0.95	0.0010
Mean	108.5	80.6	67.0	61.9	115.9	92.7	87.0	78.2
Std. Dev.	55.2	37.2	34.2	26.8	55.7	38.4	35.7	26.4

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean number of secondary roots.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

Table 19b. Starch and Total Non-structural Carbohydrate (TNC) levels for alfalfa crowns after one season of rotational grazing for Experiments VI (Portage la Prairie, MB, 21 September 1992), IV (Glenlea, MB, 18 September 1992), VIII (Portage la Prairie, MB, 7 October 1993), X (Brandon, MB, 22 October 1993).

	Starch				TNC			
	Continuously Grazed							
Exp.	V	III	VII	IX	V	III	VII	IX
	mg kg^{-1}							
	Rotationally Grazed							
Exp.	VI	IV	VIII	X	VI	IV	VIII	X
pure	112.4	---	123.9	35.5	123.9	---	140.6	56.4
mixed	108.6	---	144.1	50.8	133.2	---	171.8	65.1
p≥f	0.63	---	0.81	0.15	0.99	---	0.49	0.26
Cultivar								
Alfagraze	108.8	57.8	128.1	51.1	122.5	61.2	137.4	71.5
Apollo	96.8	64.3	137.0	42.8	117.5	90.8	184.4	62.8
Spredor II	127.7	88.9	138.4	36.3	151.5	83.5	148.9	50.6
p≥f	0.058	0.41	0.51	0.59	0.16	0.93	0.61	0.37
Mean	110.4	70.3	134.5	43.5	128.3	83.2	155.3	61.6
Std. Dev.	42.4	33.2	57.3	27.3	34.9	38.1	59.9	26.2

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean number of secondary roots.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

4.2.3 Conclusion

Cultivars that performed well (Alfagraze) or moderately (Spredor II) under close continuous grazing in experiment I at Glenlea tended to produce fewer crown stems than those that were less persistent (Rangelander) Table 10). Brummer and Bouton (1991) reported Alfagraze produced more stems under frequent clipping than grazing intolerant or other grazing tolerant alfalfa cultivars. Juan et al (1994) found that the percentage of new shoots arising from the crown was higher in plants harvested at mid bloom than in plants harvested at mid bud. Both Algonquin-S and Cut'N'Graze produced fewer crown stems than their respective parental cultivars.

Decumbency of cultivars appears to be related to their intended purpose (grazing or haying) when they were developed. The hay types Algonquin, Apollo and Arrow were less decumbent than the other cultivars at Portage la Prairie. The grazing type cultivars such as SCMF 3713, Spredor II and Rangelander, showed greater decumbency than other cultivars at Portage la Prairie. Brummer and Bouton (1991) also reported that under frequent clipping hay type cultivars such as Apollo were less decumbent than grazing type cultivars such as Spredor II, with Alfagraze being intermediate. Both Algonquin-S and Cut'N'Graze showed greater decumbency than their respective parental cultivars. The more decumbent plants will avoid defoliation. This decreases the available forage for the animal and results in a less productive stand.

The crown size of an alfalfa plant increases as photosynthate and proteins are stored and as the plant ages (Rapoport and Travis, 1984). While Rangelander showed poor persistence under grazing at Glenlea, MB after one season of grazing, it had one of the larger crown areas at Portage la Prairie. The hay type cultivar Arrow had one of the smaller crown areas of the cultivars tested. Algonquin-S and Cut'N'Graze selected had larger crown areas than their respective parental cultivars, suggesting an increased ability to store nutrients for future regrowth. These two cultivars showed greater avoidance to grazing (more decumbent growth) than their parental cultivars and this may have contributed to the larger crown size. Smith et al (1992) found few differences between cultivars for root diameters under continuous grazing.

The hay-type cultivar Arrow and dual purpose Alfagraze produced fewer crown buds than the other cultivars tested at Portage la Prairie while plants from the grazing type cultivars Rangelander and SCMF 3713 produced higher numbers of crown buds than the other cultivars. Profusity of crown bud production has been associated with grazing tolerance (Brummer and Bouton 1991), and Alfagraze has been reported to produce large numbers of crown buds, but this did not occur in these tests. Smith et al (1992) found that under continuous grazing there were few differences between cultivars for the number of crown buds. Juan et al (1994) did not find any differences between cultivars of different fall dormancy for the number of unemerged crown buds in the fall. Cut'N'graze had a higher number of crown buds than its parental cultivar.

There was little differentiation of alfalfa morphological characteristics after one season of grazing either in the year of establishment or the first year after establishment. Characteristics such as the crown area or crown bud production that are associated with grazing tolerance have been evaluated after more than one season of grazing in other studies. The small differences between cultivars after one season suggest that in the shorter growing season of Manitoba, more than one year of evaluation may be required. As the length of time under grazing increases and plants from less grazing tolerant lines disappear, characteristics that are negatively correlated with grazing tolerance will become more difficult to detect.

5. Discussion and Summary

Close continuous grazing exerts a higher selection pressure on alfalfa than when managed for hay production (Smith and Bouton, 1993). To determine which cultivars are suitable for use in pastures, evaluation of persistence needs to be done under actual grazing conditions. Twelve cultivars were subjected to grazing stress (close continuous grazing and rotational grazing) at Glenlea, MB for persistence evaluation. The cultivars performed differently with respect to each other under the two management systems. Rank correlations between experiments I (continuous grazing) and II (rotational grazing) were nonsignificant for ground cover ($r=0.03$, $p \leq 0.82$) and percent plant interception ($r=-0.03$, $p \leq 0.85$). Rank correlations between experiments III (continuous grazing) and IV (rotational grazing) were nonsignificant for plant counts ($r=0.36$, $p \leq 0.16$) and percent plant interception ($r=-0.09$, $p \leq 0.16$), with a low correlation for percent visual ground cover ($r=0.36$, $p \leq 0.0003$). Counce et al (1984) reported faster stand decline for alfalfa under continuous grazing (64 percent) than under infrequent mowing (46 percent) in two years. Counce et al found no differences between cultivars under infrequent mowing after three years yet found cultivar differences under continuous grazing in the same time period. They also reported no correlations between cultivars when comparing continuous grazing and infrequent mowing, noting that selection for grazing persistence would be difficult to conduct under mowing. Therefore, if alfalfa is to be used in a traditional pasture system where continuous grazing is the norm, breeding and cultivar evaluation needs to be conducted under continuous grazing.

Alfalfa is often grown with one or more perennial grasses both in hay stands and in pastures. This increases the productive life of the stand, because when the alfalfa dies out it is replaced with the grasses instead of weeds. A disadvantage of this practice is that the grasses also provide competition with the alfalfa. Individual cultivar performance relative to other cultivars in these experiments was unaffected by the presence of meadow bromegrass (Table 3). Smith et al (1992) reported that "Alfalfa tolerant to grazing in pure stands also had superior persistence under severe continuous grazing in mixed stands". This indicates that evaluation under grazing stress may be conducted without the presence of a companion grass which will simplify the comparison of entries in the testing procedure.

Companion experiments at Glenlea evaluated the same cultivars in pure stand microplots ($1m^2$) to examine the usefulness of smaller plots for grazing tolerance evaluation. Smaller plots allow for the evaluation of entries with a limited amount of seed over more sites. However, fewer plants are evaluated in microplots, a disadvantage when dealing with a heterogenous species such as alfalfa.

After one season of grazing, either small (experiments I and II) or no (experiments III and IV) differences between cultivars were evident for the assessments conducted to evaluate persistence under grazing. It has been suggested elsewhere (Smith and Bouton, 1993) that two or more years may be required for sufficient segregation for grazing tolerance between cultivars to occur. In Georgia Counce et al (1984) found differences after three years of grazing, but not after three years of infrequent mowing. This requirement for more than one year of grazing may be even more applicable in western Canada where the length of the grazing season is shorter than locations of lower latitude where much of the grazing evaluations have taken place. Unfortunately a second year of grazing was not possible at Glenlea, MB due to excess late spring early summer rainfall which resulted in prolonged water ponding and subsequently a substantial stand reduction occurred.

After one season of grazing, only small differences between cultivars appeared for the characteristics that were evaluated. In experiment I (continuous grazing) evaluation for ground cover (Table 1) revealed that Alfagraze had a high ranking following the end of one grazing season, while Apollo and Spredor II showed moderate stand reductions relative to the experimental mean. In experiment III there was little difference between these cultivars for either final stand (Table 5) or stand reduction.

Stem number, a determining factor of forage productivity (Smith et al, 1989), was intermediate for Alfagraze, with Apollo showing higher stem numbers and Spredor II showing fewer when grown from transplants (experiments V to VIII) (Table 10). Brummer and Bouton (1991) reported that higher stem numbers are associated with persistence under grazing. Smith et al (1989) reported initially higher stem numbers for Alfagraze. After three years Alfagraze and the creeping rooted cultivars in the experiment had higher stem numbers than the hay type cultivars. Brummer and Bouton (1991) reported that decumbent growth is associated with persistence under frequent mechanical harvesting. After the end of one season of grazing Alfagraze tended to show intermediate decumbency between Spredor II (more decumbent) and Apollo (less decumbent). This is in agreement with the findings of Brummer and Bouton (1991) in Georgia. Decumbency is a method of grazing avoidance where stems and leaves close to the ground are not removed during grazing. Alfagraze, Apollo and Spredor II showed similar trends for individual plant ground cover as seen with decumbency. Alfagraze showed intermediate ground cover, with Spredor II tending to provide more and Apollo less. This is partly a factor of grazing avoidance (decumbency) where a decumbent growing cultivar such as Spredor II grows more prostrate, producing more of its foliage out of grazing reach of cattle than a more upright cultivar such as Apollo.

While a larger crown size has been associated with greater persistence under grazing (Berdahl et al, 1989; Daday, 1968), little difference was seen under continuous grazing (Table 13). Smith et al (1992) also did not find crown size differences between cultivars of varying grazing tolerance. Trends indicate that Apollo had a larger crown area than Spredor II and Alfagraze which were very similar (Table 13). Under rotational grazing, Apollo had a larger crown area at Brandon (Experiment X, Table 14), but was not significantly different at any other site. Trends indicate Apollo had a larger crown area following grazing in three out of four site years than Alfagraze and Spredor II. There was no difference between Alfagraze, Apollo and Spredor II for the number of unemerged crown buds after one season of grazing (Tables 15 and 16).

Brummer and Bouton (1991) found higher crown bud numbers for Alfagraze, but no differences between other cultivars including hay-type and grazing tolerant cultivars. Juan et al (1994) reported increasing bud numbers with decreasing fall dormancy. Alfagraze, Apollo and Spredor II did not differ for the number of secondary roots, although Apollo tended to have a higher number.

The storage of carbohydrates in crowns and roots of alfalfa is important for winter survival and initiation of new growth. While differences between cultivars were only significant at Brandon (Tables 19a and 19b), Alfagraze tended to have a higher concentration than Apollo and Spredor II, which tended to have the lowest concentration. Brummer and Bouton (1992) reported that under frequent mechanical clipping Alfagraze maintained high concentrations while 'Travois', a creeping rooted cultivar, had low levels. Smith et al (1989) reported that under grazing Apollo had the lowest concentration, Alfagraze had the highest and Spredor II was intermediate.

A comparison between parental cultivars (Apollo, Algonquin) and populations selected for persistence under grazing (Cut'N'Graze, Algonquin-selected) showed subtle changes for some of the characteristics evaluated. Brummer and Bouton (1991) found differences between original and selected cultivars for stem number early in the season, but the differences disappeared by the end of the grazing period. There were no differences between Apollo and Cut'N'Graze after grazing ended. While not significant, Algonquin-selected tended to have fewer stems than did Algonquin (Table

10). Algonquin-selected tended to be slightly more decumbent than Algonquin (Table 11).

Crown area was similar for Algonquin and Algonquin-selected, and for Cut'N'Graze and its parent, Apollo. This is in agreement with Brummer and Bouton (1991) who found no differences between populations selected for grazing tolerance and their respective parental cultivars. Cut'N'Graze, while not significantly different, tended to produce more crown buds than Apollo. When selecting for grazing tolerance, care must be taken to not inadvertently select against other desirable traits such as forage production or to promote a characteristic such as decumbent growth which reduces available growth.

In selecting for persistence under grazing, evaluation under actual grazing conditions is important. A visual assessment of ground cover is a useful measurement for determining stand persistence over time. While determining plant populations using a grid is useful, there are inherent inaccuracies at higher plant populations as would occur at the start of an experiment where several plants growing very closely would be recorded as one plant. This results in inaccurate measurements of early stand decline. Lodge and Gleeson (1984) reported that at plant populations of 150 or more plants per m^2 plant frequency estimates did not accurately reflect changes in plant density. They suggested that at high densities small permanently located grids would be more useful. While visually scoring for percent cover does not provide an estimation of plant numbers, it does provide an estimation of the area that alfalfa plants occupy. The evaluation of crown stem number may be a useful method of estimating potential productivity (Smith et al, 1989) on an individual plant basis and can be done in the field. Differences were found after one season of grazing under rotational grazing (Experiments VI and VIII) in both 1992 and 1993, and in 1993 (Experiment VII) under continuous grazing at Portage la Prairie, MB. Decumbency is a characteristic that is undesirable when a plant becomes so prostrate that its forage is unavailable to livestock. Decumbency can be evaluated in the field and undesirable plants can be easily removed from the list of potential parental plants. The evaluation of crown area and the number of crown buds may be useful to determine which plants have potential for use in the development of grazing tolerant cultivars as these have been reported to be associated with grazing tolerance elsewhere (crown size: Berdahl et al (1989): crown buds: Brummer and Bouton (1991)). As plants must be removed from the soil to conduct evaluations of crown area and crown bud production these should be used as the last step in the evaluation procedure so that less desirable plants can be removed from the list of potential plants prior to these evaluations. This will reduce the workload as these measurements are very time consuming. However these results suggest that two or more years of grazing will probably be needed to determine which plants are more desirable using these characteristics.

The use of transplants allowed for cultivar evaluation under grazing in the year of establishment. When stands are planted from seed, grazing evaluation cannot occur until the second growing season. In the shorter growing season of Manitoba, more than one season of grazing is required for clear differences between cultivars to be determined. Transplanting alfalfa seedlings started in a greenhouse can potentially reduce the time required for each cycle of evaluation under grazing by one year and would be a useful tool for the development of grazing tolerant cultivars.

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7. Appendix

Appendix A1 - Other Data

Table A1.1. Crown depth measured from the soil surface to the base of the crown for Experiments V (27 July, 21 September, continuous grazing), III (12 May, continuous grazing), VII (12 August, 7 October, continuous grazing) and IX (22 October, continuous grazing).

	Exp. V		Exp. III	Exp. VII		Exp. IX
Stand	27 July	21 Sept.	12 May	12 Aug.	7 Oct.	22 Oct.
			(mm)			
Pure	26.5†	39.9	17.8	22.4	24.8	18.3
Mixed	25.8	29.9	16.8	23.7	25.0	17.1
p≥f	0.85	0.10	0.35	0.64	0.99	0.42
Cultivar‡						
Alfagraze	21.2	28.3	16.0	20.7	20.4	13.9c§
Algonquin	30.6	35.1	16.7	27.9	28.3	---
Algonquin-S	25.1	35.7	---	23.4	26.8	---
Apollo	25.6	26.5	19.1	24.4	24.8	17.8ab
Cut'N'Graze	23.6	26.1	---	20.7	25.0	---
Arrow	29.5	25.1	18.0	16.1	23.3	19.6a
Grimm	21.5	27.0	---	23.4	21.5	---
Rangelander	27.6	33.8	19.7	26.0	26.6	17.3b
SCMF 3713	22.0	39.1	15.5	24.1	22.3	19.8a
Spredor II	36.0	35.4	16.4	27.4	27.8	16.9b
Spredor III	25.8	39.5	---	19.3	26.7	18.2ab
p≥f	0.33	0.16	0.49	0.48	0.21	0.0001
Mean	26.2	34.8	17.3	23.1	24.9	17.7
Std. Dev.	12.5	24.7	4.5	9.8	7.9	2.8

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean individual plant ground cover.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

§ Different letters within a column indicate significant cultivar differences using Fisher's protected LSD (0.05).

Appendix A1 - Other Data

Table A1.2. Crown depth measured from the soil surface to the base of the crown for Experiments VI (27 July, 21 September, rotational grazing), IV (12 May, rotational grazing), VIII (12 August, 7 October, rotational grazing) and X (22 October, rotational grazing).

	Exp. VI		Exp. IV	Exp. VIII		Exp. X
Stand	27 July	21 Sept.	12 May	12 Aug.	7 Oct.	22 Oct.
			Crown Depth (mm)			
Pure	9.8†	23.8	22.5	29.9	45.8	18.1a
Mixed	7.3	27.1	20.6	31.6	45.4	15.6b
p≥f	0.21	0.55	0.072	0.73	0.98	0.0087
Cultivar‡						
Alfagraze	9.4	29.3	21.2	32.6	39.8	16.8
Algonquin	9.2	27.4	21.6	29.9	41.6	---
Algonquin-S	15.2	22.6	---	31.9	45.6	---
Apollo	8.2	20.3	20.7	25.7	47.8	17.0
Cut'N'Graze	---	19.6	---	27.4	45.6	---
Arrow	5.0	22.5	21.1	27.3	47.9	17.1
Grimm	6.7	41.0	---	32.4	49.9	---
Rangelander	9.3	32.2	21.2	30.7	50.9	17.3
SCMF 3713	7.5	21.5	23.3	31.8	46.0	17.4
Spredor II	4.9	24.2	21.7	32.6	38.4	17.1
Spredor III	10.9	18.2	---	36.1	48.1	15.3
p≥f	0.25	0.45	0.9995	0.78	0.30	0.85
Mean	8.4	25.2	21.5	30.8	45.6	16.9
Std. Dev.	5.9	19.1	5.9	11.4	11.0	2.9

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean individual plant ground cover.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

Appendix A1 - Other Data

Table A1.3. Percent total nitrogen content of roots and crowns of alfalfa removed in the fall after one season of grazing.

	Continuously Grazed			
Exp.	V	III	VII	IX
			%	
pure	2.50†	---	2.14	2.09
mixed	2.31	---	2.21	1.98
p>f	0.17	---	0.39	0.46
Cultivar‡				
Alfagraze	2.40	2.22	2.17	2.17
Apollo	2.37	2.16	2.12	2.03
Spredor II	2.43	2.05	2.24	1.91
p>f	0.73	0.50	0.37	0.097
Mean	2.40	2.14	2.18	2.04
Std. Dev.	0.25	0.21	0.15	0.26

	Rotationally Grazed			
Exp.	VI	IV	VII	X
pure	2.83	---	2.28	1.75
mixed	2.54	---	2.23	1.79
p>f	0.080	---	0.24	0.45
Cultivar				
Alfagraze	2.75	2.28	2.25	1.78
Apollo	2.63	2.36	2.28	1.82
Spredor II	2.65	2.45	2.23	1.71
p>f	0.78	0.25	0.71	0.19
Mean	2.68	2.36	2.25	1.77
Std. Dev.	0.37	0.22	0.14	0.17

† Analysis of variance and cultivar mean comparison based on transformed data (x^2), but reported values were the actual mean individual plant ground cover.

‡ Since there were no interactions between pure alfalfa stands and mixed stands with meadow bromegrass, cultivar measurements were combined.

Appendix A2 - Environmental Data

Table A2.1. Mean monthly temperatures (^{0}C) for 3 locations in southern Manitoba during the growing seasons 1992-1993.

	Location/Year			
	Glenlea	Portage la Prairie		Brandon
Month	1992	1992	1993	1993
May	13.2	20.7	19.2	19.5
June	15.1	22.0	22.3	21.2
July	15.2	22.1	23.5	21.7
August	16.3	23.2	24.0	23.1
September	11.4	17.8	17.5	16.8
October	4.6			

Table A2.2. Mean monthly precipitation (mm) for 3 locations in southern Manitoba during the growing seasons 1992-1993.

	Location/Year			
	Glenlea	Portage la Prairie		Brandon
Month	1992	1992	1993	1993
May	26	13	53	40
June	98	44	68	94
July	96	109	114	103
August	98	49	89	134
September	70	50	28	32
October	4			

Appendix A3 - Analysis of Variance - Field Data

Table A3.1. Mean squares for stem counts.

Source	MS	F value	MS	F value
	Experiment V		Experiment VI	
Treatment	1.77	n.s.†	0.42	n.s.
Cultivar	0.16	n.s.	0.35	3.66^{**}
Treatment x Cultivar	0.11	n.s.	0.11	n.s.
	Experiment VII			
	Axillary		Crown	
Treatment	0.48	n.s.	0.02	n.s.
Cultivar	0.09	n.s.	0.18	2.08^{*}
Treatment x Cultivar	0.11	n.s.	0.09	n.s.
	Experiment VIII			
	Axillary		Crown	
Treatment	2.11	n.s.	0.06	n.s.
Cultivar	0.08	n.s.	0.30	2.79^{**}
Treatment x Cultivar	0.03	n.s.	0.17	n.s.

*, **, ***, **** Significance at $p \le 0.05$, $p \le 0.01$, $p \le 0.001$, $p \le 0.0001$.

† Means do not differ significantly ($p \le 0.05$).

Appendix A3 - Analysis of Variance - Field Data

Table A3.2. Mean squares for mean decumbency scores.

Source	MS	F value	MS	F value
		Experiment V		Experiment VI
Treatment	0.26	n.s.†	0.45	n.s.
Cultivar	0.13	2.36*	0.17	4.47***
Treatment x Cultivar	0.06	n.s.	0.05	n.s.
		Experiment VII		Experiment VIII
Treatment	0.13	n.s.	0.08	n.s.
Cultivar	0.11	n.s.	0.09	2.91**
Treatment x Cultivar	0.06	n.s.	0.02	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).

Table A3.3. Mean squares for individual plant ground cover.

Source	MS	F value	MS	F value
		Experiment V		Experiment VI
Treatment	14.5	18.22*	5.5	20.17*
Cultivar	0.4	n.s.†	0.4	2.10*
Treatment x Cultivar	0.2	n.s.	0.3	n.s.
		Experiment VI		Experiment VIII
Treatment	0.2	n.s.	0.8	n.s.
Cultivar	0.6	n.s.	0.3	n.s.
Treatment x Cultivar	0.4	n.s.	0.2	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).

Appendix A4 Analysis of Variance - Crown Characteristics

Table A4.1. Mean squares for crown cross sectional area of continuously grazed experiments.

Source	MS	F value	MS	F value
		Experiment V		
	27 July, 1992		21 September, 1992	
Treatment	0.8	n.s.[†]	35.1	16.16*
Cultivar	0.6	n.s.	1.3	n.s.
Treatment x Cultivar	0.5	n.s.	0.5	n.s.
	Experiment III		Experiment IX	
Treatment	13.1	n.s.	10.2	n.s.
Cultivar	0.7	n.s.	2.6	n.s.
Treatment x Cultivar	0.8	n.s.	1.5	n.s.
		Experiment VII		
	12 August, 1993		7 October, 1993	
Treatment	0.1	n.s.	0.4	n.s.
Cultivar	1.5	n.s.	4.7	n.s
Treatment x Cultivar	2.4	n.s.	2.6	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

[†] Means do not differ significantly ($p \leq 0.05$).

Appendix A4 Analysis of Variance - Crown Characteristics

Table A4.2. Mean squares for crown cross sectional area of rotationally grazed experiments.

Source	MS	F value	MS	F value
		Experiment VI		
	27 July, 1992		21 September, 1992	
Treatment	0.1	n.s.†	6.3	n.s.
Cultivar	0.9	n.s.	6.8	2.51‡
Treatment x Cultivar	0.2	n.s.	1.8	n.s.
	Experiment IV		Experiment X	
Treatment	28.7	n.s.	19.4	n.s.
Cultivar	10.0	n.s.	21.3	3.27‡
Treatment x Cultivar	2.4	n.s.	2.8	n.s.
		Experiment VIII		
	12 August, 1992		7 October, 1992	
Treatment	4.4	n.s.	0.5	n.s.
Cultivar	4.2	2.5*	9.7	3.24‡‡
Treatment x Cultivar	3.0	n.s.	0.9	n.s.

‡, ‡‡, ‡‡‡, ‡‡‡‡ Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).

Appendix A4 Analysis of Variance - Crown Characteristics

Table A4.3. Mean squares for crown bud production for continuously grazed experiments.

Source	MS	F value	MS	F value
		Experiment V		
		27 July, 1992		21 September, 1992
Treatment	0.8	n.s.†	6.9	31.08‡
Cultivar	0.2	n.s.	0.3	n.s.
Treatment x Cultivar	0.2	n.s.	0.4	n.s.
		Experiment VII		
		12 August, 1992		7 October, 192
Treatment	3.5	n.s.	0.01	n.s.
Cultivar	1.0	2.12*	0.4	2.52‡
Treatment x Cultivar	0.6	n.s.	0.1	n.s.
		Experiment IX		
Treatment	0.1	n.s.		
Cultivar	0.8	4.08‡‡		
Treatment x Cultivar	0.2	n.s.		

‡, ‡‡, ‡‡‡, ‡‡‡‡ Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).

Appendix A4 Analysis of Variance - Crown Characteristics

Table A4.4. Mean squares for crown bud production for rotationally grazed experiments.

Source	MS	F value	MS	F value
		Experiment VI		
		27 July, 1992		21 September, 1992
Treatment	0.2	n.s.†	0.2	n.s.
Cultivar	0.6	2.66‡	0.6	3.26‡
Treatment x Cultivar	0.2	n.s.	0.2	n.s.
		Experiment VIII		
		12 August, 1993		22 October, 1993
Treatment	0.1	n.s.	0.05	n.s.
Cultivar	0.2	n.s.	0.4	2.55‡
Treatment x Cultivar	0.5	2.09‡	0.2	n.s.
		Experiment X		
Treatment	0.009	n.s.		
Cultivar	0.2	n.s.		
Treatment x Cultivar	0.2	n.s.		

‡, ‡‡, ‡‡‡, ‡‡‡‡ Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

† Means do not differ significantly ($p \leq 0.05$).

Appendix A4 Analysis of Variance - Crown Characteristics

Table A4.5. Mean squares for the number of secondary roots for continuously grazed experiments.

Source	MS	F value	MS	F value
		Experiment V		
	27 July, 1992		21 September, 1992	
Treatment	0.06	n.s.†	15.2	n.s.
Cultivar	0.3	n.s.	0.7	n.s.
Treatment x Cultivar	0.5	2.08‡	0.7	n.s.
	Experiment III		Experiment IX	
Treatment	3.2	11.31‡	2.4	50.5‡‡
Cultivar	0.3	n.s.	0.3	n.s.
Treatment x Cultivar	0.8	n.s.	0.3	n.s.
		Experiment VIII		
	12 August, 1993		7 October, 1993	
Treatment	3.0	26.54‡	0.07	n.s.
Cultivar	0.5	n.s.	0.2	n.s.
Treatment x Cultivar	0.4	n.s.	0.2	n.s.

‡, ‡‡, ‡‡‡, ‡‡‡‡ Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

† Means do not differ significantly ($p \leq 0.05$).

Appendix A4 Analysis of Variance - Crown Characteristics

Table A4.6. Mean squares for the number of secondary roots for rotationally grazed experiments.

Source	MS	F value	MS	F value
		Experiment VI		
	27 July, 1992		21 September, 1992	
Treatment	0.4	n.s.†	1.0	n.s.
Cultivar	1.4	n.s.	1.2	2.5‡
Treatment x Cultivar	0.6	n.s.	0.7	n.s.
	Experiment IV		Experiment X	
Treatment	2.9	n.s.	0.2	n.s.
Cultivar	0.7	n.s.	0.2	n.s.
Treatment x Cultivar	0.5	n.s.	0.3	n.s.
		Experiment VIII		
	12 August, 1993		7 October, 1993	
Treatment	0.002	n.s.	0.006	n.s.
Cultivar	0.3	n.s.	0.3	n.s.
Treatment x Cultivar	0.4	n.s.	0.1	n.s.

‡, ‡‡, ‡‡‡, ‡‡‡‡ Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).

Appendix A5 Analysis of Variance - Physiology

Table A5.1. Mean squares for starch.

Source	MS	F value	MS	F value
	Experiment III		Experiment IV	
Cultivar	3.8	n.s.†	4.4	n.s.
	Experiment V		Experiment VI	
Treatment	0.002	n.s.	1.1	n.s.
Cultivar	0.3	n.s.	5.7	n.s.
Treatment x Cultivar	5.1	n.s.	5.2	n.s.
	Experiment VII		Experiment VIII	
Treatment	8.3	n.s.	0.3	n.s.
Cultivar	4.4	n.s.	3.4	n.s.
Treatment x Cultivar	10.6	n.s.	3.1	n.s.
	Experiment IX		Experiment X	
Treatment	10.8	12.65*	5.7	n.s.
Cultivar	11.6	11.63**	1.2	n.s.
Treatment x Cultivar	3.0	n.s.	1.1	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.

† Means do not differ significantly ($p \leq 0.05$).

Appendix A5 Analysis of Variance - Physiology

Table A5.2. Mean squares for total nonstructural carbohydrates.

Source	MS	F value	MS	F value
	Experiment III		Experiment IV	
Cultivar	2.3	n.s.†	4.4	n.s.
	Experiment V		Experiment VI	
Treatment	0.09	n.s.	0.006	n.s.
Cultivar	0.2	n.s.	1.9	n.s.
Treatment x Cultivar	5.1	n.s.	1.3	n.s.
	Experiment VII		Experiment VIII	
Treatment	5.1	n.s.	3.3	n.s.
Cultivar	2.2	n.s.	0.07	n.s.
Treatment x Cultivar	8.5	n.s.	0.1	n.s.
	Experiment IX		Experiment X	
Treatment	8.7	12.11*	3.5	n.s.
Cultivar	8.7	11.77**	2.9	n.s.
Treatment x Cultivar	2.5	n.s.	0.3	n.s.

*, **, ***, **** Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).

Appendix A5 Analysis of Variance - Physiology

Table A5.3. Mean squares for total nitrogen.

Source	MS	F value	MS	F value
	Experiment III		Experiment IV	
Cultivar	0.003	n.s.†	0.003	n.s.
	Experiment V		Experiment VI	
Treatment	0.02	n.s.	0.04	n.s.
Cultivar	0.001	n.s.	0.003	n.s.
Treatment x Cultivar	0.001	n.s.	0.02	n.s.
	Experiment VII		Experiment VIII	
Treatment	0.003	n.s.	0.002	n.s.
Cultivar	0.003	n.s.	0.0005	n.s.
Treatment x Cultivar	0.0003	n.s.	0.002	n.s.
	Experiment IX		Experiment X	
Treatment	0.008	n.s.	0.002	n.s.
Cultivar	0.16	n.s.	0.004	n.s.
Treatment x Cultivar	0.01	n.s.	0.01	7.36^{**}

$^{*}, ^{**}, ^{***}, ^{****}$ Significance at $p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$, $p \leq 0.0001$.
† Means do not differ significantly ($p \leq 0.05$).