ALFALFA MANAGEMENT EFFECTS UNDER FORAGE VS. SEED PRODUCTION ON CULTIVARS OF VARYING FALL DORMANCY

by

Gary Coukell

A Thesis

Submitted to the Faculty of Graduate Studies

In Partial Fulfilment of the Requirements for

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

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ABSTRACT
Coukell, Gary. MSc. The University of Manitoba, March 2001.
Alfalfa management effects under forage vs. seed production on cultivars of varying fall dormancy.
Major professor: Dr. S. R. Smith, Jr., Department of Plant Science.

The effect of alfalfa (*Medicago sativa* L.) management on winter survival and plant physiology has been extensively studied for forage stands, but there has been very little comparative research on alfalfa management for seed production. The objectives of this research were: 1) to compare the forage yield potential of semi- and non-dormant alfalfa cultivars to that of fall dormant cultivars; 2) to compare the survival of cultivars under a seed production system and a forage production system, 3) to determine the relationship between winter survival and root carbohydrate and nitrogen level; and 4) to evaluate the seed production potential of cultivars with less fall dormancy than those traditionally grown in western Canada. Twenty-four alfalfa cultivars ranging in fall dormancy from dormant to non-dormant were established at sites in Manitoba and Saskatchewan in 1993 and 1994, and evaluated for forage yield, seed yield, winter survival, and root carbohydrate levels. There was no forage yield advantage demonstrated in the establishment year by semi- and non-dormant cultivars in comparison to the dormant cultivars normally grown in these environments. Semi-dormant cultivars produced year two forage yields equivalent to dormant cultivars under a three cut system. When managed for seed production, semi- and non-dormant cultivars experienced less winter injury and greater stand survival in comparison to forage management, especially following a severe winter. Analysis of root soluble sugar, starch, and total nonstructural carbohydrate (TNC) indicated that fall starch and TNC levels were more indicative of winter survival potential than fall sugar content, and

that spring soluble sugar content was consistently related to higher winter survival levels. Differences in root carbohydrate levels were not consistent between management systems. In conclusion, semi- and non-dormant cultivars did not produce higher forage yields than dormant cultivars in either the establishment year or year two. Non-dormant alfalfa cultivars are only suitable for single season forage stands in Manitoba and Saskatchewan due to risk of winterkill, but semi-dormant cultivars provide a useful option for short term stands in areas of this region that receive adequate snow cover. This research also indicated that most semi-dormant alfalfa cultivars can be grown for seed production in this region with no short-term yield penalty relative to traditionally grown fall dormant cultivars.

FORWARD

This thesis is written in manuscript style, and is comprised of two manuscripts. Each includes an abstract, introduction, materials and methods, results, and discussion. Manuscript formatting follows the requirements of the Canadian Journal of Plant Science. The manuscripts are preceded by a general introduction and literature review and followed by a general summary and conclusions, cited literature, and appendices. The appendices include data collected during these studies but not included in the manuscripts.

Studies were originally implemented in 1993 to evaluate differences in winter survival between forage and seed production systems, and the potential to produce seed from semi- and non-dormant cultivars in western Canada. Research for this thesis commenced in 1994, incorporating studies initiated in 1993, and additional emphasis was then placed on determining the forage yield potential of the cultivars being evaluated.

INTRODUCTION

Cultivars of alfalfa (*Medicago sativa* L.) typically grown in Manitoba and north-eastern Saskatchewan for either forage or seed production have been highly fall dormant with good winter survival and longevity. In forage stands, dormant cultivars have been selected to insure consistent forage yields and long term stand persistence. For the seed production industry, the majority of the alfalfa seed produced in western Canada is used to establish hay and pasture stands in Canada and the north-central USA. Consequently, cultivars planted for seed production have traditionally been fall dormant with good winter survival characteristics.

Fall dormancy (FD) of alfalfa cultivars is defined by the height of growth produced in the fall, using a 1 (least growth, highly fall dormant) to 9 (most growth, non-dormant) rating scale described in the Standard Tests to Characterize Alfalfa Cultivars (Barnes et al. 1995). Throughout this research, cultivars with fall dormancy ratings of one to four were referred to as dormant, five and six as semi-dormant, and seven to nine as non-dormant. These groupings were based on accepted divisions (unpublished) among North American alfalfa breeders (S. R. Smith, Jr., pers. comm.). Fall dormancy has been shown to be positively correlated with winter survival (Sheaffer et al. 1992; Smith, 1961; Heinrichs et al. 1960; Schwab et al. 1994). This correlation has resulted in the adoption of the fall dormancy rating system as an accepted indicator of winter survival potential in alfalfa, and has contributed to the perception that cultivars of reduced fall dormancy cannot be grown for seed production in western Canada.

Semi- and non-dormant alfalfa cultivars may have potential for use in annual or short-term forage stands to provide increased nitrogen fixation (Barnes et al. 1988), to reduce the difficulty of legume crop termination in crop rotations (Kelner, 1994), or to increase late season forage production. Forage yield of semi- and non-dormant cultivars may be equal to or greater than those of dormant cultivars due to higher seedling vigour and more rapid seedling growth (Gjuric, 1995), and the greater fall growth produced as a result of non-dormancy (Schwab et al. 1994).

Western Canadian seed producers and seed companies are interested in producing seed of semi- and non-dormant varieties in order to gain access to larger and different seed markets. Many of the new cultivars being developed by companies in the U.S.A. are semi- and non-dormant, and seed sales for these cultivars are very large and increasing worldwide. Recent studies at the University of Manitoba (Smith, 1995; Gjuric, 1995) have shown that establishment year alfalfa seed production is usually not possible due to the short season and lack of growing degree day accumulation. For western Canadian seed producers to gain access to the large market for semi- and non-dormant alfalfa seed, these cultivars must overwinter and produce seed in at least one subsequent season. Recent research suggests that under management for seed production semi- and non-dormant cultivars may have greater winter survival in western Canada than previously expected. Sheaffer et al. (1988) showed that winter survival is greater with constant snow cover. Additionally, stand survival increases with decreased cutting frequency (McKenzie and McLean, 1980) and with increased pre-harvest cutting interval (Sheaffer et al. 1992).

This research involved growing 24 alfalfa cultivars ranging in fall dormancy from highly fall dormant (FD 1) to non-dormant (FD 9) under both forage and seed management systems. Experiments were established at Arborg, MB, Homewood, MB, and Melfort, SK in 1993, and at Arborg, Melfort, and Carman, MB in 1994.

The objectives of this research were:

1. To compare the forage yield potential of semi- and non-dormant alfalfa cultivars to that of fall dormant cultivars,
2. to compare the survival of cultivars under a seed production system and a forage production system,
3. to determine the relationship between winter survival under these management systems and root carbohydrate and nitrogen level, and
4. to evaluate the seed production potential of cultivars with less fall dormancy than those traditionally grown in western Canada.

LITERATURE REVIEW

Origin of alfalfa (*Medicago sativa* L.) and introduction to Canada

Alfalfa is known to have been cultivated since before recorded history. The earliest record of its cultivation was as animal feed in Persia and Turkey more than 3300 years ago (Goplen et al. 1987). *Medicago sativa ssp. sativa* (L.) originated in the area of Asia Minor, Transcaucasia, Iran and Turkmenistan, while *M. sativa ssp. falcata* (L.) originated in Siberia (Fairey et al. 1996). *M. sativa ssp. sativa* (L.) is purple-flowered, and provides modern cultivars with a good source of high yield and resistance to diseases and insects. *M. sativa ssp. falcata* (L.) is yellow-flowered, and provides the genetic source for winterhardiness, drought resistance, and the creeping rooted growth habit (Michaud et al. 1988). These two species cross readily, resulting in *M. sativa ssp. varia* (L.) genotypes with variegated flower colour and a wide range of characteristics and adaptations.

Alfalfa was first introduced to Canada in 1871 when a French immigrant brought one kilogram of seed with him. This strain became know as 'Ontario Variegated' (Goplen et al. 1987), but did not result in the widespread cultivation of alfalfa outside of Ontario. Production spread to the western provinces with the importation of the cultivar 'Grimm' from Minnesota in 1908. Grimm was introduced to the USA in 1858 by a German immigrant of the same name. Mr. Grimm selected winterhardy plants over a period of years and the resulting seed source was recognized by the University of Minnesota in 1908 and given the name Grimm (Michaud et al. 1988). Grimm was a variegated cultivar and had very good winterhardiness, allowing the widespread expansion of alfalfa production in the northern USA and Canada. By 1982, Canadian alfalfa production was estimated at 4 to 5 million hectares (Goplen et al. 1987).

Fall dormancy classification

Alfalfa plant breeders assign a fall dormancy score to each cultivar when it is registered (Fairey et al. 1996). Fall dormancy is a measure of the amount of fall growth produced by a cultivar in comparison to a set of standard checks. Plants are cut two to three times during the summer, and the last cut is timed such that plant regrowth can be measured 25 to 30 days later, but prior to a severe frost (Barnes et al. 1995). Regrowth is measured as the distance from the soil surface to the top of the canopy, irrespective of decumbency. A fall dormancy rating for each test cultivar is then assigned by comparing its canopy height to the height of a range of standard check cultivars. The cultivar rating scale ranges from 1= fall dormant to 9 = non-dormant (Barnes et al. 1995). Examples of fall dormant and non-dormant checks are Beaver (1) and CUF 101 (9), respectively. Cultivars with fall dormancy of one to four are commonly referred to as fall dormant; five and six as semi-dormant; and seven to nine as non-dormant. These groupings are based upon accepted divisions (unpublished) among North American alfalfa breeders (S. R. Smith, Jr., pers. comm.).

Fall dormancy is positively correlated with winter survival (Sheaffer 1992; Smith 1961; Heinrichs et al. 1960; Schwab et al. 1994). This correlation has resulted in the adoption of the fall dormancy rating system as an accepted indicator of winter survival potential in alfalfa.

Semi- and non-dormant cultivars may be more productive than dormant cultivars in short-term stands due to increased rates of regrowth following cutting and greater fall growth (Sheaffer et al. 1992). Among genotypes with similar stand density, past research has shown that those with the most rapid recovery after cutting produce maximum forage yields (Rumbaugh et al. 1972). Brink and Marten (1989) have shown that in Minnesota a moderately winter-hardy cultivar has greater forage yields early in the life of the stand than a more dormant cultivar.

Seed production

The majority of alfalfa seed produced in North America comes from the western US states of California, Oregon, Washington, and Idaho (Rumbaugh et al. 1971), and the western Canadian provinces of Manitoba, Saskatchewan, and Alberta. Canadian pedigreed seed hectares ranged from approximately 18 780 to 25 500 during the period from 1993 to 1999 (Whiting 2000; Huebner 2000). From 1993 to 1996, pedigreed production was distributed among provinces as follows: Manitoba 32%, Saskatchewan 46%, Alberta 22% and British Columbia 0.5% (Manitoba Forage Seed Association 1996). Total Manitoba seed production for 1999, including common seed, was 12 140 hectares (Huebner 2000).

Until the mid-1990's, fall dormancy of cultivars grown for seed production in western Canada ranged from one to four. Production was limited to these cultivars since fall dormancy has traditionally been closely associated with winter survival (Smith 1961; Heinrichs et al. 1960; Sheaffer et al. 1992). Less fall dormant cultivars (i.e. greater numerical rating) were not expected to have sufficient winter survival in western Canada, based on their survival under management for forage production.

Since management practices for alfalfa stands grown for forage differ from those grown for seed, it is reasonable to expect differences in cultivar stand survival between the two systems. Traditional management of a forage stand typically entails: planting in rows of 15 to 30 centimetres, a seeding rate of 4.5 to 9 kg ha^{-1} or higher (Tesar and Marble 1988), and two to three harvests throughout the growing season, with the last harvest occurring either before or after the critical fall period (the three week periods before and after the first killing frost). Conversely, management of a seed stand typically includes: planting in rows of 75 to 90 centimetres, a seeding rate of 0.25 to 1.5 kg ha^{-1}, and a single harvest (Rincker et al. 1988), typically right before or after the first fall frost. The lower stand densities used in seed production result in less competition between plants and therefore larger plants, crowns, and roots. Schwab et al. (1996) found that crown size was directly related to cold tolerance, especially at lower temperatures. Harvesting seed stands only once in the fall also increases winter survival (McKenzie and McLean 1980). Greater cutting frequency (typical in forage stands) increases the risk of poor winter survival, but lengthening the interval before the last cut can diminish the effect of increased cutting frequency (Sheaffer et al. 1992).

The fact that the majority of alfalfa winter survival information comes from evaluations in the north-central USA may have also contributed to the belief that less dormant cultivars could not be grown in western Canada. Winter survival may actually be greater in western Canada than in the north-central USA since snow cover is more dependable throughout the winter, resulting in less temperature fluctuation at the soil surface.

Management of leafcutter bees (*M. rotundata* Fabricius) for alfalfa seed production

The production of economically viable alfalfa seed yields is dependant upon cross-pollination by insects since most alfalfa plants are self-sterile or partially self-incompatible (Viands and Barnes 1988). Additionally, the anthers and stigma of an alfalfa floret are enclosed within fused keel petals which can only be opened by applying pressure to the keel. The application of pressure then causes the anthers and stamen to spring forward and impact the standard petal. This process of opening the keel petals and releasing the anthers and stamen is referred to as 'tripping' the floret, and rarely occurs in nature without the involvement of insects which forage for pollen. In the event that a floret is tripped by some force other than an insect, the chances of cross-pollination by wind or rain are small due to the adhesive nature of alfalfa pollen. Alfalfa requires an insect to trip the floret and carry pollen from floret to floret in order for efficient cross-pollination and seed production to occur.

In western Canada the only domesticated insect which is effective in pollinating alfalfa and producing commercial seed yields is the leafcutter bee *Megachile rotundata* (Fabricius), which originated in Eurasia (Richards 1989). Honey bees (*Apis mellifera* L.) trip very few florets (Lejeune and Olson 1940; Peck and Bolton 1946), and native Bumblebee populations (*Bombus* sp.) are not reliable, nor have they been sufficiently domesticated for large scale commercial use in alfalfa. Leafcutter bees are effective pollinators because they always trip the floret when foraging. The process of tripping the floret transfers pollen to the leafcutter bee when the stamen and anthers strike its body. The leafcutter bee also collects pollen on the underside of its abdomen, and cross-pollination is accomplished as the bee moves from plant to plant feeding and collecting pollen.

Release of leafcutter bees into an alfalfa seed production field should be timed so that less than 10% of the plants are in bloom (Murrell and Gayton 1987). This ensures that the leafcutter bees will be able to pollinate all the flowers as they bloom. If the bees are placed on a field with a lot of bloom already present, they will not have time to pollinate all the flowers and some seed yield potential will be lost. When all florets are being pollinated as they open, the raceme will have seed pods developing at its base, open florets in the middle, and unopen florets at the tip of the raceme. This produces a field with a greyish appearance rather than showing a lot of bloom (Richards 1989). A field with this appearance indicates a well-timed release, proper stocking rate, and good conditions for bee flight.

A general guideline for the number of bees needed to achieve efficient pollination is 50 000 bees per hectare (Richards 1989), and the recommended ratio of two tunnels per female necessitates 33 300 nesting tunnels per hectare. Shelter placement is important in maximizing pollination. They are generally faced due east or slightly southeast in order to capture the warmth of the morning sun and get the bees moving in the morning. Shelters should also be spaced evenly across the field, with pollination areas overlapping slightly.

Since commercial seed production in western Canada requires leafcutter bees, it is essential that seed production research also uses these pollinators. Pollination has a direct effect on seed production and may influence stand longevity and winter survival due to photosynthate partitioning and vegetative regrowth during the seed filling period.

Harvest management and persistence

The traditional fall management recommendation for alfalfa forage production is to avoid cutting during the period four to six weeks prior to the average date of the first killing frost (Smith 1962; Tesar and Yager 1985; Edmisten and Wolf 1988). A killing frost consists of an air temperature of -2 °C (Stout 1986) to -3 °C (Smith 1962), that kills the above ground vegetative portion of an alfalfa plant. This four to six week period is referred to as the "critical fall period" and extends from approximately early September to mid-October in southern Canada and the northern USA (Sheaffer et al. 1986). In Manitoba, the critical fall period encompasses the period from 10 August to 25 September, varying slightly with location (Gottfred 1987). Goplen et al. (1987) states that leaf growth and photosynthesis are required during this period to synthesize root storage carbohydrates required for winter survival. Cutting during the critical fall period reduces winter survival because root carbohydrates are depleted without a sufficient regrowth interval for replenishment before winter (Goplen et al. 1987). Stand persistence and yield are subsequently reduced.

The validity of a critical fall period has been questioned recently because of a lack of consistent evidence that cutting during this period reduces winter survival (Stout 1986). The concept of a critical fall period ignores the influence of environmental factors within a given region, the frequency of harvest prior to fall (Sheaffer et al. 1986), and improvements in the disease resistance of cultivars (Kust and Smith 1961).

In the southern USA, some leaf area can be maintained late into the fall or even overwinter, therefore low root carbohydrate levels as a result of harvesting during the critical fall period can be compensated for by late season photosynthesis (Reynolds 1971). In the southern USA, fall management recommendations may not need to allow for high levels of root carbohydrate storage (Brown et al. 1990). In British Columbia, Canada, cutting during the critical fall period did not result in decreased winter survival after a typical winter, and low temperature injury only occurred periodically during severe winters with extended periods of below average temperatures (Stout 1986). Both the southern USA and British Columbia have milder winter temperatures than those encountered in the mid-western regions of Canada and the USA. However, Sheaffer et al. (1986) also found that cutting during the critical period in Minnesota had no effect on stand persistence for the first three to four years following establishment, except prior to a severe winter (Sheaffer and Marten 1990). Taking the last cut during the critical period prior to a mild winter (ie lengthening the interval before the last harvest) increased stand survival in two, three, or four cut systems compared to a final harvest before the critical fall period.

Researchers have confirmed that in many environments the length of the interval between the penultimate and final harvest has as much or more effect on winter survival than the date of the final harvest (Sheaffer et al. 1986; Edmisten et al. 1988; Brink and Marten 1989), especially under high snowfall conditions and in short-term stands (Sheaffer et al. 1986). Alfalfa stands managed for seed production are harvested only once in the fall which increased stand survival relative to stands cut more frequently (McKenzie and McLean 1980). Sheaffer et al. (1992) have specifically shown that for less winter hardy cultivars, the lowest cutting frequency produces the least amount of winter injury.

Harvest management and root carbohydrate content

In alfalfa, root carbohydrate levels in fall are associated with winter survival and the development of cold tolerance, and are recognized as an energy source utilized throughout winter and the initiation of spring growth (Chatterton et al. 1977; Brummer and Bouton 1992; Edmisten and Wolf 1988). Low carbohydrate levels have been associated with poor winter survival, losses in stand and reduced forage yield (Reynolds 1971). Some researchers believe that root carbohydrate level is the main factor determining winter survival.

Smith (1962) and Reynolds and Smith (1962) investigated root carbohydrate content of alfalfa plants left uncut in Wisconsin and Tennessee. Uncut plants produced three distinct periods of growth from the crown. The first growth occurred in early spring (1 April, in Wisconsin), the second in late June, and the third in late July in Tennessee, and late August or early September in Wisconsin. A fourth growth (during September) in Tennessee was inhibited due to the restriction of light penetration by plant material accumulated above the crown. Uncut plants attained maximum root carbohydrate levels in early July at the mid-flower to early seed stage. These levels decreased slightly until early to mid-September, and then increased until the end of October. The mid-season decrease in carbohydrates did not correspond with the second or third regrowth in either environment.

As the frequency of harvests per year increases, the level of stored root carbohydrates in the fall decreases (Kust and Smith 1961; Reynolds 1971), and the size of the crown and taproot decreases (Avice et al. 1997). Schwab et al. (1996) demonstrated a relationship between root size, measured as diameter below the crown, and cold tolerance. Plants with larger root diameters were more cold tolerant, and the correlation between root size and cold tolerance increased with lower temperatures. This suggests that root size becomes more important for winter survival with decreasing temperatures.

Root carbohydrate reserves decline following defoliation until the amount of carbohydrate produced by photosynthesis exceeds utilization (Smith and Marten, 1970). This period of decline lasts for two to three weeks, depending on growing conditions, and then root carbohydrates increase until the early- to full-bloom stage (Cooper and Watson 1968; Davis et al. 1995; Smith and Silva 1969; Gabrielson et al. 1985). Robison and Massengale (1968) found that cutting prior to bloom stage resulted in decreased levels of stored root carbohydrates, a more rapid and earlier decline in carbohydrate levels the following spring, and a more rapid decline in stand density. These decreases could be somewhat offset by increasing the cutting height, thereby leaving more leaf tissue to contribute to regrowth through photosynthesis. Leaf area index (LAI) and total nonstructural carbohydrate (TNC) content were highly correlated for all harvest intervals. A harvest frequency of more than five cuts per season in Tennessee did not allow recovery of carbohydrate levels between cuts

(Reynolds 1971).

Regardless of the number of cuts prior to 1 September in Wisconsin, in plants not cut after 1 September, root TNC levels were approximately 30 percent in November, while levels in plants cut 1 October were approximately 19 percent in November (Kust and Smith, 1961). Sheaffer and Martin (1990) found that root TNC levels in the fall were not consistently affected by fall cutting treatments, and therefore were not consistently related to stand persistence. Surprisingly, some cutting treatments which reduced fall carbohydrate content actually showed increased stand persistence.

Plants cut late in the fall and which experience less than thirty days regrowth after cutting may be susceptible to reduced carbohydrate levels and to winter injury in areas where environmental conditions inhibit winter survival. However, Chatterton et al. (1974) suggested that the activation of bud growth creates a strong metabolic sink that may increase the efficiency of assimilate use, and plants entering dormancy just after initiating new crown bud growth should have higher root reserves than those lacking crown bud activation. As long as crown buds do not elongate into tillers (a carbohydrate consuming process) plants should have higher TNC levels available for either respiration over winter or resumption of growth in the spring (Chatterton et al. 1974). The initiation of crown buds in the fall also contributes to rapid spring regrowth and leaf area development.

In summary, root carbohydrates are positively related to alfalfa winter survival, but winter survival is also very dependant on management, stand age, cultivar, and many other factors.

Cold Tolerance

Cold tolerance is a complicated conditioning process initiated by combinations of environmental factors (Jung and Larson 1972). As such, it has been difficult to determine the exact processes involved in developing cold tolerance, and the compounds involved, despite several decades of research into the subject. Cold tolerance has been defined as the ability of a plant to withstand freezing temperatures (McKenzie et al. 1988) and associated with the ability of plant cells to endure desiccation (Wilding et al. 1960). Cold tolerance is defined as the ability of a plant to survive exposure to freezing temperatures, and winterhardiness is the ability of a plant to tolerate the combination of stresses that can occur over winter including: diseases, ice encasement, soil heaving, moisture imbalance, etc. (McKenzie et al. 1988).

In general, cold tolerance develops in alfalfa plants in the upper mid-west USA during the fall through a process called "hardening" (Duke and Doehlert 1981; Schwab et al. 1996; Jung and Larson 1972) which commences during the period from mid-September to mid-October and reaches a maximum by early December (Bula and Smith 1954). Although alfalfa plants cannot survive temperatures of -2 to -5 °C during the summer, plants of some cultivars can survive temperatures as low as -20°C after hardening(Schwab et al. 1996).

The development of cold tolerance is triggered by a combination of shortening photoperiod (Jung and Larson 1972; Duke and Doehlert 1981) and reduction in air and soil temperature. Maximum cold tolerance is attained when air and soil temperatures reach and maintain a sub-freezing level (Bula and Smith 1954). Bula and Smith (1954) also found that in Wisconsin, cold tolerance decreases in the spring as snow cover recedes and soil temperatures increase in mid-February. Therefore, fluctuating spring temperatures increase the risk of winter injury, particularly for less cold tolerant cultivars. Jung and Larson (1972) asserted that cultivars lacking cold tolerance may be more prone to initiating growth during brief warming periods, as well as earlier in the spring. They also indicated that hardening occurs over a temperature range of 15 to -5°C, and that seasonal fluctuations in cold tolerance are closely related to changes in soil temperature. A gradual decline in soil temperature increases the development of cold tolerance.

Changes in root carbohydrate levels are also associated with the development of cold tolerance. Starch forms the majority of root carbohydrate prior to hardening, and is rapidly converted to sugars as cold tolerance develops (Bula and Smith 1954; Duke and Doehlert 1981; Li et al. 1996). Sugars provide the energy source for respiration during hardening and over winter, and the level of TNC may decrease by approximately fifty percent from mid-October to late March (Bula and Smith 1954). In the upper mid-west USA, sugar levels reach a maximum between October (Nelson and Smith 1968) and mid-December (Wilding et al. 1960) coinciding with the decline in root starch concentration (Boyce and Volenec 1992). Jung and Larson (1972) stated that the concentration of total soluble sugars (approximately 90% sucrose) is usually closely associated with cold tolerance, however, concentrations of TNC and starch have seldom been related to variations in cold tolerance. Castonguay et al. (1995) have shown that the LT_{50} of the cold tolerant cultivar, 'Apica', was inversely related to crown concentrations of sucrose, raffinose, and stachyose, and directly related to crown concentrations of glucose, fructose, and starch.

Root Nitrogen Content

Early research by Graber et al. (1927) indicated that root protein was very important to cold tolerance. Bula and Smith (1954) observed an increase in percent total nitrogen in alfalfa roots from fall to spring, but the relative increase was related more to the depletion of carbohydrates than to the development and maintenance of cold tolerance. They suggested that the role of nitrogen in cold tolerance was not likely due to levels of total nitrogen, implying that there are specific nitrogenous compounds which are involved in cold tolerance. Subsequent research has attempted to determine the role of root nitrogen in alfalfa plant growth and survival, but results can be difficult to compare because some researchers measured total nitrogen while other measured specific nitrogenous compounds.

Wilding et al (1960) investigated the amino acid and specific protein components of total nitrogen content, and found that arginine and alanine increased approximately 245 and 360 percent, respectively, from August to December, in both cold tolerant and cold sensitive cultivars. They also noted that levels of total amino acids and total non-amino acid nitrogen increased by 20 and 31 percent in the roots of tolerant cultivars, but that there was little change in sensitive cultivars. Approximately one-half to one-third of total amino acid content was asparagine. Li et al. (1996) observed that in Indiana, root protein levels increased in the fall, were maintained throughout the winter, and then decreased in spring with the resumption of growth. Similar to carbohydrate depletion and re-accumulation cycles, protein levels increased again with growth in May, and were again depleted with the first defoliation in June, although proportionately less nitrogen than carbohydrate was translocated from the root for the production of new top growth (Smith and Silva 1969). Li et al. (1996) believed that several of the polypeptides that accumulated in the roots were vegetative storage proteins, and that one specific polypeptide with a molecular weight of 17 kD played a role in cold acclimation.

Avice et al. (1997) determined that root nitrogen concentration was positively correlated to harvest interval, and that the content of vegetative storage and soluble protein in the root on the day of defoliation was related to shoot dry matter production. Soluble proteins represented between 20 and 65 percent of total taproot nitrogen, depending on the competitiveness of the plant. Their results suggest that root protein is a key nutrient for shoot regrowth after harvest.

Duke and Doehlert (1981) also found differences in enzyme and total nitrogen content between cold tolerant and cold sensitive cultivars. Cold tolerant cultivars demonstrated greater ability to fix nitrogen than cold sensitive cultivars, and exhibited greater increases in respiration, enzyme content, and enzyme activity during hardening. They suggested that increased nitrogen level could reflect an increase in proteins which contribute to freezing resistance, or enzymes that hydrolyze starch. Duke and Doehlert (1981) and Jung and Larson (1972) both concluded that many nitrogen fractions could contribute to cold tolerance.

Carbohydrate storage and degradation

Energy reserve compounds in plants are lipids, proteins, and carbohydrates. Although the previous section discussed the importance of proteins, carbohydrates are the primary energy reserve source in biennial and perennial forage legumes and TNC content is often used as an estimate of the energy reserves readily available to a plant (Batten et al. 1993; Smith 1969). Nonstructural carbohydrates include glucose, fructose, sucrose and starch (Hendrix 1993), but alfalfa primarily accumulates sucrose and starch (Smith 1969).

Goodwin and Mercer (1983) define starch as a mixture of two polysaccharides, amylose and amylopectin. Amylose molecules are long, unbranched chains of 100 to several thousand glucopyranose units linked together by α-1,4 bonds. In contrast, amylopectin molecules are highly branched, containing up to 50 000 glucopyranose units linked primarily by α-1,4 bonds, but by α-1,6 bonds at branch points. Starch synthesis begins with the creation of amylose, most of which is then re-configured to form amylopectin. Most starch grains contain 15-25% amylose and 75-85% amylopectin. Frankhauser et al. (1989) found that regardless of total starch content, in a single high-starch alfalfa genotype the ratio of amylopectin to amylose remained consistent near 80:20.

Starch is stored in organelles called plastids: chloroplasts in photosynthetic tissue, and amyloplasts in non-photosynthetic tissue such as alfalfa roots (Steup 1988). Starch grains containing both amylose and amylopectin are deposited inside the plastids. At high starch content, parenchyma cells in the root contain high numbers of starch grains which occupy much of the cell volume. Habben and Volenec (1990) suggested that the size of the parenchyma cells might actually present a physical limitation to starch accumulation. In comparing a low-starch genotype to a high-starch genotype, they found that the low-starch genotype had less tissue in which to store starch, fewer starch grains per cell, and smaller starch grains.

It is not clear whether root carbohydrate storage in alfalfa is greater in the root wood (tissue inside the cambium) than the root bark (tissue outside the cambium), or equally distributed throughout the tissues. Ueno and Smith (1970) found that 46 to 52 percent of stored nonstructural carbohydrate was in the root wood, and 21 to 26 percent was in the root bark, but Habben and Volenec (1990) did not find a difference in storage between the two tissues. They suggested that the difference in research results might be due to the genotype used or the conditions under which the plants were cultured. Deposition of starch in the taproot was uniform throughout the ray cells, but starch degradation occurred first in cells located adjacent to the vascular cambium, and moved outward from the cambium as taproot starch levels declined (Habben and Volenec 1990).

There is a negative relationship between accumulation of root carbohydrates and temperature (Feltner and Massengale 1965; Robison and Massengale 1968; Nelson and Smith 1969), but this relationship varies between cultivars (Brown et al. 1990). Respiration rate increases steadily with temperature, and the optimum temperature for growth of alfalfa is between 10 and 25 °C, with a reduction in growth above 30 °C (Nelson and Smith, 1969). In environments with elevated nighttime temperatures, plants consume more stored carbohydrate through respiration, reducing the rate of carbohydrate accumulation in roots. Over a prolonged period, this can result in lower TNC accumulation (Brown et al. 1990).

Steup (1988) and Goodwin and Mercer (1983) described starch degradation in plants. The degradation of starch within a plant refers to a reaction in which a polyglucan (starch) is converted into a product with a lower degree of polymerization (sugars). Reserve starch degradation is the main source of carbohydrate for metabolism and growth at times when energy is not available from photosynthesis (Steup 1988). Starch is hydrolysed and transported in the form of sucrose when energy is needed. (Goodwin and Mercer 1983).

Starch is degraded to its component monosaccharides by hydrolase enzymes. Within a plant only the enzyme α-amylase can initiate starch degradation, producing the end products maltose and glucose from amylose, and maltose, glucose and small oligosaccharides with α-1,6 linkages from amylopectin. Amyloglucosidase then cleaves both the α-1,4 and

α-1,6 linkages of maltose and the small oligosaccharides, resulting in complete degradation to glucose.

Steup (1988) noted that there are differences in the activity of various α-amylases within a plant. Up to 22 forms of α-amylase have been isolated from wheat kernels, and the various forms were found to vary in activity with the maturity of the kernel. There are also varying forms of enzymes, called "isozymes", which are genetically determined and can differ in efficiency of starch degradation, and in the conditions under which they are activated. Steup (1988) also noted that there have been a variety of proteinaceous α-amylase inhibitors isolated from plants. These inhibitors may play a role in the regulation of starch degradation. The majority of the total amylase content in alfalfa roots is comprised of β-amylase (exoamylase), which is not involved in starch hydrolysis, but decreases with spring growth, indicating that it may function as a vegetative storage protein (Li et al. 1996).

Root content of α-amylase is very important due to its exclusive role in initiating starch degradation within the plant. The relative concentration of α-amylase isozymes is important in regulating TNC degradation and energy availability. The importance of protein content to cold tolerance and winter survival is likely due to the activity of enzymes and proteinaceous inhibitors in the regulation of TNC, as well as to the presence of vegetative storage proteins.

Laboratory nonstructural carbohydrate extraction

Most laboratory extractions of nonstructural carbohydrates from alfalfa roots start with dried tissue. Tissue is typically dried either by forced hot air or freeze drying. Smith (1969) reported that heat drying should be conducted at 100°C for the first ninety minutes in order to rapidly denature enzymes and at 70°C for the completion of drying, but many studies complete the entire drying process at 70°C (Peterson et al. 1987). Smith (1969) also reported that freeze drying fails to inactivate some enzymes, and could result in some interconversion of sucrose to reducing sugars (glucose and fructose) during post-drying storage.

Following drying, tissues are typically ground through either a Wily mill or cyclone mill, or both. Greub and Wedin (1969) reported that grinding through either a 0.42 or 1.00 mm screen was sufficient for all samples, and that a 0.42 mm screen was only necessary for root samples high in starch. Finer grinding than 0.42 mm provided no benefit to the laboratory recovery of TNC from root tissues.

Storage methods of ground root tissue vary. A common method is to re-dry the samples in bottles after grinding, and then seal the bottles until analysis. Samples are then typically subdivided for laboratory analysis, and many researchers run duplicate chemical analyses to ensure accuracy, and report a mean value of the duplicates (Ellingboe et al. 1986). Hall (1990) found that the subdivision of the sample could be a source of error due to separation by particle size, and recommended that the best repeatability could be attained by using a gravimetric divider.

Laboratory extraction of root carbohydrates can be comprised of either a single-step evaluation for TNC, or a two-step evaluation for the determination of sugar and starch content. The difference observed in values obtained by each method is small (Ueno and Smith 1970). In the two-step evaluation, sugars are readily extracted with water (Smith 1969) or ethanol, which also causes non-water soluble carbohydrates to precipitate in solution (Hendrix 1993; Slominski et al. 1993). Sugars are then separated from the non-soluble carbohydrate fraction either through filtration (Hendrix 1993) or centrifugation (Slominski et al. 1993). The extracted soluble sugars are then exposed to a weak acid solution, commonly of HCl or H_2SO_4, which readily hydrolyzes fructosans to monomers (Smith 1969). In a single-step evaluation of TNC, the previous step is omitted, and the entire sample is subjected to the following procedure for the extraction of starch in the two-step procedure.

The starch fraction remaining after extraction of soluble sugars is typically degraded to glucose by incubation with the enzymes α-amylase and amyloglucosidase, and the glucose content of both fractions is determined by a colorimetric comparison to known glucose standards (Hendrix 1993; Slominski 1993; Batten et al. 1993; Kim et al. 1990).

Determination of carbohydrate content by near infrared spectroscopy

While chemical analysis of large numbers of samples for carbohydrate content is complex, slow, and expensive, near infrared spectroscopy (NIRS) provides a rapid and economical alternative. Batten et al. (1993) found that determination of nonstructural carbohydrates by NIRS was possible, and that errors of determination were comparable with traditional chemical methods. Peterson et al. (1987) specifically showed that NIRS could be successfully used to determine root nonstructural carbohydrate content in various legume species, and the technique has been utilized by several researchers including Smith et al.

(1989) and Davis et al. (1995).

NIRS functions by scanning samples, which have already been analyzed chemically, with light in the 1100 to 2500 nm spectrum, and recording the reflectance from the sample as log (1/*R*), where *R* is apparent reflectance. The reflectance at various wavelengths is then related to the known concentration of a given compound in the sample set by development of a calibration equation. The accuracy of the calibrated equation is then tested by scanning a second set of samples with known chemical content, and comparing the NIRS predicted values to the known values (Batten et al. 1993; Buxton and Mertens 1991; Kim and Williams 1990). The equation with the highest correlation between NIRS and known values, and lowest standard deviation of differences between NIRS and the chemical analysis (standard error of performance) is selected for use (Kim and Williams 1990; Peterson et al. 1987). Once an appropriate calibration has been determined, samples with unknown content can be scanned and estimated by NIRS.

The accuracy of NIRS depends upon the choice of a proper calibration sample set (Reeves and Blosser 1988). To produce an accurate predictive equation, the calibration set must be as large and diverse as possible, represent the range of samples encountered and include unusual samples in order to broaden the range of the calibration set (Ellingboe et al. 1986), be specific to the tissue and species being tested (Buxton and Mertens 1991), and be of uniform preparation and particle size (Kim and Williams 1990; Peterson et al. 1987; Hall 1990). Other sources of error in NIRS determinations are differences in water content, relative contents of protein, fibre, oil, and bonding between atoms (Kim and Williams 1990). The accuracy of a given NIRS equation must be monitored by comparing the similarity between the spectra of tested samples and those of the calibration set (Ellingboe et al. 1986), and by periodic chemical testing of NIRS predicted samples (Buxton and Mertens 1991).

Summary

The winter survival of alfalfa cultivars cannot be easily predicted or quantified due to the large number of plant characteristics, management decisions, and environmental factors involved in determining survival. Crop management choices such as planting density, cultivar selection, cultivar dormancy level, and harvesting interval affect root size and the accumulation of stored carbohydrates and nitrogen. Levels of stored root carbohydrate and nitrogen in turn affect alfalfa cultivar cold tolerance, winter survival, and subsequent forage or seed yield.

MANUSCRIPT #1

Forage Yield Potential of Semi- and Non-dormant Alfalfa (*Medicago sativa* L.) Cultivars in Manitoba and North-eastern Saskatchewan

1.1. ABSTRACT

Cultivars of alfalfa (*Medicago sativa* L.) typically grown for forage production in Manitoba and north-eastern Saskatchewan are highly fall dormant with good winter survival and longevity. The objectives of this research were to compare the forage yield potential, stand survival, and winter injury of semi- and non-dormant alfalfa cultivars to that of fall dormant cultivars . The following characteristics were evaluated in six environments during 1993 to 1995: establishment year forage yield, year two cultivar height, percent stand survival, winter injury, and year two forage yield. There was no establishment year yield advantage from semi- and non-dormant alfalfa cultivars over the environments tested. Measurements of plant height in year two showed that the most dormant cultivars had the most rapid development in early spring, but that the semi- and non-dormant cultivars had more rapid regrowth after the first cut, and more growth in late fall. Non-dormant cultivars sustained greater winter injury and stand losses than dormant cultivars, but semi-dormant cultivars often had the same level of winter injury and stand survival as dormant cultivars. Year two forage yield varied with environment and the number of cuts that were possible in a given environment. Under a two cut system, dormant cultivars had the highest year two yield, while semi-dormant cultivars had yields equivalent to the dormant cultivars under a three cut system. In conclusion, semi- and non-dormant cultivars did not produce higher

yields than dormant cultivars in either the establishment year or year two. The increased mortality and winter injury of these cultivars may facilitate stand termination and be an advantage for use in short term stands (one to two years).

1.2. INTRODUCTION

The benefits of forage legumes in a crop rotation include the addition of nitrogen to the soil through the symbiotic nitrogen fixation of *Rhizobium sp.*, the reclamation of leached nitrates through deep water extraction, improved soil structure and water infiltration, increased organic matter, and weed suppression. In a survey of Manitoba and Saskatchewan producers, Entz et al. (1995) showed that 67% of producers surveyed noted greater grain yields following forages in rotation and 83% observed weed control benefits for one to three years following forages. Despite these benefits, a majority of producers are not managing forages to maximize rotational benefits, and on average maintain forage stands for six to nine years.

Many of the benefits of including alfalfa in a rotation can be realized from a shorter duration stand. In Manitoba, Kelner et al. (1997) demonstrated that alfalfa stands of two years duration have the potential to provide significant benefit to soil nitrogen status. In southern Saskatchewan, Jefferson and Cutforth (1997) showed that alfalfa extracts most of the deep soil water within the first two years, as evidenced by the high variation in alfalfa yield with environmental conditions after the second year. Therefore, a two year stand duration may have sufficient root penetration to access leached nitrates, and to improve water infiltration.

The rotational benefits of forages could be better realized by increasing the amount of land exposed to forage stands. Entz et al. (1995) suggested that one of the ways to increase land exposure to the rotational benefits of forages would be to reduce forage stand duration, allowing more frequent rotation cycles.

One of the major reasons that producers do not cycle forage stands through rotations more often is the difficulty of stand termination. Semi- and non-dormant alfalfa cultivars may provide a viable option for short-term or annual forage systems in western Canada. Since these cultivars show increased winter injury in comparison to traditionally grown dormant cultivars (Kelner and Vessey 1995), they should reduce the difficulties normally associated with stand termination. Interest in this possibility has been increasing over the last fifteen years. The non-dormant cultivar 'Nitro', which was also bred for high nitrogen fixation, was released specifically for use in an annual forage system (Barnes et al. 1988). Smith (1996) has been crossing Arabian and North American alfalfa germplasm in order to produce a cultivar with improved characteristics that is consistently winter killed.

Kelner (1994) noted that winterkill of the non-dormant cultivars 'Nitro' and 'CUF-101' was probably sufficient to facilitate direct seeding of a subsequent crop in two of the three site-years tested in Manitoba. There has also been research conducted in Minnesota by Zhu et al. (1996) to evaluate the potential of medics (annual *Medicago* spp.) for use as annual legume crops in rotations. They found that although medics yielded as well as Nitro alfalfa in the establishment year, they produced no regrowth following defoliation. If semi- and non-dormant alfalfa cultivars produce fall regrowth in these environments, they would be more desirable than medics as a short-rotation legume crop.

Semi- and non-dormant cultivars must also show good forage productivity in order for them to be adopted for use in shorter term stands. Kelner and Vessey (1995) showed that semi- and non-dormant cultivars demonstrate increased rates of regrowth following cutting and greater fall growth. Rumbaugh et al. (1972) showed that among genotypes with similar stand, those with the most rapid recovery after cutting provide maximum forage yields.

The objectives of this research were to compare the forage yield potential, stand survival, and winter injury of semi- and non-dormant alfalfa cultivars to that of fall dormant cultivars.

1.3. MATERIALS AND METHODS

1.3.1 Experimental design and management

Alfalfa yield and winter survival experiments were established at three locations in 1993 (Arborg, MB, 97°W & 51°N; Homewood, MB, 98°W & 49.5°N; and Melfort, SK, 104.4°W & 52.5°N) and at three locations in 1994 (Arborg, MB, Melfort, SK, and Carman, MB, 98°W & 49.5°N). Environments were defined by the combination of location and planting year.

Table 1. Alfalfa forage yield experiments conducted at four locations in western Canada from 1993-1995.

Environment					Years harvested	
Location	Planting year	Code	Planting date	Row spacing (cm)	Establishment year	Year 2
Homewood, MB	1993	H93	13 May	30	–[z]	√
Carman, MB	1994	C94	14 July[y]	15	–	√
Arborg, MB	1993	A93	14 May	30	–	×[x]
Arborg, MB	1994	A94	16 May	15	√	√
Melfort, SK	1993	M93	21 May	30	√	√
Melfort, SK	1994	M94	24 May	30	√	√

z - trials were cut, no yield taken
y - re-seeded due to poor emergence of original stand seeded 12 May
x - A93 did not survive through the first winter.

The soil types at each location were as follows: Homewood, Sperling mixed loam; Carman, Hochfeld series loamy sand; Arborg, Tano series clay (Peat meadow); and Melfort, Melfort series silty clay. Sites were fertilized to soil test recommendâtions with phosphorous, potassium and sulfur prior to seeding, and all cultivars were scarified and inoculated with *Rhizobium meliloti* L. Dang prior to seeding.

Fall dormancy (FD) of alfalfa cultivars is described using a 1-9 rating scale described in the Standard Tests to Characterize Alfalfa Cultivars (Barnes et al. 1995), "1" denoting those cultivars exhibiting the least fall growth, and "9" denoting those cultivars with the most fall growth, measured as canopy height. In these experiments 24 alfalfa cultivars covering the full range of FD were planted in each experiment (Table 2). Planting dates over both years ranged from 13 May to 24 May for all sites except C94, which had to be re-seeded on 14 July as outlined in Table 1. The experimental design was a partially randomized complete block with four replicates. Within each trial, entries were grouped into three ranges of FD with one to four referred to as dormant, five and six as semi-dormant, and seven to nine as non-dormant. Fall dormancy groupings were not randomized between replicates. Cultivars within each grouping were completely randomized. This grouping arrangement was used to minimize potential differences in inter-plot competition that may have resulted from differential winter survival between non-dormant and dormant cultivars. Fall dormancy groups were based on accepted divisions (unpublished) among North American alfalfa breeders.

Plot size was 6.8 m x 1.8 m at Arborg, Homewood, and Carman, and 6.8 x 1.2 m at Melfort, with a seeding rate of 12 kg $ha^{-1.}$ The experiments established in 1994 at Carman and Arborg were planted at a 15 cm row spacing and all other trials were planted at a 30 cm row spacing (Table 1).

Weed control was performed using combination of preplant and postemergent broadcast herbicide applications at recommended rates (Table 3), and hand weeding.

Table 2. Alfalfa cultivars included in forage yield experiments over six environments in western Canada.

Cultivar	FD[z]	Cultivar	FD	Cultivar	FD
Rangelander	1	CimmaronVR	4[y]	P5683	7
Beaver	2	Key	4[x]	Valley +	7
Vernal	2	Mede	5	Rio	7
Algonquin	2	Archer	5	Moapa 69	8
Arrow	3	Belmont	5	Nitro	8
Multiking	3	ABI 700	6	GT13R	8
Excalibur	4	P581	6	CUF 101	9
Saranac	4	Express	6	P5929	9

z - FD, fall dormancy rating: 1 = nondormant, 9 = dormant
y - Initially entered in trials as fall dormancy 5.
x - Initially entered in trials as fall dormancy 6.

Table 3. Herbicides used in alfalfa trials managed for forage production in six environments in western Canada from 1993-1995.

Pesticide	Trade Name	Common Name	Chemical Name
Pre-emergent herbicide	Treflan EC	trifluralin	∝,∝,∝-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine
Post-emergent herbicides	Pursuit	imazethapyr	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridine carboxylic acid
	Pardner	bromoxynil	3,5-dibromo-4-hydrobenzonitrile
	Embutox 625	2,4-DB	4-(2,4-dichlorophenoxy)butyric acid
	Poast	sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one

1.3.2. Assessment of cultivar persistence

Cultivar persistence was evaluated in the spring of year two using visual assessments of percent stand survival and winter injury. Percent stand survival reflects the percentage of the establishment year stand remaining the following spring. Winter injury ratings reflect the health of the live plants remaining in the plot and were made using the NAAIC (North American Alfalfa Improvement Conference) rating scale (McCaslin and Woodward, 1995) shown in Table 4. Ratings were conducted by pairs of researchers in order to reduce the possible subjectivity or bias of a single evaluator. Within plot variation in winter injury was taken into account and each researcher determined a winter injury rating. One mean value was then assigned for each plot. Assessments of cultivar persistence were made after all cultivars had broken dormancy and commenced growth. Dates of assessment were: A93, 31 May 1994; A94, 24 May 1995; H93, 13 May 1994; C94, 18 May 1995; M93, 12 May 1994; and M94, 24 May 1995.

Table 4. Scale used for rating winter injury of 24 alfalfa cultivars grown in six environments in western Canada.

Rating	Characteristics
1 - No injury	Plant has uniform, symmetrical appearance, all shoots are about equal in length.
2 - Some injury	The plant is symmetrical, but regrowth is slightly uneven.
3 - Significant injury	Regrowth varies in length, reduced vigor.
4 - Severe injury	Plant has sparse shoots, regrowth is very irregular, poor vigor.
5 - Dead plant	

1.3.3 Forage yield determination

Due to the relatively slow speed of establishment, forage harvest in the first year did not occur until August at all locations, with the exception of C94 where drought-induced re-seeding prevented an establishment year harvest (Table 5). Establishment year forage yield was measured at M93, M94 and A94. Late season regrowth in the establishment year was determined only for A94, and was measured as the forage yield on 14 November 1994. Year two forage yield was determined on the basis of a two cut system for A94, M93 and M94. At the more southern sites, H93 and C94, a three cut system was used (Table 5). Monthly precipitation and mean temperatures are presented in Tables 6 and 7.

Table 5. Number of forage cuts per year for 24 cultivars of alfalfa over six environments in western Canada.

Environment			Establishment year		Year 2	
Location	Planting year	Code	No. of Cuts	Cut Dates	No. of Cuts	Cut Dates
Homewood	1993	H93	1[z]	mid-Aug.[w]	3	15 June 22 July 21 Aug.
Carman	1994	C94	0[y]		3	13 June 15 July 16 Aug.
Arborg	1993	A93	1[z]	mid-Aug.[w]	–[x]	–
Arborg	1994	A94	2	26 Aug. 14 Nov.	2	19 June 18 July
Melfort	1993	M93	1	20 Aug.[w]	2	7 July 23 Aug.
Melfort	1994	M94	1	17 Aug.	2	22 June 26 Aug.

z - No yield recorded.
y - No establishment year harvest due to drought-induced re-seeding.
x - A93 did not survive through the first winter.
w - Estimated harvest date.

It was not feasible to harvest each cultivar at each site at a consistent maturity stage. Therefore, trials were harvested when the average bloom across the experiment was 10 percent. The front and back edges of each replicate were trimmed prior to harvesting each plot in order to produce uniform plot lengths and reduce the edge effect of mowed alleyways between replicates. Either the whole plot was harvested or a consistent number of rows were cut from the centre of each plot, depending on the harvester used, and a gross forage yield determined prior to harvesting the next plot. Subsamples of approximately 400 g were taken from each plot for moisture content determination, weighed at the time of sampling, dried to a constant weight and re-weighed to determine moisture content at cutting. Plot yields were adjusted to a consistent moisture content and converted to kg ha^{-1} for comparison. The harvester used at Melfort was a Haldrup (J. Haldrup a/s, Løgstør, Denmark). At Carman, Homewood and Arborg either a Haldrup or a Swift walk-behind flail (Swift Machine and Welding, Swift Current, Saskatchewan) were used, depending on availability.

1.3.4 Assessment of plant growth

Plant heights were measured at two to three week intervals after each harvest throughout year two at Carman, Homewood, and Arborg. Ten stems per plot were chosen randomly and measured for height at each measurement date. Plant heights were not monitored in the establishment year in any environment.

1.3.5. Statistical Analysis

Cultivars were not completely randomized between replicates, in that they were grouped by fall dormancy rating (dormant: FD 1-4; semi-dormant: FD 5-6; non-dormant: FD 7-9) and dormancy groups were not randomized between replicates. This grouping arrangement was used to minimize differences in inter-plot competition that were expected to result from differential winter survival between non-dormant and dormant cultivars. The study design was initiated prior to the inclusion of these experiments in this thesis project. These groupings did not have any definable treatment effect, therefore each test was analyzed as a randomized complete block design.

Homogeneity of variance was determined across environments using Bartlett's Chi-square Test for Homogeneity of Variances (Little and Hills, 1978). Results of the Bartlett's Test prevented pooling of data over environments for mean comparisons (results not shown). Comparisons were instead made within each environment as distinguished by site and planting year. Three environments were available for the comparison of establishment year forage yield, five environments for year two forage yield, five environments for winter injury, and four environments for percent stand survival. No single variable can be compared across all six environments due to errors and/or omissions in data recording across locations, stand establishment of some experiments prior to study initiation, and very low winter survival of the 1993 Arborg experiments. Analysis of variance was conducted on non-transformed data using the statistical program Agrobase (Agronomix Software, Inc., 1996). Mean comparisons were made using Fisher's protected LSD. Rank correlations were determined using Spearman's Coefficient of Rank Correlation (Little and Hills, 1978).

Table 6. Long term average (normal) and actual monthly precipitation (mm) at three sites in western Canada from 1993 to 1995.

	Melfort, SK[z]				Arborg, MB[y]				Carman, MB[y]			
Month	1993	1994	1995	Normal	1993	1994	1995	Normal	1993	1994	1995	Normal
January	7	11	17	18	22	7	28	20	18	13	17	19
February	3	10	21	14	T	4	15	17	1	5	26	18
March	14	5	40	19	14	2	26	24	9	14	27	22
April	40	8	21	21	47	12	19	34	17	11	10	43
May	13	55	5	41	20	37	51	49	70	39	83	53
June	119	60	55	62	112	69	34	75	120	54	58	73
July	158	78	29	67	78	75	44	66	153	48	65	69
August	46	45	135	53	146	40	107	75	114	103	132	66
September	49	22	1	41	64	45	8	50	29	55	44	49
October	14	16	40	27	20	46	60	38	31	162	62	34
November	13	20	26	18	T	34	54	24	25	49	58	19
December	9	20	18	23	15	27	19	20	14	17	20	21

z - Source: Agriculture Canada, Melfort, SK.
y - Source: Environment Canada Climate Services, Winnipeg, MB.

Table 7. Long term average (normal) and actual mean monthly temperatures (°C) at three sites in western Canada from 1993 to 1995.

	Melfort, SK[z]				Arborg, MB[y]				Carman, MB[y]			
Month	1993	1994	1995	Normal	1993	1994	1995	Normal	1993	1994	1995	Normal
January	-17.0	-23.4	-16.1	-19.1	-18.7	-25.2	-17.8	-20.2	-16.1	-22.9	-14.9	n/a[x]
February	-14.0	-21.1	-14.3	-15.5	-16.3	-20.2	-18.3	-17.0	-13.3	-18.1	-13.6	
March	-1.9	-5.2	-8.5	-9.0	-6.2	-3.8	-7.5	-8.7	-4.6	-1.3	-5.9	
April	3.6	7.4	-2.3	2.2	2.9	1.7	-1.1	2.3	4.2	4.3	1.0	
May	11.0	10.8	10.3	10.6	9.5	9.8	9.0	10.1	11.5	12.8	11.0	
June	13.2	15.7	18.1	15.5	14.6	16.2	18.6	15.5	15.0	17.7	20.0	
July	15.3	16.9	16.7	17.6	16.6	17.0	17.8	18.4	17.1	18.0	19.6	
August	15.4	15.9	16.0	16.3	16.4	15.1	18.1	16.9	17.5	16.9	18.9	
September	8.7	13.5	12.1	10.4	8.3	13.0	11.5	10.9	10.6	14.8	13.0	
October	3.0	5.2	4.2	3.9	1.4	6.7	4.2	4.5	3.5	8.3	5.0	
November	-8.3	-6.6	-11.4	-7.0	-7.3	-3.1	-11.9	-5.8	-6.0	-2.0	-9.5	
December	-11.4	-13.0	-16.4	-16.2	-14.2	-11.8	-17.7	-16.5	-12.0	-10.5	-15.1	

z - Source: Agriculture Canada, Melfort, SK.
y - Source: Environment Canada Climate Services, Winnipeg, MB.
x - n/a, not available. Long term climate normals are not available for Carman, MB.

1.4 RESULTS AND DISCUSSION

1.4.1. Assessment of establishment year forage yield

The highest establishment year mean forage yield was in A94, at 5363 kg dry matter (DM) ha^{-1}, and the lowest in M93, at 3273 kg DM ha^{-1} (Table 8). There were cultivar differences in forage yield within all three environments (Table 8), however there was little consistency in the relative yields of cultivars across environments as determined by rank correlation (Table 9).

Table 8. Analysis of variance for establishment year forage yield of twenty four alfalfa cultivars grown in three environments in western Canada.

Environment		Grand Mean	Source	d.f.	MS	F value	
Arborg	1994	5363 kg ha^{-1}	Rep	3	29 687 879	48.75	***
			Cultivar	23	1 859 256	3.05	***
Melfort	1993	3273 kg ha^{-1}	Rep	3	70 966	1.39	NS
			Cultivar	23	92 483	1.81	*
Melfort	1994	4505 kg ha^{-1}	Rep	3	1 443 000	16.3	***
			Cultivar	23	649 868	7.34	***

*, *** Significance at $P \leq 0.05$ and 0.001

Table 9. Spearman's rank correlation of cultivar ranking for establishment year forage yield of 24 cultivars grown in three environments in western Canada.

Correlation	R value	
A94 to M93[z]	0.23	NS
A94 to M94	-0.22	NS
M93 to M94	0.51	*

* ; Significant at $P \leq 0.05$.
z - A94, Arborg 1994; M93, Melfort 1993; M94, Melfort 1994.

The only significant correlation for establishment year forage yield over cultivars occurred between M93 and M94, but it was relatively low at 0.51. Figures 1, 2 and 3 illustrate that both relative yield between cultivars and absolute yield of individual cultivars varied widely across environments. The semi-dormant and non-dormant cultivars did not exhibit a consistent yield advantage over the dormant cultivars typically grown in western Canada for hay production.

Although there were differences in cultivar yield within each environment, the relative ranking of cultivars was not consistent across environments and there was no yield advantage from semi- or non-dormant cultivars in the establishment year. If more than one harvest had been taken during the establishment year, continued late season growth of the less dormant cultivars (Figure 4) would have likely given them a yield advantage.

These results are consistent with previous research which showed that although less dormant cultivars have more rapid growth and development in early spring due to a larger seed size, the differences diminished later in the season (Gjuric 1995; Kelner and Vessey 1995). In this research, any early season advantage in growth, development, or vigour by the less dormant cultivars had diminished by harvest, and was not reflected in the establishment year forage yield from a single mid-season harvest.

Although the amount of regrowth in the establishment year following the mid-August harvest was not considered sufficient for commercial harvest, regrowth of semi- and non-dormant cultivars was measured as forage yield following frost on the 14 November for A94 (Figure 4). The additional fall growth averaged 1662 kg ha^{-1}, and may be advantageous in short-term stands in these environments to increase fall nitrogen fixation (Kelner et al. 1997), or as additional forage yield in the form of hay, silage, or late season grazing. There were not many differences in late season regrowth among the semi- and non-dormant cultivars tested in A94, with the exception of the cultivars 'Mede' (FD 5) and 'Rio' (FD 7) (Figure 4). This was surprising, since fall dormancy rating reflects comparative fall regrowth using standard checks (McCaslin and Woodward 1995), and greater regrowth might have been expected from the cultivars ranked as the least dormant. This discrepancy may be due to the fact that fall dormancy ratings reflect canopy height, rather than stem length or the number of stems. The flail type harvester used for this harvest normally lifts up and cuts decumbent growth as well as erect stems. The highest yielding cultivars may not have had the greatest canopy height, but may have had greater stem length and/or a greater number of stems per plant.

Fall growth potential is also a feature which provides an advantage for semi- and non-dormant alfalfa cultivars over spring seeded annual medics (annual *Medicago* spp.). Zhu et al. (1996) investigated the forage yield potential of six types of annual medic in Minnesota, and found that most of the cultivars tested had a single cut yield equivalent to or greater than Nitro alfalfa, but that the medics did not regrow following defoliation.

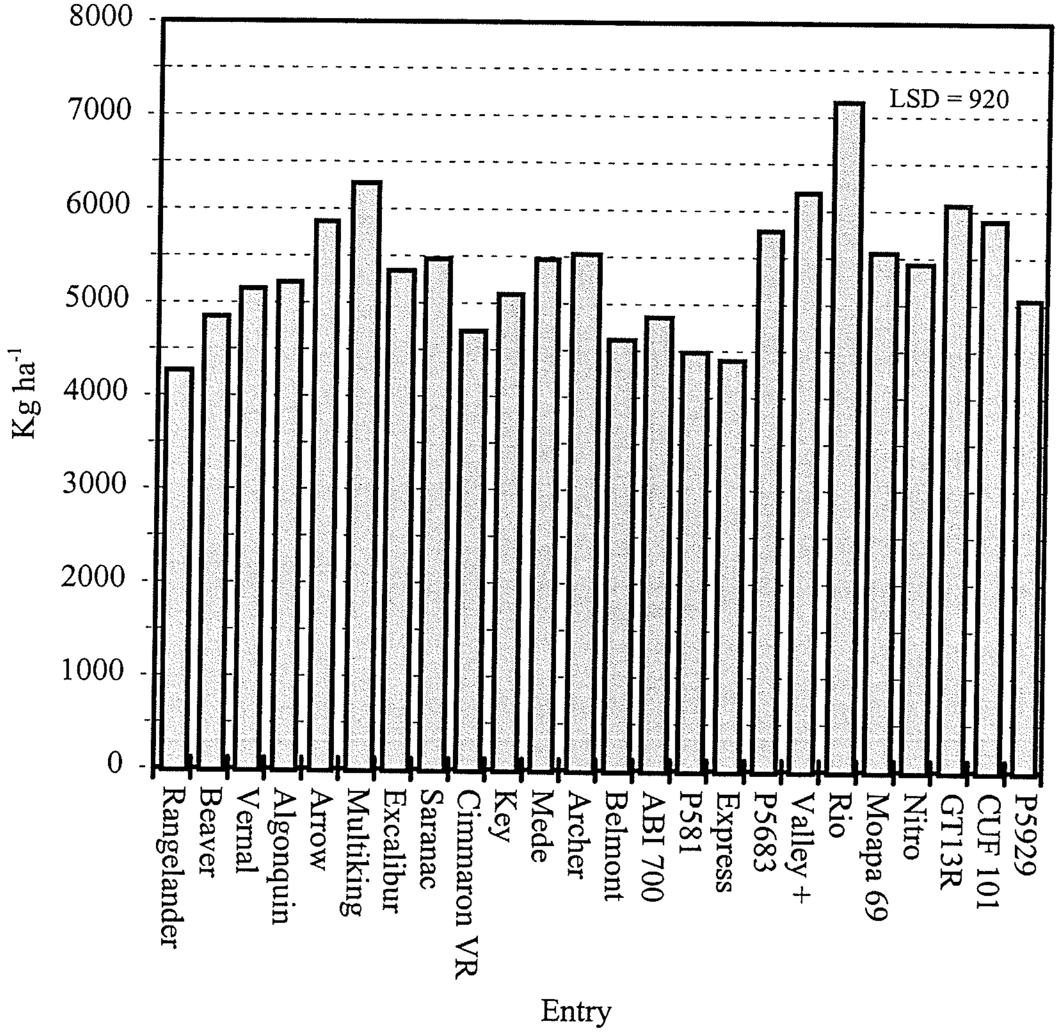

Figure 1. Establishment year forage yield of 24 cultivars of alfalfa ranging in fall dormancy (FD) from one to nine, planted at Arborg, MB in 1994. (Left to right: Entries 1-10, FD of 1-4; entries 11-16, FD of 5-6; entries 17-24, FD of 7-9)

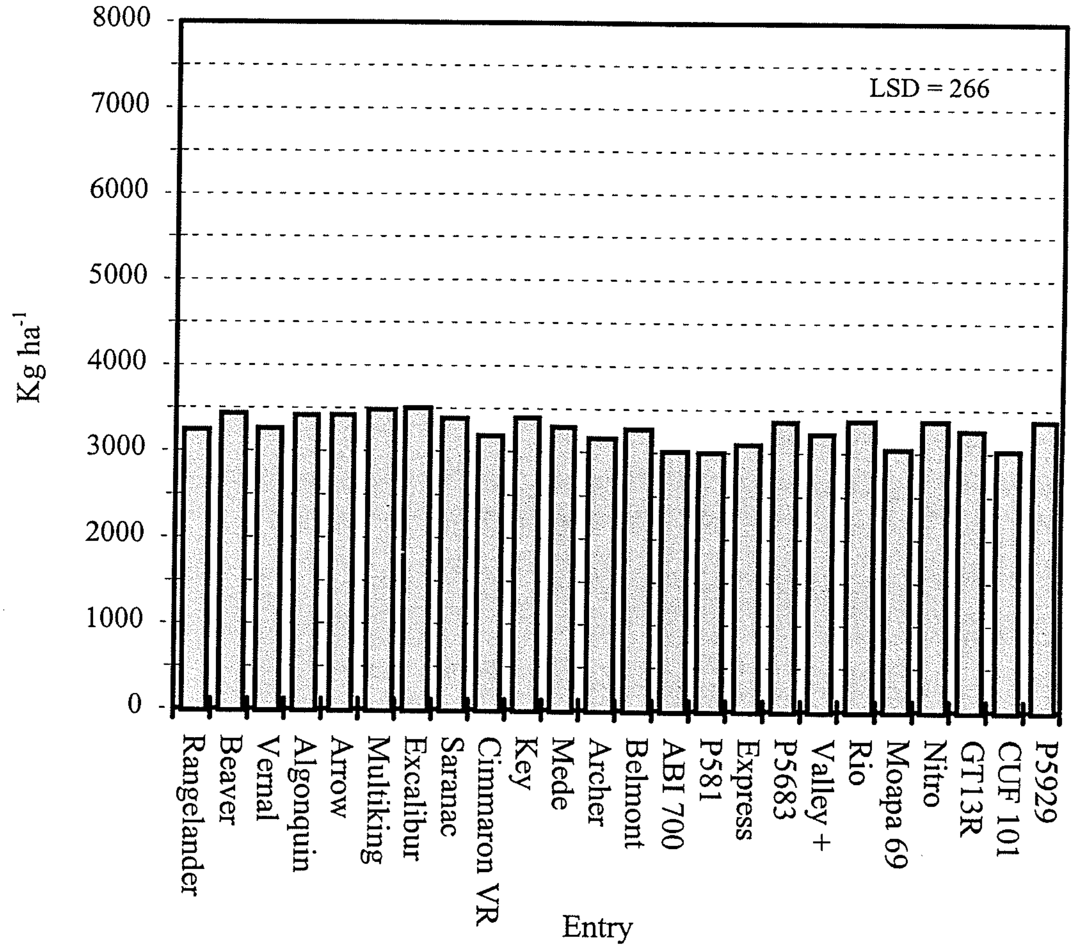

Figure 2. Establishment year forage yield of 24 cultivars of alfalfa ranging in fall dormancy (FD) from one to nine, planted at Melfort, SK in 1993. (Left to right: Entries 1-10, FD of 1-4; entries 11-16, FD of 5-6; entries 17-24, FD of 7-9)

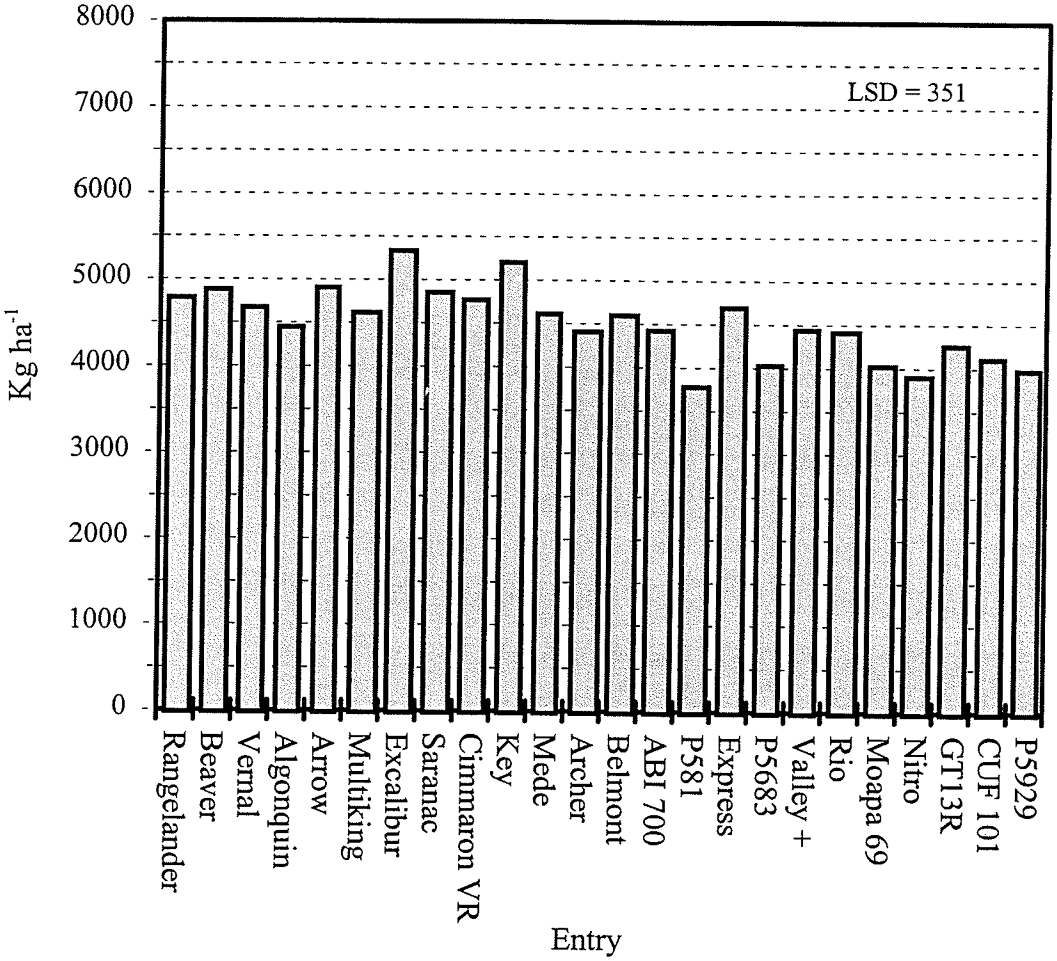

Figure 3. Establishment year forage yield of 24 cultivars of alfalfa ranging in fall dormancy (FD) from one to nine, planted at Melfort, SK in 1994. (Left to right: Entries 1-10, FD of 1-4; entries 11-16, FD of 5-6; entries 17-24, FD of 7-9)

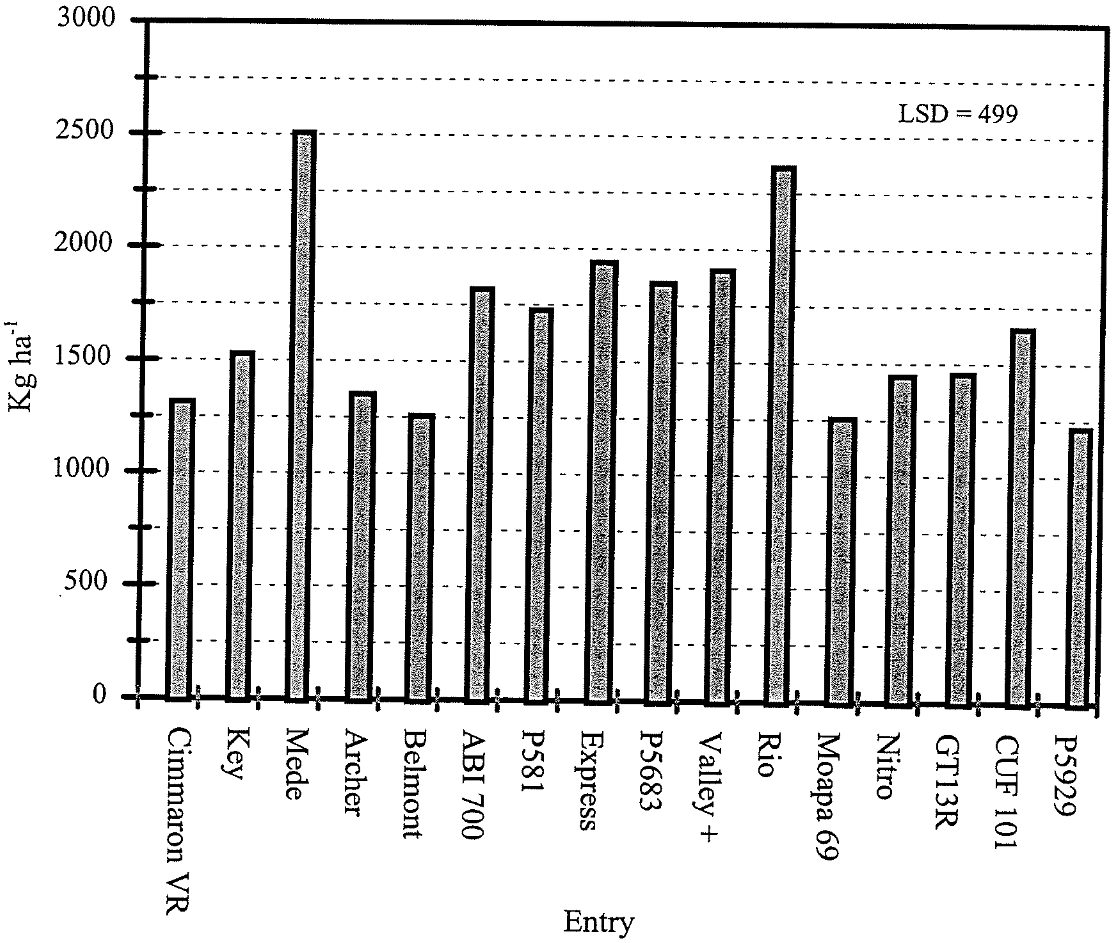

Figure 4. Late season regrowth of semi- and non-dormant cultivars in fall of the establishment year as determined by a 14 November forage harvest following a killing frost at Arborg, 1994.

1.4.2. Assessment of cultivar persistence

1.4.2.1. Winter injury

Winter injury was assessed for five environments: A94, C94, H93, M94 and A93 in the spring of year two. There were highly significant ($P \leq 0.001$) differences between cultivars within all environments (Table 10 and 12). Winter injury levels were generally higher in non-dormant cultivars and lower in the dormant cultivars.

Table 10. Analysis of variance for winter injury of 24 alfalfa cultivars in spring of year two over five environments in western Canada.

Environment		Source	d.f.	MS	F value	
Arborg	1994	Rep	3	0.250	1.35	NS
		Cultivar	23	5.145	27.84	***
Carman	1994	Rep	3	0.708	5.84	**
		Cultivar	23	2.353	19.39	***
Melfort	1994	Rep	3	1.528	9.23	***
		Cultivar	23	2.580	15.59	***
Homewood	1993	Rep	3	5.819	18.64	***
		Cultivar	23	2.172	6.96	***
Arborg	1993	Rep	3	0.194	2.27	NS
		Cultivar	23	2.174	25.35	***

, * Significance at $P \leq 0.01$ and 0.001

Winter injury of the 24 cultivars tested was extremely consistent across environments, as indicated by rank correlation values of 0.79 to 0.94 (Table 11), with the exception of A93 which experienced severe winter injury to all cultivars and had very little rank separation (Table 12). In A93 all dormant cultivars, except 'Multiking' (FD 3) and 'Excalibur' (FD 4), and the semi-dormant cultivar Mede (FD 5), had less winter injury than all non-dormant cultivars. No cultivar with a fall dormancy rating greater than five survived, and 'Rangelander', the most dormant cultivar tested, had a winter injury rating of 2.5 (Table 12). In M94, all cultivars in the non-dormant group had greater winter injury than both the semi-dormant and dormant cultivars.

Table 11. Spearman's rank correlation of cultivar ranking for winter injury of 24 cultivars grown in five environments in western Canada.

Correlation	R value	
A94 to C94^z	0.87	***
A94 to M94	0.86	***
A94 to H93	0.87	***
C94 to M94	0.94	***
C94 to H93	0.79	***
M94 to H93	0.83	***

*** - Significance at P≤0.001.
z - A94, Arborg 1994; C94, Carman 1994; M94, Melfort 1994; H93, Homewood 1993.

Similar to the findings of Sheaffer et al. (1992), there was not a consistent relationship between fall dormancy classification and winter injury, as cultivars with the same level of fall dormancy had different levels of winter injury in some environments. For example, among the cultivars with FD 6, 'P581' had greater winter injury than 'ABI 700' in A94, C94, and H93. Among cultivars of FD 5, Mede had greater winter injury than both 'Archer' and 'Belmont' in four of five environments. All non-dormant cultivars had significantly higher levels of winter injury than dormant cultivars in every environment but A93, with the exception of 'Valley +' (FD 7) in A94 and Rio (FD 7) in C94 (Table 12).

Although the non-dormant cultivars exhibited greater winter injury than the dormant cultivars, they were not completely killed in any environment except A93. This was surprising, considering that most of these non-dormant cultivars were developed for hay production in the south western USA, and Nitro was developed for use in annual rotations in the upper mid-west USA (Barnes et al. 1988). Reduced winter injury in all environments except A93 can be attributed to the insulating effects of snow cover for the duration of the winter (McKenzie et al. 1988; Sheaffer et al. 1988). In A93, which received only 22% of normal precipitation from November 1993 to March 1994 (Table 6) and therefore had very little winter snow cover, winter injury was dramatically increased (Table 12).

Under severe winter conditions such as environment A93, complete winter kill of cultivars with FD 5-9 can occur. Despite this risk, these results show that under typical winter conditions with adequate snow cover, cultivars with FD 5-6 may have equal or less winter injury than cultivars with FD 1-4. These semi-dormant cultivars may be a viable option for use in short term forage stands in western Canada.

Table 12. Winter injury of 24 alfalfa cultivars in spring of year two over five environments in western Canada.

		Environment									
Cultivar	FD[z]	A94[y]		C94		M94		H93		A93	
Rangelander	1	1.0	g[x]	1.0	d	2.0	f	1.3	ef	2.5	d
Beaver	2	1.5	efg	1.3	cd	2.3	ef	1.0	f	2.8	d
Vernal	2	1.5	efg	1.0	d	2.3	ef	1.0	f	3.8	c
Algonquin	2	1.0	g	1.0	d	2.3	ef	1.0	f	3.5	c
Arrow	3	1.8	def	1.0	d	1.5	g	1.0	f	4.5	b
Multiking	3	1.5	efg	1.0	d	2.0	f	1.0	f	5.0	a
Excalibur	4	1.0	g	1.0	d	2.0	f	1.0	f	5.0	a
Saranac	4	1.3	fg	1.3	cd	2.3	ef	1.0	f	4.5	b
Cimmaron VR	4[w]	1.5	efg	1.5	c	2.5	de	1.3	ef	5.0	a
Key	4[w]	1.5	efg	1.0	d	2.3	ef	1.8	de	5.0	a
Mede	5	3.0	b	2.0	b	2.8	cd	1.5	def	4.5	b
Archer	5	1.3	fg	1.0	d	2.3	ef	1.0	f	5.0	a
Belmont	5	1.8	def	1.0	d	2.3	ef	1.3	ef	5.0	a
ABI 700	6	2.0	de	1.3	cd	2.8	cd	1.8	de	5.0	a
P581	6	3.3	b	2.0	b	3.0	c	2.5	bc	5.0	a
Express	6	3.0	b	2.0	b	3.0	c	2.0	cd	5.0	a
P5683	7	2.8	bc	2.3	b	3.8	ab	2.0	cd	5.0	a
Valley +	7	2.0	de	2.0	b	3.5	b	2.0	cd	5.0	a
Rio	7	2.3	cd	1.5	c	3.8	ab	2.0	cd	5.0	a
Moapa 69	8	4.3	a	3.0	a	4.0	a	3.0	ab	5.0	a
Nitro	8	4.3	a	3.0	a	4.0	a	2.8	ab	5.0	a
GT13R	8	3.3	b	2.3	b	3.8	ab	2.5	bc	5.0	a
CUF 101	9	4.0	a	3.3	a	4.0	a	2.8	ab	5.0	a
P5929	9	4.5	a	3.0	a	4.0	a	3.3	a	5.0	a

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).

y - A94, Arborg 1994; C94, Carman 1994; M94, Melfort 1994; H93, Homewood 1993; A93, Arborg 1993.

x - Cultivar means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD.

w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

1.4.2.2. Stand survival

While winter injury is a measure of the health of the plants remaining in a plot in the spring, percent stand survival is a measure of the proportion of plants present in the fall which survived the winter. Percent stand survival was assessed over four environments: A94, C94, H93 and A93 in the spring of year two. There were highly significant ($P \leq 0.001$) differences between cultivars within each of these environments (Tables 13 and 14). There was also a high degree of consistency in relative stand survival between cultivars across all environments tested, as determined by rank correlation (Table 15). These results show that cultivar stand survival was a very consistent trait across environments, in contrast to the variability discussed previously for cultivar forage yield in the establishment year.

Table 13. Analysis of variance for stand survival of 24 alfalfa cultivars in spring of year two over four environments in western Canada.

Environment		Source	d.f.	MS	F value	
Arborg	1994	Rep	3	89.15	1.73	NS
		Cultivar	23	2365.12	45.79	***
Carman	1994	Rep	3	75.96	1.17	NS
		Cultivar	23	628.79	9.66	***
Homewood	1993	Rep	3	4621.63	25.54	***
		Cultivar	23	1071.96	5.92	***
Arborg	1993	Rep	3	44.58	3.32	*
		Cultivar	23	714.49	53.23	***

*,*** - Significance at $P \leq 0.05$ and 0.001.

Table 14. Percent stand survival of 24 alfalfa cultivars in spring of year two over four environments in western Canada.

		Environment							
Cultivar	FD[z]	A94[y]		C94		H93		A93	
Rangelander	1	75	ef[x]	78	abc	84	a-d	49	a
Beaver	2	84	a-d	80	abc	88	ab	42	b
Vernal	2	80	b-f	81	ab	89	ab	4	d
Algonquin	2	86	abc	81	ab	91	ab	25	c
Arrow	3	84	a-d	84	a	93	a	2	d
Multiking	3	88	ab	79	abc	88	ab	0	d
Excalibur	4	85	abc	83	ab	85	abc	0	d
Saranac	4	88	ab	79	abc	89	ab	2	d
Cimmaron VR	4[w]	86	abc	74	b-e	84	a-d	0	d
Key	4[w]	83	a-e	76	a-d	76	b-e	0	d
Mede	5	66	gh	68	def	80	a-e	1	d
Archer	5	89	a	80	abc	85	abc	0	d
Belmont	5	80	b-f	78	abc	80	a-e	0	d
ABI 700	6	79	c-f	75	a-d	78	a-e	0	d
P581	6	48	i	71	cde	56	fg	0	d
Express	6	64	h	68	def	71	cde	0	d
P5683	7	73	fg	65	ef	66	ef	0	d
Valley +	7	76	def	76	a-d	69	de	0	d
Rio	7	79	c-f	74	b-e	71	cde	0	d
Moapa 69	8	15	k	54	g	48	g	0	d
Nitro	8	25	j	44	hi	49	g	0	d
GT13R	8	65	gh	61	fg	53	fg	0	d
CUF 101	9	20	j	53	gh	45	g	0	d
P5929	9	16	k	38	i	42	g	0	d

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; H93, Homewood 1993; A93, Arborg 1993.
x - Cultivar means followed by the same letter are not significantly difference at $P \leq 0.05$, Fisher's protected LSD.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Table 15. Spearman's rank correlation of cultivar ranking for stand survival of 24 cultivars grown in three environments in western Canada.

Correlation	R value	
A94 to C94[z]	0.83	***
A94 to H93	0.85	***
C94 to H93	0.93	***

*** - Significance at $P \leq 0.001$.
z - A94, Arborg 1994; C94, Carman 1994; H93, Homewood 1993.

In environment A93, almost all cultivars showed a total lack of stand survival. Rangelander (FD 1), 'Beaver' (FD 2) and 'Algonquin' (FD 2) had greater survival than all other cultivars, and significant differences were also present among these cultivars as follows: Rangelander > Beaver > Algonquin (Table 14). The percent stand survival of all other cultivars was low enough to be considered complete winter kill. These results reflect a very severe winter, since there are usually a few plants surviving of most cultivars, even in tests which intentionally stress plants prior to winter (S. R. Smith, Jr., pers. comm.).

In the other three environments tested (A94, C94, and H93), cultivars with less fall dormancy had lower stand survival (Table 14). These differences were not always significant, and were not consistent within a given fall dormancy rating. Cultivars with fall dormancy ratings of eight and nine had lower stand survival than all dormant cultivars. Among the three cultivars classified as a fall dormancy of seven, the percent stand survival of Valley + and Rio was equivalent to at least one dormant cultivar in all three environments, while 'P5683' had lower stand survival than all dormant cultivars in H93 and C94 and all but one dormant cultivar in A94 (Table 14). Percent stand survival of semi-dormant cultivars (FD 5-6) were often not different than either dormant or non-dormant cultivars. The cultivars Mede, P581, and 'Express' were unique because they had lower stand survival than all dormant cultivars in two of the three environments.

Overall, stand survival results were similar to those for winter injury. The most non-dormant cultivars (FD 8-9) were very susceptible to stand losses over winter, while cultivars with fall dormancy ratings of five (semi-dormant) to seven (least dormant of non-dormant cultivars) sometimes had survival levels comparable to dormant cultivars. The lower stand survival of the non-dormant cultivars makes them useful as an annual rotation legume crop because it alleviates some of the problems normally associated with stand termination, including potential soil erosion due to intensive tillage, cost of stand termination, and competition in the following crop due to surviving alfalfa (Bullied et al. 1999).

Differences in stand survival were also apparent among cultivars within the same fall dormancy classification. In A94, all three cultivars of FD 6 had different levels of stand survival (Table 14). Sheaffer et al. (1992) also found differences in stand survival between cultivars of the same fall dormancy level, and pointed out that cultivars of the same fall dormancy could differ in many other characteristics, including: cold tolerance, disease resistance, and crown depth.

In summary, year two stand survival of cultivars with FD 5-7 can be comparable to that of dormant cultivars, but stand survival within a given dormancy rating is cultivar specific. Accurate stand survival predictions for semi-dormant cultivars cannot be made based on fall dormancy rating alone, but this research indicates that some cultivars of FD 5-7 may be useful as a two year legume crop for inclusion in rotations. Cultivars of FD 8-9 have potential for use as an annual legume crop in rotations.

These experiments employed both a rating of winter injury (a measure of plant health) and percent stand survival (percent of establishment year stand remaining in spring of year two) to evaluate cultivar persistence. Both ratings were used so that if two cultivars had the same percent stand survival, but dissimilar levels of plant health, these differences between cultivars would be reflected. However, in these experiments winter injury and percent stand survival were highly correlated (Table 16), indicating that there was no appreciable divergence of winter injury and stand survival characteristics. The same results might not be obtained for different cultivars, management systems, or environments.

Table 16. Correlation between winter injury and percent stand survival ratings of experiments managed for forage production over four environments from 1993-1994.

Environment	R value	
Homewood 1993	-0.98	**
Arborg 1993	-0.94	**
Arborg 1994	-0.91	**
Carman 1994	-0.93	**

** - Significance at $P \leq 0.01$.

1.4.3. Measurement of plant growth

Year two height measurements were not always comparable between environments due to differences in cutting dates, and dates of height measurement relative to cutting date. Height measurements were comparable for A94, C94 and H93 environments as follows: height in the first week of June prior to cutting, height in the first week of July at 23 (+/-5) days after cut one, height in the first week of August at 18 (+/- 4) days after cut two, and height in late fall at the last assessment date. Differences between cultivars were noted within each environment at all four comparable measurements (Tables 17-20).

In the first week of June, prior to the first forage cut, there was very little difference in height among cultivars of FD 1-7, but these cultivars were generally taller than the cultivars of FD 8-9 (Table 17). There was considerable overlap in height between the dormant and semi-dormant cultivars at C94 and H93, but with two exceptions there was no overlap at A94. Although non-dormant cultivars are generally expected to exhibit faster spring regrowth than dormant cultivars (Gjuric 1995; Massengale et al. 1971), these results were not unexpected due to the greater winter injury sustained by the non-dormant cultivars (Table 12). Increased winter injury in the non-dormant cultivars in these environments likely retarded the normal response of these cultivars to photoperiod and temperature. This interpretation is supported by the fact that in the environment with the least winter injury, C94, the height differences between the dormant and semi-dormant cultivars were less than in A94, which experienced greater winter injury.

By 23 (+/- 5) days after cut one, cultivar ranking was reversed and the non-dormant cultivars were taller than the dormant cultivars with FD 1-2 at Arborg and Carman (Table 18). At 18 (+/- 4) days after cut two, cultivar effect on plant height had increased, and the height of the non-dormant cultivars was greater than all of the dormant cultivars in C94 and H93, with two exceptions in C94 (Table 19). Although not significant, height of the semi-dormant cultivars was numerically greater than that of the dormant cultivars with the exception of two dormant cultivars at each site. Differences in plant height between non-dormant and dormant cultivars were not as great at A94 due to dry conditions in June and July that reduced growth of all cultivars during midsummer (Table 6). These results show that once the plants have recovered from winter injury, less dormant cultivars are capable of more rapid regrowth following cutting.

At the last measurement date in late fall, the height of all semi-dormant cultivars was greater than that of the dormant cultivars at Carman and Homewood, with the exception of the cultivars 'Cimmaron VR' and 'Key' (both FD 4). At Arborg growth had progressed enough that the non-dormant cultivars were taller than the dormant cultivars at the last measurement date, with the exception of Key (Table 20). The greater late fall height of the cultivars entered as semi- and non-dormant is an indication that they were truly less dormant. However, these heights do not truly reflect fall dormancy ratings, since stem length was measured instead of canopy height, and the proper management regime for a fall dormancy test (McCaslin and Woodward 1995) was not followed.

Plant growth in the spring of year two indicated that sufficient winter injury occurred in most of the semi- and non-dormant cultivars to offset any early season growth advantage that might have been expected over the traditionally-grown dormant cultivars. By the time cut one was harvested, the semi- and non-dormant cultivars had recovered from winter injury and regrew more quickly following harvest than the dormant cultivars. As the season progressed these cultivars responded to photoperiod and temperature as expected, and the differences in FD between cultivars, as measured by plant height in the fall, became more apparent.

Table 17. Plant height (cm) of 24 alfalfa cultivars in the first week of June prior to cutting in year two at three environments in western Canada.

		Environment					
Cultivar	FD[z]	A94 (9 June)[y]		C94 (2 June)		H93 (1 June)	
Rangelander	1	38.0	a-d[x]	51.0	hi	44.5	abc
Beaver	2	38.0	a-d	52.7	gh	49.8	a
Vernal	2	39.8	a	57.6	a-d	49.3	a
Algonquin	2	39.8	a	55.5	c-f	48.0	a
Arrow	3	38.5	abc	59.3	ab	47.8	a
Multiking	3	38.8	abc	57.4	a-e	48.5	a
Excalibur	4	39.5	a	59.9	a	47.8	a
Saranac	4	39.0	ab	57.3	a-e	49.5	a
Cimmaron VR	4[w]	37.0	b-e	57.0	a-e	49.0	a
Key	4[w]	36.0	de	58.4	abc	48.3	a
Mede	5	31.3	fgh	56.2	c-f	47.8	a
Archer	5	36.0	de	58.4	abc	48.8	a
Belmont	5	35.5	e	58.3	a-d	49.0	a
ABI 700	6	33.0	f	56.8	b-e	43.8	abc
P581	6	29.0	hi	53.3	fgh	38.0	cd
Express	6	32.8	fg	54.9	d-g	47.0	ab
P5683	7	35.8	de	50.7	hi	43.3	abc
Valley +	7	36.5	cde	54.4	efg	44.0	abc
Rio	7	36.5	cde	56.0	c-f	45.8	ab
Moapa 69	8	28.3	i	45.0	k	44.8	ab
Nitro	8	30.5	ghi	44.5	k	38.0	cd
GT13R	8	32.0	fg	49.2	ij	41.0	bcd
CUF 101	9	29.3	hi	41.2	l	35.3	d
P5929	9	29.0	hi	45.4	jk	36.3	d

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; H93, Homewood 1993.
x - Cultivar means followed by the same letter are not significantly different at P≤0.05, Fisher's protected LSD.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Table 18. Plant height (cm) of 24 alfalfa cultivars in the first week of July in year two at 23 (+/- 5) days after cut one at three environments in western Canada.

Cultivar	FD[z]	A94 (7 July)[y]		C94 (10 July)		H93 (7 July)	
		Environment					
Rangelander	1	12.8	l[x]	47.3	j	38.5	f
Beaver	2	15.8	jkl	50.9	I	45.0	e
Vernal	2	15.8	jkl	53.0	hi	45.0	e
Algonquin	2	14.8	kl	51.0	i	48.3	cde
Arrow	3	18.5	f-j	57.3	efg	48.3	cde
Multiking	3	17.3	ijk	57.8	efg	51.3	abcd
Excalibur	4	17.5	h-k	56.0	gh	51.5	abcd
Saranac	4	19.3	f-j	57.3	efg	52.5	ab
Cimmaron VR	4[w]	19.5	f-i	56.3	gh	51.3	abcd
Key	4[w]	18.3	g-j	60.2	c-f	52.5	ab
Mede	5	24.8	d	60.6	b-e	48.8	bcde
Archer	5	18.5	f-j	57.1	fg	52.3	abcd
Belmont	5	17.8	hij	61.3	a-d	51.3	abcd
ABI 700	6	21.3	efg	56.9	fg	52.5	ab
P581	6	23.5	de	57.5	efg	44.8	e
Express	6	23.8	de	59.3	d-g	51.8	abcd
P5683	7	21.5	def	63.1	abc	51.8	abcd
Valley +	7	19.5	f-i	62.0	a-d	53.0	a
Rio	7	20.8	e-h	64.6	a	54.5	a
Moapa 69	8	32.3	ab	61.0	bcd	48.0	de
Nitro	8	29.0	bc	59.1	d-g	51.8	abcd
GT13R	8	28.5	c	60.1	c-f	50.5	abcd
CUF 101	9	32.8	a	59.1	d-g	50.8	abcd
P5929	9	31.3	abc	63.9	ab	50.8	abcd

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; H93, Homewood 1993.
x - Cultivar means followed by the same letter are not significantly different at P≤0.05, Fisher's protected LSD.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Table 19. Plant height (cm) of 24 alfalfa cultivars in the first week of August at18 (+/- 4) days after cut two in year two at three environments in western Canada.

		Environment					
Cultivar	FD[z]	A94 (3 August)[y]		C94 (7 August)		H93 (5 August)	
Rangelander	1	11.3	i[x]	32.6	l	21.5	l
Beaver	2	13.5	f-i	34.5	kl	29.0	k
Vernal	2	13.5	f-i	39.2	ijk	30.5	k
Algonquin	2	12.8	hi	38.6	jk	30.0	k
Arrow	3	13.8	fgh	43.0	g-j	35.5	ij
Multiking	3	14.0	e-h	45.9	e-h	36.0	ij
Excalibur	4	14.3	d-h	41.0	hij	36.0	ghi
Saranac	4	13.8	fgh	43.4	g-j	37.3	ghi
Cimmaron VR	4[w]	14.5	d-h	42.9	g-j	34.8	j
Key	4[w]	13.3	ghi	49.0	def	37.0	ghi
Mede	5	18.0	c	48.9	def	39.0	efg
Archer	5	14.8	d-h	45.3	f-i	39.5	ef
Belmont	5	15.3	d-g	45.3	f-i	36.8	hij
ABI 700	6	16.5	cd	48.1	d-g	39.5	ef
P581	6	18.0	c	47.4	efg	38.5	fgh
Express	6	18.0	c	50.2	c-f	40.3	def
P5683	7	17.8	c	55.8	ab	40.0	def
Valley +	7	15.8	c-f	51.3	b-e	40.8	cde
Rio	7	16.3	cde	55.3	abc	41.8	bcd
Moapa 69	8	26.0	a	57.0	a	43.8	ab
Nitro	8	26.3	a	55.3	abc	42.5	abc
GT13R	8	21.8	b	55.6	abc	43.5	ab
CUF 101	9	27.3	a	53.2	a-d	44.3	a
P5929	9	27.5	a	56.1	ab	42.8	abc

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; H93, Homewood 1993.
x - Cultivar means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Table 20. Plant height (cm) of 24 alfalfa cultivars at the late fall measurement date in year two at three environments in western Canada.

		Environment					
Cultivar	FD[z]	A94 (21 October)[y]		C94 (20 September)		H93 (27 October)	
Rangelander	1	10.8	m[x]	25.8	k	25.0	k
Beaver	2	13.5	klm	30.4	j	30.8	j
Vernal	2	13.8	jkl	37.7	i	37.5	i
Algonquin	2	13.3	lm	37.2	i	40.5	hi
Arrow	3	15.3	ijk	41.8	h	43.8	gh
Multiking	3	16.3	h-k	43.9	gh	43.5	gh
Excalibur	4	16.8	ghi	43.3	h	47.3	f
Saranac	4	14.8	i-l	41.5	h	45.0	fg
Cimmaron VR	4[w]	16.5	g-j	47.6	ef	50.8	e
Key	4[w]	18.3	e-h	46.6	fg	52.3	de
Mede	5	21.8	cd	50.1	b-e	53.0	de
Archer	5	19.3	d-g	47.3	ef	52.8	de
Belmont	5	17.3	f-i	47.3	ef	53.8	de
ABI 700	6	19.3	d-g	48.0	def	55.5	cd
P581	6	21.5	cd	49.8	cde	52.5	de
Express	6	22.3	c	51.1	a-d	58.0	bc
P5683	7	20.5	cde	49.8	c-f	55.0	cd
Valley +	7	19.8	c-f	50.9	bcd	59.0	ab
Rio	7	22.3	c	53.1	ab	60.8	ab
Moapa 69	8	26.0	b	51.3	abc	57.5	bc
Nitro	8	28.5	ab	51.9	abc	59.5	ab
GT13R	8	25.8	b	49.8	c-f	55.0	cd
CUF 101	9	28.3	ab	54.1	a	60.8	ab
P5929	9	29.3	a	52.8	abc	61.5	a

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; H93, Homewood 1993.
x - Cultivar means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

1.4.4. Assessment of forage yield in year two

Due to the complete lack of winter survival of cultivars in A93, there were only five environments in which to compare forage yield in year two. In environments A94, M93 and M94, a two cut system was utilized. At the two more southernly sites, H93 and C94, a three cut system was more suitable. A fourth harvest after the first fall frost was also taken, but yields were not of economic value (<200 kg ha^{-1}), therefore they were not included in these results.

In the three northern environments, A94, M93 and M94, mean trial yields were 3241, 3783 and 5430 kg ha^{-1} under a two cut system, respectively. In the two more southern environments, C94 and H93, mean trial yields were 9348 and 9028 kg ha^{-1} using a three cut system, respectively (Table 21).

Table 21. Analysis of variance for year two forage yield of 24 alfalfa cultivars grown in five environments.

Environment		Trial Mean	Source	d.f.	MS	F value	
Arborg (2 cuts)	1994	3241 kg ha^{-1}	Rep	3	286 016	0.94	NS
			Cultivar	23	5 894 878	19.38	***
Melfort (2 cuts)	1993	3783 kg ha^{-1}	Rep	3	1 549 180	1.92	NS
			Cultivar	23	7 259 922	8.99	***
Melfort (2 cuts)	1994	5430 kg ha^{-1}	Rep	3	9 613 729	10.29	***
			Cultivar	23	9 150 968	9.79	***
Carman (3 cuts)	1994	9384 kg ha^{-1}	Rep	3	3 089 585	3.18	*
			Cultivar	23	4 090 188	4.21	***
Homewood 1993 (3 cuts)		9028 kg ha^{-1}	Rep	3	1 145 427	0.78	NS
			Cultivar	23	6 822 918	4.67	***

*, *** - Significance at P≤0.05, 0.001.

The large difference in mean trial yield between the northern and southern environments was probably attributable to differences between environments, primarily moisture. Carman (which is also the most representative data for Homewood) received 134% and 129% of normal May to October precipitation in 1994 and 1995. In contrast, Arborg and Melfort received less than normal precipitation (Table 6). A large part of the difference in mean trial yield was due to the additional yield of the third cut in H93 and C94, however the yield of the first two cuts at C94 (7185 kg ha^{-1}) and H93 (5960 kg ha^{-1}) was still higher than the two cut yield at the other three sites.

In the environments where only two harvests were possible (A94, M93 and M94), the highest yields were obtained by cultivars in the fall dormancy range of one to four (Table 22). The higher yield of the dormant cultivars under a two harvest system reflects the earlier plant development of the dormant cultivars in spring (Table 17) due to higher levels of winter injury sustained by the less dormant cultivars (Table 12).

In the environments where three harvests were possible (C94 and H93), some cultivars of FD 5-7 yielded as well as the dormant cultivars. The difference in cultivar ranking between the two and three harvest systems indicates that at the time of the third harvest, the less dormant cultivars had produced more regrowth than the dormant cultivars. This indicated that the dormant varieties were experiencing a reduction in plant growth in response to shorter day length and cooler temperatures (Brown et al. 1990), and was also reflected in the plant height measurements in the first week of August (Table 19). Several cultivars with FD five and all cultivars with FD seven yielded as well as cultivars with fall dormancy ratings of one to four in the three harvest environments.

Although the cultivars rated as fall dormancy eight and nine exhibited more growth in the late fall, as determined by plant height measurement (Tables 19 and 20), the greater fall growth did not compensate for reductions in percent stand survival (Table 14) and these cultivars had the lowest yield in all environments, under either a two or three harvest system (Table 22).

Table 22. Forage yield (kg ha^{-1}) of 24 alfalfa cultivars in year two over five environments in western Canada from 1993-1995.

		Environment									
Cultivar	FD^z	A94^y		C94		M93		M94		H93	
Rangelander	1	4054	bcd^x	9714	a-e	5838	a	5840	cde	7959	fgh
Beaver	2	4494	abc	9063	efg	5754	a	6962	abc	9741	a-d
Vernal	2	4647	ab	9989	a-e	4839	abc	6216	bcd	9506	a-e
Algonquin	2	4617	ab	9099	d-g	5745	a	6282	bcd	9712	a-d
Arrow	3	4048	bcd	10 884	a	4785	abc	7229	ab	9167	b-f
Multiking	3	4691	a	9879	a-e	4912	ab	7254	ab	8697	c-f
Excalibur	4	4427	abc	9436	c-e	5111	ab	7695	a	10 413	ab
Saranac	4	4956	a	9793	a-e	5118	ab	6834	abc	10 556	ab
Cimmaron VR	4^w	3522	def	9527	b-e	4482	bc	5994	cd	10 667	a
Key	4^w	3963	cde	10 228	a-d	4214	bcd	6631	a-d	9796	a-d
Mede	5	3081	fgh	9586	b-e	4295	bcd	6059	cd	10 226	ab
Archer	5	3473	d-g	10 545	abc	4452	bc	6327	bcd	9434	a-e
Belmont	5	2835	ghi	9864	a-e	3827	cde	6403	bcd	10 555	ab
ABI 700	6	3080	fgh	9283	def	3132	efg	5536	de	8419	d-g
P581	6	1447	j	9537	b-e	3270	def	4077	fg	6543	hi
Express	6	2658	hi	9230	def	2982	e-h	5578	de	8930	c-f
P5683	7	3355	efg	9875	a-e	2091	ghi	3969	fg	9538	a-e
Valley +	7	3232	fgh	10 657	ab	3016	efg	4730	ef	10 111	abc
Rio	7	3639	def	10 558	abc	2722	f-i	4816	ef	10 045	abc
Moapa 69	8	1045	j	7748	h	1685	i	2822	h	7084	ghi
Nitro	8	1499	j	7946	gh	1885	i	3278	gh	8200	efg
GT13R	8	2411	i	8155	fgh	2419	f-i	4013	fg	7858	f-i
CUF 101	9	1538	j	7577	h	1936	hi	2969	gh	7053	ghi
P5929	9	1085	j	7109	h	2273	f-i	2817	h	6471	i

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; M93, Melfort 1993; M94, Melfort 1994; H93, Homewood 1993.
x - Cultivar means followed by the same letter are not significantly different at P≤0.05, Fisher's protected LSD.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

1.5. SUMMARY

The number of forage harvests in the establishment year was limited to one due to the speed of establishment and relative length of the growing season in these environments. Under this management system semi- and non-dormant alfalfa cultivars provided no establishment year yield advantage over dormant cultivars, but did produce single-cut yields comparable to the dormant cultivars. These cultivars may be advantageous in these environments as single season stands because of their increased late season regrowth following cutting, and the corresponding potential for fall nitrogen fixation. Additionally, the potential for increased winter injury and reduced stand survival of semi- and non-dormant cultivars could alleviate some of the stand termination problems normally associated with alfalfa.

Cultivars with fall dormancy levels of eight and nine had significantly higher winter injury and lower stand survival than cultivars with fall dormancy levels of one to four. Semi-dormant cultivars (FD 5-6) also showed greater winter injury and stand reduction than dormant cultivars in some environments. Increased winter injury for less dormant cultivars delayed the resumption of spring growth prior to the first cut in year two. Cultivars with less dormancy exhibited faster regrowth after the first cut and greater fall growth than more dormant cultivars. In the more northern environments where the number of cuts in year two was limited to two, the slow resumption of spring growth and the lack of a third cut meant that year two yield of cultivars with a fall dormancy greater than four was generally diminished. In the southern environments a third cut was possible, and many cultivars with fall dormancy levels of five to seven yielded as well or better in year two than some of the more dormant cultivars.

For cultivars with fall dormancy of eight and nine, winter injury and stand reduction offset the additional growth harvested by the third cut, and these cultivars produced significantly lower forage yields in year two than all others tested.

In conclusion, semi- and non-dormant cultivars did not produce higher forage yields than dormant cultivars in either the establishment year or year two. Non-dormant alfalfa cultivars are only suitable for single season forage stands in Manitoba and Saskatchewan due to risk of winterkill, but semi-dormant cultivars provide a useful option for short term stands in areas of this region that receive adequate snow cover.

MANUSCRIPT #2

Alfalfa (*Medicago sativa* L.) Winter Survival under Seed vs. Forage Management and Relationship to Root Carbohydrate Levels

2.1 ABSTRACT

Alfalfa producers generally agree that alfalfa (*Medicago sativa* L.) grown for seed production exhibits better winter survival than the same cultivar grown for forage production, but little research has been conducted to quantify survival differences or the factors responsible under these two management systems. Traditionally, alfalfa seed production in western Canada has been limited to the fall dormant cultivars recommended for forage production. Although the worldwide market for semi- and non-dormant cultivars has been increasing, concerns over the winter survival of these cultivars have prevented Canadian producers from taking advantage of this market opportunity. The objectives of this research were to compare the survival of cultivars under a seed production system and a forage production system, to determine the relationship between winter survival and root carbohydrate and nitrogen level, and to evaluate the seed production potential of cultivars with less fall dormancy than those traditionally grown in western Canada. Twenty four cultivars of alfalfa, ranging from highly fall dormant (rating of 1) to non-dormant (rating of 9), were managed for both seed and forage production at several locations in Manitoba and Saskatchewan from 1993 to 1995, and evaluated for winter injury and stand survival each spring. Root soluble sugar, starch, total non-structural carbohydrate, nitrogen, and total root biomass were measured in fall of the establishment year and the following spring. Seed yield was measured in year two. Stand survival of semi- and non-dormant cultivars was much

better under management for seed production than for forage production, especially following severe winter conditions. Relative winter survival between cultivars was consistent across management systems. Fall root content of soluble sugars, starch and total nonstructural carbohydrate (TNC) did not relate consistently to stand survival the following spring. Spring soluble sugar content of roots was more reflective of stand survival and winter injury than any other carbohydrate fraction measured. Many of the cultivars in the five to seven fall dormancy range had year two seed yields equivalent to those of dormant cultivars, and can be successfully grown for seed production in western Canada.

2.2 INTRODUCTION

Alfalfa producers generally agree that alfalfa (*Medicago sativa* L.) grown for seed production exhibits better winter survival than the same cultivar grown for forage production, but little research has been conducted to quantify survival differences or to determine the factors responsible for differential survival under these two management systems. As the alfalfa seed industry continues to grow in western Canada, potential cultivar differences and the reasons for these differences are becoming increasingly important.

Traditionally, the majority of the alfalfa seed produced in western Canada has been for hay and pasture stands in Canada and the north-central USA. Consequently, the majority of the cultivars planted for seed production have been classified as fall dormant with good winter survival characteristics. Many of the new cultivars being developed by companies in the USA are semi- and non-dormant, and seed sales for these cultivars are increasing worldwide.

Fall dormancy (FD) of alfalfa cultivars is defined by the height of growth produced in the fall, using a 1 (least fall growth) to 9 (most fall growth) rating scale described in the Standard Tests to Characterize Alfalfa Cultivars (Barnes et al. 1995). Cultivars with fall dormancy ratings of one to four are usually referred to as dormant, five and six as semi-dormant, and seven to nine as non-dormant, based on accepted divisions (unpublished) among North American alfalfa breeders (S. R. Smith, Jr., pers. comm.). Fall dormancy has been shown to be positively correlated with winter survival (Sheaffer 1992; Smith 1961; Heinrichs et al. 1960; Schwab et al. 1994). This correlation has resulted in the adoption of the fall dormancy rating system as an accepted indicator of winter survival potential in alfalfa, and has contributed to the perception that cultivars of reduced fall dormancy cannot be grown for seed production in western Canada.

Less fall dormancy in many of the new cultivars being released, and the size of the seed market for these alfalfa cultivars, has created interest in western Canada in producing seed of semi- and non-dormant cultivars. Recent studies at the University of Manitoba (Smith 1995; Gjuric 1995) have shown that establishment year alfalfa seed yields are often not economically viable due to the short season and lack of growing degree day accumulation. For western Canadian seed producers to gain access to the large market for semi- and non-dormant alfalfa seed, these cultivars must overwinter and produce seed in at least one subsequent season. Therefore, it is becoming increasingly important to know the winter-survival potential for semi- and non-dormant cultivars when managed for seed production in western Canada. Anecdotal reports have indicated that assessments of stand survival and winter injury under a forage management system may not accurately represent the potential for seed production.

Previous research on the effect of harvest schedule and frequency has suggested that alfalfa stand survival may be greater under seed management due to the cutting schedule employed. Researchers have confirmed that in many environments the length of the interval prior to the last harvest has as much or more effect on winter survival than the date of the final harvest (Sheaffer et al. 1986; Edmisten et al. 1988; Brink and Marten 1989), especially under high snowfall conditions and in short-term stands (Sheaffer et al. 1986). Harvesting alfalfa stands managed for seed production only once in the fall has been shown to be advantageous to stand survival (McKenzie and McLean 1980). Sheaffer et al. (1992) have specifically shown that for less winter hardy cultivars, the lowest cutting frequency produces the least amount of winter injury.

The relationship between cutting frequency and winter survival is probably due to differences in accumulation of stored carbohydrates and nitrogen in the roots. Many researchers have associated winter survival and cold tolerance with high fall levels of stored root carbohydrates (Chatterton et al. 1977; Brummer and Bouton 1992; Edmisten and Wolf 1988) and stored nitrogen (Graber et al. 1927; Bula and Smith 1954; Duke and Doehlert 1981).

The level of stored root carbohydrates in the fall decreases as the number of harvests per year increases (Kust and Smith 1961; Reynolds 1971), and root nitrogen and protein content follow similar patterns of accumulation and depletion (Li et al. 1996; Avice et al. 1997).

The relationship between harvest interval, carbohydrate and nitrogen accumulation, and winter injury and survival suggest that differences in alfalfa cultivar survival might be expected between forage and seed production systems.

The objectives of this research were:

1) To compare the survival of cultivars under a seed production system and a forage production system,

2) to determine the relationship between winter survival and root carbohydrate and nitrogen level, and

3) to evaluate the seed production potential of cultivars with less fall dormancy than those traditionally grown in western Canada.

2.3 MATERIALS AND METHODS

2.3.1 Experimental design

Experiments were established at three locations in 1993 (Arborg, MB, 97°W & 51°N; Homewood, MB, 98°W & 49.5°N; and Melfort, SK, 104.5°W & 53°N) and at two locations in 1994 (Arborg, MB, and Melfort, SK). Environments were defined by the combination of location and planting year.

The soil types at each location were as follows: Homewood, Sperling mixed loam; Carman, Hochfeld series loamy sand; Arborg, Tano series clay (Peat meadow); and Melfort, Melfort series silty clay. Sites were fertilized to soil test recommendations with phosphorous, potassium and sulfur prior to seeding, and all cultivars were scarified and inoculated with *Rhizobium meliloti* L. Dang prior to seeding.

Within each environment, 24 alfalfa cultivars ranging from dormant to non-dormant were planted under two management systems (Table 23). Each management system was designed as a partially randomized complete block with four replicates. Entries within each replicate were grouped as dormant (FD 1-4), semi-dormant (FD 5-6), and non-dormant (FD 7-9). Fall dormancy groupings were not randomized between replicates in order to minimize potential differences in inter-plot competition that were expected to result from differential winter survival between dormant and non-dormant cultivars. Cultivars within each grouping were completely randomized. One system was managed for forage production and the other was managed for seed production.

Table 23. Alfalfa cultivars included in winter survival experiments over five environments in western Canada from 1993 to 1995.

Cultivar	FD[z]	Cultivar	FD	Cultivar	FD
Rangelander	1	CimmaronVR	4[y]	P5683	7
Beaver	2	Key	4[x]	Valley +	7
Vernal	2	Mede	5	Rio	7
Algonquin	2	Archer	5	Moapa 69	8
Arrow	3	Belmont	5	Nitro	8
Multiking	3	ABI 700	6	GT13R	8
Excalibur	4	P581	6	CUF 101	9
Saranac	4	Express	6	P5929	9

z - FD, fall dormancy rating: 1 = nondormant, 9 = dormant
y - Initially entered in trials as fall dormancy 5.
x - Initially entered in trials as fall dormancy 6.

Plot size for the forage trials was 6.8 m x 1.8 m at Arborg and Homewood, and 6.8 m x 1.2 m at Melfort, with a seeding rate of 12 kg ha^{-1}. The forage trial established in 1994 at Arborg was planted at a 15 cm row spacing and all other forage trials were planted at a 30 cm row spacing (Table 24).

In the trials managed for seed production, plot size was one 12 m row, planted at a row spacing of 0.60 m (Table 24). To minimize potential inter-plot competition effects, a single row of the dormant alfalfa cultivar 'Algonquin' (FD 2) was planted between all test cultivar rows. The seeding rate for the seed production trials was 2 kg ha^{-1}. This seeding rate was higher than production seeding rates (ie. 0.5-1.0 kg ha^{-1}), and was used as part of the management package to enhance the possibility of harvesting seed in the establishment year from cultivars that were expected to exhibit poor winter survival.

Table 24. Alfalfa winter survival experiments conducted at three locations in western Canada from 1993-1995.

Environment			Trials		
Location	Planting year	Planting date	Management	Code	Row spacing (cm)
Homewood, MB	1993	13 May	seed	H93S	60
			forage	H93F	30
Arborg, MB	1993	14 May	seed	A93S	60
			forage	A93F	30
Arborg, MB	1994	16 May	seed	A94S	60
			forage	A94F	15
Melfort, SK	1993	21 May	seed	M93S	60
			forage	M93S	30
Melfort, SK	1994	24 May	seed	M94S	60
			forage	M94F	30

2.3.2 Establishment year management

In the year of establishment, forage trials were harvested once for biomass yield when the average percent bloom across all 24 cultivars was 10 percent. Subsequent regrowth was insufficient for a second forage cut. At Arborg and Homewood, regrowth was cut and removed after frost and prior to snowfall (Table 25). All seed trials except Melfort 1993 were pollinated with approximately 88 000 Leafcutter bees (*Megachile rotundata* L.) per hectare, distributed through several small shelters within and around each trial. This stocking density was almost twice the recommended rate of 50 000 bees ha^{-1} (Richards, 1989) so that number of pollinators would not be a limiting factor in establishment year seed yield. Seed trials were not cut during the establishment year prior to the cessation of growth in the fall. Arborg and Homewood trials were desiccated (Table 26) in late September (Table 25), and plant material was removed prior to snowfall, either through harvest for seed yield determination or by mowing the plots. Trials established in Melfort did not have plant material removed prior to winter in the establishment year (Table 25).

Table 25. Establishment year cutting schedule of alfalfa trials managed for forage and seed production and evaluated for winter survival over five environments in western Canada from 1993-1995.

Environment		Trials		Date of Event		
Location	Planting year	Management	Code	Cut for Forage	Desiccated	Cut for Seed/Fall Removal
Homewood, MB	1993	seed	H93S	n/a	24 Sept.	5 Oct.
		forage	H93F	mid Aug. [z]	n/a	5 Oct.
Arborg, MB	1993	seed	A93S	n/a	25 Sept.	4 Oct.
		forage	A93F	mid Aug. [z]	n/a	4 Oct.
Arborg, MB	1994	seed	A94S	n/a	19 Sept.	4 Nov.
		forage	A94F	26 Aug.	n/a	4 Nov.
Melfort, SK	1993	seed	M93S	n/a	not [y]	not [y]
		forage	M93S	24 Aug.	n/a	not [x]
Melfort, SK	1994	seed	M94S	n/a	not [y]	not [y]
		forage	M94F	17 Aug.	n/a	not [x]

z - Exact cutting date not recorded.
y - Seed trials established Melfort were neither desiccated nor cleaned off prior to snowfall.
x - Regrowth on forage trials established in Melfort was not cleaned off after first cut and prior to snowfall.

Weed control was performed using combinations of preplant and postemergent broadcast herbicide applications at recommended rates (Table 26) and hand weeding. Insects were controlled in the seed trials with applications of insecticide made in the evening or early morning while the pollinators were at rest.

Table 26. Pesticides used for weed and insect control in alfalfa trials managed for forage and seed production in four environments in western Canada from 1993-1995.

Pesticide	Trade Name	Common Name	Chemical Name
Pre-emergent herbicide	Treflan EC	trifluralin	∝,∝,∝-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine
Post-emergent herbicides	Pursuit	imazethapyr	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridine carboxylic acid
	Pardner	bromoxynil	3,5-dibromo-4-hydrobenzonitrile
	Embutox 625	2,4-DB	4-(2,4-dichlorophenoxy)butyric acid
	Poast	sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one
Insecticides ^{z}	Cygon	dimethoate	O,O-dimethyl S-[2-(methylamino)-2-oxoethyl] phosphorodithioate
	Malathion	malathion	O,O-dimethyl phosphorodithioate of diethyl mercaptosuccinate
	Dylox	trichlorfon	dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate
Desiccants ^{z}	Reglone	diquat	6,7-dihydrodipyrido(1,2-∝:2', 1'c) pyrazidinium
	Harvest	glufosinate	(±)2-amino-4-(hydroxymethylphosphinyl) butanoic acid

z - applied only to seed trials

2.3.3 Assessment of cultivar persistence

Cultivar persistence under each management system was evaluated in spring of year two using visual assessments of stand survival (percent stand) and winter injury. Percent stand survival reflected the percentage of the establishment year stand remaining as live plants each spring. Winter injury ratings indicated the health of the live plants remaining in the plot and were made using the NAAIC (North American Alfalfa Improvement Conference) rating scale (McCaslin and Woodward 1995) as shown in Table 27. Ratings were conducted by pairs of researchers in order to reduce the possible subjectivity or bias of a single evaluator. Within plot variation in winter injury was taken into account and a mean value was assigned for each plot. Assessments of cultivar persistence were made after all cultivars had broken dormancy and commenced growth. Dates of assessment were: A93, 31 May 1994; A94, 24 May 1995; H93, 13 May 1994; C94, 18 May 1995; M93, 12 May 1994; and M94, 24 May 1995.

Table 27. Scale used for rating winter injury of 24 alfalfa cultivars evaluated under both forage and seed management at four environments in western Canada.

Rating	Characteristics
1 - No injury	Plant has uniform, symmetrical appearance, all shoots are about equal in length.
2 - Some injury	The plant is symmetrical, but regrowth is slightly uneven.
3 - Significant injury	Regrowth varies in length, reduced vigour.
4 - Severe injury	Plant has sparse shoots, regrowth is very irregular, poor vigour.
5 - Dead plant	

2.3.4 Determination of seed yield

Seed trials at Homewood (1993) and Arborg (1993 and 1994) were pollinated in the establishment year in an attempt to harvest seed from the cultivars which were not expected to survive the first winter, but seed set was low in these environments and no establishment-year seed harvest was taken. Melfort trials (1993 and 1994) were not pollinated in the establishment year, and an establishment-year seed harvest was not possible. In each environment, cultivars in the seed trials which survived the first winter were pollinated again in year two and the seed yield determined. Prior to seed harvest in year two, seed trials at Melfort were desiccated with Reglone, and seed trials at Homewood and Arborg were desiccated with Harvest (Table 28). Plots were harvested with plot combines, a Wintersteiger Nurserymaster Elite (Wintersteiger, Salt Lake City, UT) at Melfort, and a Hege model 125B (Hege Maschinen, Waldenburg, Germany) at all other sites. Harvested material was bagged and hung to air dry at ambient temperature. The harvested material was then rethreshed using a cyclone-type thresher at Melfort and a stationary belt thresher (Agriculex, Scarborough, Ont.) for all other trials, to complete threshing of the seed pods. Seed was cleaned with a Clipper Office Tester (Clipper Separation Technologies, Bluffton, IN) prior to weighing.

Table 28. Management of alfalfa seed trials in year two in five environments across western Canada from 1994 to 1995.

Environment			Date of Event		
Location	Planting year	Code	Pollinators placed in trial [z]	Desiccated	Seed harvest
Homewood, MB	1993	H93S	21 June 1994	18 Sept. 1994	28-29 Sept. 1994
Arborg, MB	1993	A93S	21 July 1994	19 Sept. 1994	5 Oct. 1994
Arborg, MB	1994	A94S	7 July 1995	31 Aug. 1995	12 Sept. 1995
Melfort, SK	1993	M93S	30 June 1994 [y]	28 Sept. 1994	not recorded
Melfort, SK	1994	M94S	30 June 1995 [y]	26 Sept. 1995	10 Oct. 1995

z - Pollinators used were Leafcutter bees (*Megachile rotundata* L.); at least 88,000 bees ha^{-1} to ensure pollinators were not limiting.
y - Date is approximate.

2.3.5 Determination of root nitrogen, starch and sugar levels

2.3.5.1 Collection of root samples

Plant root samples were excavated from each plot in the fall of the establishment year and the following spring for analysis of root carbohydrate levels. Each sample consisted of at least 15 plants per plot. Samples were obtained in the fall after temperatures had declined such that further growth was not anticipated, and in the spring prior to the occurrence of new growth (Table 30). Since spring sampling occurred prior to growth, samples included roots from both live and dead plants. In most samples there were very few dead roots and the majority of the analyzed sample was derived from live plants. However, due to the almost complete winterkill in A93 trials, samples from cultivars with low survival contained a higher proportion of dead roots. Plant samples were maintained at 0-10°C following excavation and frozen as soon as possible (generally within a few hours). Frozen plant samples were removed from storage, washed by hand, and trimmed to include the crown and 15 cm of root below the crown. The entire trimmed sample from each plot was immediately dried at 65°C for at least 48 hours, and then ground with a Wiley mill through a 1-mm sieve.

2.3.5.2 Analysis of percent nitrogen in root samples

Root samples from two environments, A93 and H93, were analyzed for percent nitrogen in both the fall of the establishment year and the following spring. Samples from a third environment, M93, were analyzed for percent nitrogen in fall of the establishment year only. Subsamples of ground root tissue from each of the 24 cultivars in each trial were re-dried and then analyzed by the combustion (Dumas) method, using a Leco N Determinator (Model FP-428, Mississauga, Ontario).

2.3.5.3 Extraction and analysis of sugars in calibration set

Fifty ground root samples, anticipated to represent a range of low to high starch and sugar concentrations, were selected for wet lab extraction and analysis for a near infrared reflectance spectroscopy (NIRS) calibration set. Sugars were extracted from dried 50 mg samples (run in duplicate) of ground root tissue by adding one millitre of 800 ml L^{-1} ethanol and then mixing the suspension for 15 seconds, allowing the fibrous material to precipitate, and repeating the mixing and precipitation two more times. The extracted mixture was centrifuged at 14,000 RPM for 10 minutes and the supernatant removed. This process was repeated for the same 50 mg of sample another two times, and the combined supernatant containing mono- and di-saccharides was stored at 4°C in a sealed container for later analysis.

A 100 μL aliquot of the ethanol extracted solution was then removed and diluted with 800 mL L^{-1} ethanol to a total volume of 0.5 mL and 3.5 mL of anthrone solution (product A-1631, Sigma Chemical Company, St. Louis, MO) was added. This mixture was incubated in a boiling water bath for eight minutes, cooled in a cool-water bath and the absorbance of each sample was measured at 625 nm. The absorbance of each sample was compared to a standard curve of known standards (average r^2 of 0.98) in order to calculate the sugar concentration of each duplicate and the mean concentration of the duplicates calculated as the glucose concentration of the root sample. Glucose concentration was multiplied by 0.9 to obtain the correct concentration of polysaccharides (Koehler 1952).

2.3.5.4 Hydrolysis and analysis of starch content in calibration set

Ethanol in the residue remaining after the extraction of soluble sugars was evaporated off overnight, 500 μL of RO-water was added to each tube, and the tubes were sealed and placed in a hot block at 100°C for ten minutes. After cooling, 400 μL of 200 mM acetate buffer (pH 5.0) and 100 μL of enzyme solution (equal to one unit amyloglucosidase (Sigma product A3514) and 40 units alpha-amylase (Sigma product A2643)) were added, and tubes were sealed, vortexed, and incubated at 55°C for 24 hours. Tubes were vortexed several times during incubation. Following incubation tubes were centrifuged at 14,000 RPM for five minutes, and stored at 4°C until analysis.

Duplicate samples from each tube (each tube was already a duplicate from a single root sample) of 50 μL were diluted 1:20 with RO-water. An aliquot of 50 μL of this dilution was further diluted 1:20 with RO-water, combined with one millilitre of Glucose [TRINDER] Reagent, vortexed, and incubated at 37°C for one hour in a water bath. Absorbance was read at 506 nm and compared to a standard curve of known concentrations (average r^2 of 0.99) in order to calculate the glucose concentration in the samples. The average concentration of the two duplicates was calculated, and starch concentration determined as the glucose concentration multiplied by 0.9 to adjust for the mass difference between glucose and the anhydroglucose that comprises starch (Smith 1981; Volenec 1988).

2.3.5.5 Prediction of soluble sugar and starch concentration using NIRS

Near infra-red reflectance spectroscopy (NIRS) was performed using a research composition analyser (RCA), Model 6250 (Pacific Scientific Ltd.). Ground samples from those already analyzed by the wet lab procedures were scanned with the RCA 6250 between

1100 and 2500 nm, and each absorbance spectrum recorded as log (1/*R*) (apparent reflectance). Multiple linear regression analysis of the data and the known starch and soluble sugar concentrations from the wet lab procedure was performed using the software program NSAS. The most accurate prediction equation was selected based on the standard error of performance (SEP), the standard deviation of differences between NIRS and the standard chemical analysis (Kim and Williams 1990), and the standard error of correlation between NIRS values and the standard chemical analysis.

Root material from one cultivar of each fall dormancy class (ie. nine total) per replicate (Table 29) was scanned with the NIRS system and the reflectance spectrum recorded. The starch and soluble sugar content of each cultivar was then predicted based on the calibration equations.

Table 29. Alfalfa cultivars analyzed for root carbohydrates in the fall of the establishment year and spring of year two, under two management systems.

Cultivar	FD[z]	Cultivar	FD
Rangelander	1	ABI 700	6
Vernal	2	P5683	7
Arrow	3	Moapa 69	8
Saranac	4	CUF 101	9
Belmont	5		

z - FD, fall dormancy rating: 1 = fall dormant, 9 = non-dormant

Several predicted values were less than zero, indicating that some sample sets could not be accurately predicted by the equations developed from the calibration samples. In order to evaluate which sample sets could be accurately predicted, the average spectrum of all cultivar root samples for each excavation event per trial (sample set) were then compared to the average spectrum of the calibration samples (Ellingboe et al. 1986). Sample sets for which the average spectrum was either much higher or much lower in reflectance than the calibration set were considered as unrepresented in the calibration set, and therefore could not be predicted. Sample sets for which the carbohydrate content could be predicted by the calibration equations developed are listed in Table 30.

Table 30. Alfalfa trials and sampling periods for which root starch and soluble sugar concentration was determined using NIRS.

Environment		Trials		Date of Root Sampling	
Location	Planting year	Management	Code	Fall of Establishment Year	Spring of Year Two
Homewood, MB	1993	seed	H93S	–[z]	18 Apr. 1994
		forage	H93F	–[z]	18 Apr. 1994
Arborg, MB	1993	seed	A93S	–[z]	25 Apr. 1994
		forage	A93F	–[z]	25 Apr. 1994
Arborg, MB	1994	seed	A94S	25Oct. 1994	28 Apr. 1995
		forage	A94F	25 Oct. 1994	28 Apr. 1995

z - Samples were attained following fall frost and cessation of plant growth, and prior to soil freezing; exact dates are unavailable.

2.3.6 Statistical Analysis

Cultivars were not completely randomized between replicates, in that they were grouped by fall dormancy rating (dormant: FD 1-4; semi-dormant: FD 5-6; non-dormant: FD 7-9) and dormancy groups were not randomized between replicates. This grouping arrangement was used to minimize differences in inter-plot competition that were expected to result from differential winter survival between non-dormant and dormant cultivars. The study design was initiated prior to the inclusion of these experiments in this thesis project. These groupings did not have any definable treatment effect, therefore for analysis of within management comparisons, individual trials were analyzed as a randomized complete block design.

Due to the blocking of cultivars by dormancy group within trials, comparisons between management systems (experiments) in each environment were made separately for each dormancy group. Cultivars 'Key' and 'Cimmaron VR' (both FD 4) were erroneously entered in the semi-dormant group, therefore they were removed from the comparison of management effect within dormancy group. Although not a valid design, management systems were compared by analysing them as main factors within the analysis of variance.

Analysis of variance was conducted using the statistical program Agrobase (Agronomix Software, Inc. 1996). Homogeneity of variance was determined using Bartlett's Chi-square Test for Homogeneity of Variances (Little and Hills 1978). Transformations were conducted on non-homogeneous data to enable analysis across environments. Winter injury ratings were transformed by $(x + 0.5)^{1/2}$, percent stand survival data was transformed by arc sine $x^{1/2}$, and carbohydrate data was transformed by log (x + 1).

Table 31. Long term average (normal) and actual monthly precipitation (mm) at three sites in western Canada from 1993 to 1995.

	Melfort, SK[z]				Arborg, MB[y]				Carman, MB[y]			
Month	1993	1994	1995	Normal	1993	1994	1995	Normal	1993	1994	1995	Normal
January	7	11	17	18	22	7	28	20	18	13	17	19
February	3	10	21	14	T	4	15	17	1	5	26	18
March	14	5	40	19	14	2	26	24	9	14	27	22
April	40	8	21	21	47	12	19	34	17	11	10	43
May	13	55	5	41	20	37	51	49	70	39	83	53
June	119	60	55	62	112	69	34	75	120	54	58	73
July	158	78	29	67	78	75	44	66	153	48	65	69
August	46	45	135	53	146	40	107	75	114	103	132	66
September	49	22	1	41	64	45	8	50	29	55	44	49
October	14	16	40	27	20	46	60	38	31	162	62	34
November	13	20	26	18	T	34	54	24	25	49	58	19
December	9	20	18	23	15	27	19	20	14	17	20	21

z - Source: Agriculture Canada, Melfort, SK.
y - Source: Environment Canada Climate Services, Winnipeg, MB.

Table 32. Long term average (normal) and actual mean monthly temperatures (°C) at three sites in western Canada from 1993 to 1995.

	Melfort, SK[z]				Arborg, MB[y]				Carman, MB[y]			
Month	1993	1994	1995	Normal	1993	1994	1995	Normal	1993	1994	1995	Normal
January	-17.0	-23.4	-16.1	-19.1	-18.7	-25.2	-17.8	-20.2	-16.1	-22.9	-14.9	n/a[x]
February	-14.0	-21.1	-14.3	-15.5	-16.3	-20.2	-18.3	-17.0	-13.3	-18.1	-13.6	
March	-1.9	-5.2	-8.5	-9.0	-6.2	-3.8	-7.5	-8.7	-4.6	-1.3	-5.9	
April	3.6	7.4	-2.3	2.2	2.9	1.7	-1.1	2.3	4.2	4.3	1.0	
May	11.0	10.8	10.3	10.6	9.5	9.8	9.0	10.1	11.5	12.8	11.0	
June	13.2	15.7	18.1	15.5	14.6	16.2	18.6	15.5	15.0	17.7	20.0	
July	15.3	16.9	16.7	17.6	16.6	17.0	17.8	18.4	17.1	18.0	19.6	
August	15.4	15.9	16.0	16.3	16.4	15.1	18.1	16.9	17.5	16.9	18.9	
September	8.7	13.5	12.1	10.4	8.3	13.0	11.5	10.9	10.6	14.8	13.0	
October	3.0	5.2	4.2	3.9	1.4	6.7	4.2	4.5	3.5	8.3	5.0	
November	-8.3	-6.6	-11.4	-7.0	-7.3	-3.1	-11.9	-5.8	-6.0	-2.0	-9.5	
December	-11.4	-13.0	-16.4	-16.2	-14.2	-11.8	-17.7	-16.5	-12.0	-10.5	-15.1	

z - Source: Agriculture Canada, Melfort, SK.
y - Source: Environment Canada Climate Services, Winnipeg, MB.
x - n/a, not available. Long term climate normals are not available for Carman, MB.

2.4 RESULTS AND DISCUSSION

2.4.1 Assessment of cultivar persistence

2.4.1.1 Winter injury

Analysis of variance for winter injury in the spring of year two (the year after establishment) was compared between management systems for each dormancy group over four environments: H93, A93, A94 and M94 (Tables 33 to 37). There were no winter injury ratings taken for the Melfort forage trial planted in 1993, and therefore no comparison of management effect on winter injury was possible for that environment.

There was no consistent effect of management on winter injury for dormant cultivars (FD 1-4). This was not surprising since these relatively dormant cultivars exhibit good winter hardiness. In Homewood 1993 there was no significant difference in winter injury between management systems for dormant cultivars (Table 33), likely because of abundant snow cover for the duration of the winter, as indicated by precipitation (Table 31). However, in Arborg 1993 snow cover was only 22% of normal (Table 31) and no cultivar with fall dormancy greater than six survived the winter. Winter injury in this environment was considerably less under seed management than under forage management. These results reflect research by McKenzie and McLean (1980) which demonstrated that harvesting a seed stand only once in the fall was advantageous to winter survival. Conversely, in trials which were established in 1994 at Arborg and Melfort, winter injury of dormant cultivars was higher under seed management than forage management (Table 34). The difference in winter injury between the 1993 and 1994 established experiments may be due in part to differences in management. The A94 seed trial suffered from severe weed competition due to an ineffective spray application, while weed competition in the forage trial was not as severe (data not presented).

There was no cultivar by management interaction for winter injury in any environment except A93 (Table 33), indicating that the relative winter injury of the eight dormant cultivars could be predicted from evaluation under either management system. Research by Sheaffer (1986) and Sheaffer and Marten (1990) also found that cutting treatments had no effect on the relative persistence of cultivars within a narrow range of fall dormancy. Analysis was not combined across environments due to non-heterogeneity of variances.

Table 33. Analysis of variance for winter injury of eight dormant (FD 1 to 4) alfalfa cultivars under two management systems, in the spring of year two in four environments across western Canada.

Environment		Source	d.f.	MS	F value	
Homewood, MB	1993	Management	1	0.002	1.00	NS
		Cultivar	7	0.002	1.00	NS
		Cv x Mnmt	7	0.002	1.00	NS
Arborg, MB	1993	Management	1	7.198	573.2	***
		Cultivar	7	0.338	26.9	***
		Cv x Mnmt	7	0.013	2.3	*
Arborg, MB	1994	Management	1	0.523	22.9	***
		Cultivar	7	0.095	4.2	**
		Cv x Mnmt	7	0.017	0.7	NS
Melfort, SK	1994	Management	1	2.346	190.9	***
		Cultivar	7	0.021	1.7	NS
		Cv x Mnmt	7	0.021	1.7	NS

*, **, *** ; Significance at $P \leq 0.05$, 0.01, and 0.001.

Table 34. Winter injury comparisons between seed and forage management of eight fall dormant alfalfa cultivars (FD 1to 4) in the spring of year two in four environments across western Canada.

Management	Environment			
	Homewood 1993	Arborg 1993	Arborg 1994	Melfort 1994 [z]
Seed	1.00 [xy]	1.56 b [w]	1.84 a	3.44 a
Forage	1.03	3.94 a	1.31 b	2.06 b

z - 1994 Melfort trials were not mowed off prior to snowfall in fall of establishment year.
y - Winter injury; 1 = no injury, 5 = dead.
x - No significant management differences.
w - Management means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by $(x + 0.5)^{1/2}$. Non-transformed data presented.

Analysis of management system for both the semi- (FD 5-6) and non-dormant (FD 7-9) groups were combined across environments. There was no effect of management on winter injury of semi-dormant cultivars (Table 35). Winter injury of non-dormant cultivars was affected by management system (Table 36), with management for forage production resulting in higher winter injury (Table 37). Management for forage production may have produced greater winter injury because of the date of harvest. Establishment year forage stands were cut soon after the beginning of the critical fall period (CFP) of 10 Aug to 25 September (Gottred 1987), while cultivars managed for seed production were either desiccated close to the end of the CFP and cut after the end of the CFP, or were not cut at all (Table 25). Harvesting the cultivars under the forage system at the beginning of the CFP likely resulted in subsequent regrowth and depletion of root carbohydrates for a period of two to three weeks (Cooper and Watson 1968; Davis et al. 1995; Gabrielson et al. 1985), and perhaps longer under reduced photoperiod and declining temperatures.

The effect of management on winter injury was probably more apparent in the non-dormant cultivars because fall growth score is more highly correlated to winter injury in stressful environments (Sheaffer et al. 1992). Any given winter environment would be more stressful to non-dormant cultivars than to dormant cultivars, and therefore the effects of management are more likely to be seen in non-dormant cultivars in the absence of a very severe winter.

Table 35. Analysis of variance for winter injury of six semi-dormant alfalfa cultivars (FD 5 and 6) under two management systems, in spring of year two combined over four environments in western Canada.

Environments	Source	d.f.	MS	F value	
H93, A93, A94, M94	Environment	3	5.900	218.64	***
	Management	1	0.000	0.00	NS
	Cultivar	5	0.423	15.68	***
	Cv x Env	15	0.059	2.19	**
	Cv x Mnmt	5	0.006	0.23	NS

, * - Significant at P≤ 0.01 and 0.001.

Table 36. Analysis of variance for winter injury of eight non-dormant alfalfa cultivars (FD 7 to 9) under two management systems, in spring of year two combined over four environments in western Canada.

Environments	Source	d.f.	MS	F value	
H93, A93, A94, M94	Environment	3	8.749	555.3	***
	Management	1	0.185	11.8	***
	Cultivar	7	0.244	15.5	***
	Cv x Env	21	0.066	4.2	***
	Cv x Mnmt	7	0.018	1.1	NS

*** - Significant at P≤ 0.001.

Table 37. Winter injury comparisons between seed and forage management systems of semi- and non-dormant alfalfa across four environments in western Canada.

Management	Dormancy Group	
	Semi-dormant [z]	Non-dormant
Seed	2.91 [xy]	3.59 b [w]
Forage	2.91	3.70 a

z - Semi-dormant: FD 5 and 6; non-dormant : FD 7 to 9.
y - Winter injury; 1 = no injury, 5 = dead.
x - No significant management differences.
w - Management means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by $(x + 0.5)^{1/2}$. Non-transformed data presented.

2.4.1.2 Percent stand survival

Percent stand survival between management systems was assessed for each dormancy group in the spring of year two over five environments: H93, A93, A94, M93 and M94 (Tables 37, 39, and 40). Management had no effect on the percent stand survival of dormant cultivars in H93, A94 and M94 (Table 38). Management for seed production resulted in higher percent stand survival than management for forage production in A93 and M93 (Table 39).

For semi-dormant cultivars (FD 5-6) there was a management effect on percent stand survival that varied with environment (Table 40). In environments H93, A93, and M93, management for seed production resulted in a greater percent stand survival. Differences between management systems were large for A93 and M93, which both experienced severe winter conditions not conducive to stand survival. November to March precipitation was 52 and 22 percent of normal in Melfort and Arborg, respectively (Table 31). Reduced snow cover results in lower soil temperatures and conditions not conducive to alfalfa stand survival (Sheaffer et al. 1986). These environments also experienced below normal mean monthly temperatures in November, January, and March (Table 32). Differences in stand survival were more apparent in these environments due to the more severe winter conditions (Stout 1986). Differences in survival between management systems were most striking in M93, where mean percent survival of the semi-dormant cultivars under the seed system was 83%, compared to only 4% under the forage system.

In contrast, where percent stand survival was greater under forage management than seed management (A94 and M94) (Table 41), differences in survival were not as large and overall stand survival levels were much higher. Although survival under the forage system was greater in these environments, survival under the seed system was relatively high and sufficient for stand maintenance. Cultivars exhibiting winter injury are more likely to recover if left uncut until they reach late flowering (Goplen et al. 1987). Therefore, a cultivar under seed production that maintains sufficient stand density will be more likely to recover from winter injury than a forage stand. Low levels of winter injury can be beneficial to seed production by reducing excess vegetative growth which limits seed yield. Some alfalfa seed producers in western Canada are utilizing management practices such as space planting and spring discing of established stands in order to thin stands and increase seed yield.

Semi-dormant cultivars showed improved survival under the seed management system following severe winter conditions. This suggests that seed production of semi-dormant (FD 5-6) cultivars may be possible in western Canada.

Table 38. Analysis of variance for percent stand survival of eight dormant alfalfa cultivars (FD 1 to 4) under two management systems, in spring of year two in five environments across western Canada.

Environment	Code	Source	d.f.	MS	F value	
Homewood 1993	H93	Management	1	0.005	0.8	NS
		Cultivar	7	0.007	1.0	NS
		Cv x Mnmt	7	0.007	1.0	NS
Arborg 1993	A93	Management	1	4.964	848.8	***
		Cultivar	7	0.334	57.1	***
		Cv x Mnmt	7	0.084	14.3	***
Arborg 1994	A94	Management	1	0.000	0.1	NS
		Cultivar	7	0.011	3.3	**
		Cv x Mnmt	7	0.013	4.0	**
Melfort 1993	M93	Management	1	2.255	91.1	***
		Cultivar	7	0.156	6.3	***
		Cv x Mnmt	7	0.093	3.7	**
Melfort 1994	M94	Management	1	0.000	1.0	NS
		Cultivar	7	0.000	1.0	NS
		Cv x Mnmt	7	0.000	1.0	NS

*, **, *** ; Significant at P≤ 0.05, 0.01, and 0.001.

Table 39. Percent stand survival comparisons between management for seed and forage production of eight dormant alfalfa cultivars (FD 1 to 4) in spring of year two in five environments across western Canada.

	Environment				
Management	Homewood 1993	Arborg 1993	Arborg 1994	Melfort 1993	Melfort 1994
Seed	87[z]	58 a[y]	84[z]	96 a	100[z]
Forage	88	15 b	83	68 b	100

z - No significant management differences.

y - Management means followed by the same letter are not significantly different at P≤0.05, Fisher's protected LSD. Mean separations calculated from data transformed by arc sine $x^{1/2}$. Non-transformed data presented.

Table 40. Analysis of variance for percent stand survival of six semi-dormant alfalfa cultivars (FD 5 and 6) under two management systems, in spring of year two in four environments in western Canada.

Environment		Code	Source	d.f.	MS	F value	
Homewood	1993	H93	Management	1	0.362	42.0	***
			Cultivar	5	0.074	8.6	***
			Cv x Mnmt	5	0.014	1.7	NS
Arborg	1993	A93	Management	1	1.082	120.5	***
			Cultivar	5	0.111	12.3	***
			Cv x Mnmt	5	0.102	11.3	***
Arborg	1994	A94	Management	1	0.308	20.4	***
			Cultivar	5	0.249	16.5	***
			Cv x Mnmt	5	0.006	0.4	NS
Melfort	1993	M93	Management	1	12.601	838.0	***
			Cultivar	5	0.159	10.6	***
			Cv x Mnmt	5	0.080	5.3	**
Melfort	1994	M94	Management	1	0.217	28.0	***
			Cultivar	5	0.022	2.8	*
			Cv x Mnmt	5	0.022	2.8	*

*, **, *** ; Significant at $P \leq 0.05$, 0.01 and 0.001.

Table 41. Percent stand survival comparisons between seed and forage management of six semi-dormant alfalfa cultivars (FD 5 and 6) in spring of year two in five environments across western Canada.

	Environment									
Management	Homewood 1993		Arborg 1993		Arborg 1994		Melfort 1993		Melfort 1994	
Seed	88	a [z]	17	a	56	b	83	a	95	b
Forage	74	b	0	b	71	a	4	b	100	a

z - Management means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by arc sine $x^{½}$. Non-transformed data presented.

Management system had an effect on percent stand survival of non-dormant cultivars

(FD 7 to 9) in all environments except A93 (Table 42). The lack of difference between management systems for non-dormant cultivars A93 was due to complete winter kill of all non-dormant varieties under both management systems, likely resulting from a lack of snow cover. In H93 and M93, percent stand survival under seed management was better in comparison to forage management. Conversely, in A94 and M94, stand survival was greater under forage management (Table 43). These are the same management effects on survival that were obtained for the semi-dormant varieties.

Only H93 and M94 had sufficient stand survival across the non-dormant cultivars to retain the stands for a year two seed harvest in a commercial production situation (Table 43). However, the mean survival of cultivars of FD 7 was much better under the seed management system than reflected by analysis across all non-dormant cultivars. The mean stand survival of cultivars of FD 7 under management for seed production was: H93, 88%; A93, 1%; A94, 56%; M93, 62%; and M94, 91%. With the exception of A93, the stand survival of cultivars of FD 7 was sufficient in all environments to keep the cultivars in for a second season.

Preliminary reporting of these results at the Manitoba Forage Seed Association annual meeting in January 1996 encouraged some Manitoba producers and seed companies to grow cultivars of FD 7 for seed production (S. R. Smith, Jr. pers. comm.). Generally, producer experience has been consistent with these research results, with cultivars of FD 7 showing good stand survival.

Table 42. Analysis of variance for percent stand survival of eight non-dormant alfalfa cultivars (FD 7 to9) under seed and forage management, in spring of year two in five environments across western Canada.

Environment		Code	Source	d.f.	MS	F value	
Homewood	1993	H93	Management	1	1.709	249.6	***
			Cultivar	7	0.082	12.0	***
			Cv x Mnmt	7	0.016	2.4	*
Arborg	1993	A93	Management	1	0.010	3.7	NS
			Cultivar	7	0.002	0.6	NS
			Cv x Mnmt	7	0.002	0.6	NS
Arborg	1994	A94	Management	1	0.814	52.3	***
			Cultivar	7	0.712	45.8	***
			Cv x Mnmt	7	0.038	2.4	*
Melfort	1993	M93	Management	1	4.268	319.9	***
			Cultivar	7	0.215	16.1	***
			Cv x Mnmt	7	0.200	15.0	***
Melfort	1994	M94	Management	1	4.853	118.8	***
			Cultivar	7	0.198	4.9	***
			Cv x Mnmt	7	0.198	4.9	***

*, *** - Significant at $P \leq 0.05$ and 0.001.

Table 43. Percent stand survival comparisons between seed and forage management of eight non-dormant alfalfa cultivars (FD 7 to 9) in five environments across western Canada.

	Environment				
Management	Homewood 1993	Arborg 1993	Arborg 1994	Melfort 1993	Melfort 1994
Seed	83 a [z]	0 [y]	27 b	33 a	64 b
Forage	55 b	0	46 a	0 b	100 a

z - Management means followed by the same letter are not significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by arc sine $x^{1/2}$. Non-transformed data presented.

y - No significant management differences due to complete winter kill.

A potential factor confounding winter injury and stand ratings in the seed management system was the use of the desiccant glufosinate (Trade name: 'Harvest'; Table 26) on the Homewood and Arborg trials. At the time of this research, it appeared that glufosinate would become a preferred alfalfa desiccant in western Canada. For reasons other than product performance, glufosinate has since been removed from the market for this use, and anecdotal reports from seed producers indicated that it may have played a role in variable stand survival observed after its use (S. R. Smith, Jr., pers. comm.). In contrast, Moyer et al. (1996) observed no visible winter injury in the spring after either glufosinate or diquat applications. It is unclear whether winter injury and/or stand survival of cultivars managed for seed production in Homewood and Arborg may have been adversely affected by the use of glufosinate.

2.4.2 Comparison of percent nitrogen of roots

Percent root nitrogen at each sampling period was compared between management systems for each dormancy group within A93, H93, and M93. Management for seed production resulted in higher percent root nitrogen than management for forage production in all dormancy classes and sampling periods with the exception of non-dormant cultivars (FD 7-9) in H93, for which there was no difference in percent nitrogen between management systems (Table 44). Stand survival under seed management was greater in all three of these environments, however root nitrogen content was not determined in any environment in which forage management had greater stand survival.

In the three environments for which root nitrogen was measured, greater survival of cultivars managed for seed coincided with higher percent nitrogen in roots. Cultivars managed for seed production also had larger roots (Figure 5), and the combination of higher percent nitrogen content with larger root size would result in there being a substantially greater quantity of nitrogen available to the cultivars managed for seed production.

Percent root nitrogen of cultivars in each dormancy group increased numerically from fall to spring within all environments, with the exception of semi-dormant cultivars under forage management and non-dormant cultivars under both management systems in A93. These exceptions correspond to the cultivars which had no stand survival following severe winter conditions. The roots of those cultivars which were excavated and analyzed in the spring of year two were later determined to be completely dead. The increase in percent nitrogen from fall to spring in the roots of the other cultivars was probably a result of the depletion of carbohydrates from the root overwinter (Bula and Smith 1954), and not any increase in the actual quantity of nitrogen in the root.

Although it has been demonstrated previously that total root nitrogen levels were not well-related to cold tolerance (Bula and Smith 1954), Duke and Doehlert (1981) proposed that higher nitrogen levels might indicate higher levels of enzymes, which could be advantageous to stand survival over winter if these compounds are involved in the hydrolyzation of starch to sugars. Higher root nitrogen levels might also be comprised of vegetative storage proteins, some of which have been identified as having a role in cold tolerance (Li et al. 1996).

Table 44. Effect of management on percent nitrogen of alfalfa roots in fall of the establishment year and the following spring in three environments in western Canada.

Env.	Sampling Period	Management	Dormancy Group: Dormant [z]	Semi-dormant	Non-dormant
A93[y]	fall	seed	2.93 a[x]	2.96 a	2.97 a
		forage	2.61 b	2.56 b	2.56 b
	spring	seed	3.36 a	3.25 a	2.37 a
		forage	2.74 b	1.99 b	1.71 b
H93	fall	seed	2.81 a	2.63 a	2.62
		forage	2.28 b	2.33 b	2.55
	spring	seed	3.43 a	3.27 a	3.45
		forage	2.95 b	3.12 b	3.44
M93	fall	seed	2.50 a	2.52 a	2.69 a
		forage	1.94 b	1.97 b	2.27 b

z - Dormant (FD 1 to 4), Semi-dormant (FD 5 and 6), Non-dormant (FD 7 to 9).
y - A93, Arborg 1993; H93, Homewood 1993; M93, Melfort 1993.
x - Management means followed by different letters are significantly different at $P \leq 0.05$, Fisher's protected LSD.

2.4.3 Comparison of root starch and sugar levels

Comparisons of the effect of management on root carbohydrate levels (mg g^{-1} dry weight) in fall of the establishment year and the following spring were made for each dormancy group within each environment. Non-homogeneity of variance prevented analysis across environments in most cases, therefore analysis was only conducted within individual environments. Carbohydrate levels compared were soluble sugar content, starch content, and total nonstructural carbohydrate content.

2.4.3.1 Fall carbohydrate levels

Fall sugar content (mg g^{-1} dry weight) did not appear to relate to stand survival the following spring, and was not different between management systems within dormancy groups in most environments. Where differences were observed, there was no consistent relationship between sugar content and stand survival. In H93 sugar content was higher under the forage management system in the dormant and semi-dormant cultivars (Tables 45 and 46), but there was no difference in stand survival of dormant cultivars between management systems (Table 39), and greater stand survival of semi-dormant cultivars under the seed management system (Table 41). In contrast, in A94 non-dormant cultivars had greater fall sugar content under the forage management system than the seed management system (Table 47), which corresponded with greater survival under the forage management system at that site (Table 42).

The lack of relationship between fall sugar content and stand survival may be a function of the date at which the fall root samples were obtained. Root carbohydrate is composed primarily of starch in fall (Bula and Smith 1954), and is converted to sugar during the development of cold tolerance (Li et al. 1996). The concentration of sugars in alfalfa roots generally increases from October to mid-December as cold tolerance is developing (Wilding et al. 1960). Since the fall root samples generally collected at the end of October prior to soil freezing, it is likely that very little conversion of starch to sugars had occurred yet. Sampling at a later date might have resulted in higher sugar levels in the root, and a relationship between fall sugar content and stand survival.

The relationship between fall starch and TNC contents and stand survival was more consistent than that of fall sugar content in these roots, but results were still variable. Starch and TNC contents were greater under the seed management system for both semi-dormant and non-dormant cultivars in H93 (Tables 46 and 47), and this corresponded to greater stand survival (Tables 41 and 43). As well, in A94 greater TNC content for semi-dormant cultivars under the forage management system (Table 46) corresponded to greater stand survival (Table 41).

In contrast, higher levels of fall starch and TNC did not always correspond to greater stand survival. In H93 and A94, there were significant differences between management systems in the starch and TNC content of dormant cultivars (Table 45), but no differences in stand survival (Table 39). However, there were no cases in which the trend was reversed, i.e. greater survival never corresponded to lower fall starch and/or TNC levels.

A similar lack of relationship between fall root carbohydrate content and stand survival was apparent in environment A93 when comparing fall carbohydrate content to stand survival. There were no differences in fall carbohydrate between management systems for any dormancy group in A93 (Tables 45, 46, and 47), but there were striking differences in stand survival. Most cultivars with fall dormancy of one to six survived under seed management, while there was almost no stand survival of any cultivar under forage management (Tables 39, 41 and 43). A93 demonstrates that factors other than percent fall root carbohydrate were important in determining winter survival. Differences in winter survival may be due to inter-relationships of fall dormancy, cold tolerance, disease resistance, carbohydrate reserves, crown depth, nitrogen reserves, and other characteristics (Sheaffer et al. 1992).

Table 45. Summary of effect of management on fall and spring root carbohydrate levels (mg g^{-1}) of four fall dormant cultivars (FD 1 to 4) in three environments in western Canada.

Env.[z]	Management	Sugar Content		Starch Content		TNC [y]	
		Fall	Spring	Fall	Spring	Fall	Spring
A93	seed	79	144 a [x]	358	122 b	438	266 a
	forage	74	57 b	339	165 a	413	222 b
H93	seed	76 b	174 a	332 a	89	408 a	263
	forage	112 a	156 b	246 b	98	359 b	254
A94	seed	78	123 b	310 b	119 b	389 b	242 b
	forage	89	162 a	381 a	137 a	469 a	299 a

z - A93, Arborg 1993; H93, Homewood 1993; A94, Arborg 1994.
y - Total non-structural carbohydrate.
x - Management means followed by different letters are significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by log (x+1). Non-transformed data presented.

Table 46. Summary of effect of management on fall and spring root carbohydrate levels (mg g^{-1}) of two semi-dormant cultivars (FD 5-6) in the establishment year in three environments in western Canada.

Env.[z]	Management	Sugar Content		Starch Content		TNC [y]	
		Fall	Spring	Fall	Spring	Fall	Spring
A93	seed	66	94 a [x]	363	167 b	429	261
	forage	64	11 b	337	243 a	402	255
H93	seed	55 b	183 a	388 a	104	443 a	286
	forage	91 a	135 b	285 b	130	376 b	265
A94	seed	45	113	363	211	407 b	234
	forage	69	134	413	197	482 a	331

z - A93, Arborg 1993; H93, Homewood 1993; A94, Arborg 1994.
y - Total non-structural carbohydrate.
x - Management means followed by different letters are significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by log (x+1). Non-transformed data presented.

Table 47. Summary of management effect on fall and spring root carbohydrate levels (mg g^{-1}) of three non-dormant cultivars (FD 7 to 9) in the establishment year in three environments in western Canada.

Env.[z]	Management	Sugar Content		Starch Content		TNC [y]	
		Fall	Spring	Fall	Spring	Fall	Spring
A93	seed	74	18	346	246	420	264
	forage	62	3	342	249	405	251
H93	seed	41	150 a [x]	414 a	150	455 a	301 a
	forage	57	93 b	321 b	129	378 b	222 b
A94	seed	18 b	43 a	469	231 b	487	274 b
	forage	40 a	35 b	473	331 a	513	367 a

z - A93, Arborg 1993; H93, Homewood 1993; A94, Arborg 1994.
y - Total non-structural carbohydrate.
x - Management means followed by different letters are significantly different at $P \leq 0.05$, Fisher's protected LSD. Mean separations calculated from data transformed by log (x+1). Non-transformed data presented.

Although the seed management system incorporated only a single harvest in late fall, the forage management system included a previous harvest in mid-August (Table 25), during the critical fall period for Manitoba (10 Aug. to 25 Sept.; Gottfred 1987). Research by Smith (1962) and Reynolds and Smith (1962) indicates that 30 to 45 days of regrowth may be required at that time of year to replenish carbohydrate reserves in alfalfa. The absence of consistent and striking differences in fall root carbohydrate content (expressed as a proportion of root dry weight) between the two systems indicated that the forage stands were harvested early enough to allow replenishment of root carbohydrates prior to the cessation of growth in the fall.

The different response of carbohydrate level to management system between environments indicated that measurement of percent fall root carbohydrate was not a good predictor of winter survival in these experiments, and that other factors had a greater impact on winter survival.

2.4.3.2 Spring carbohydrate levels

There were differences in spring sugar levels between management systems for seven of the nine dormancy group by environment situations evaluated (Tables 45, 46, and 47). Sugar levels were higher under the seed management system in all but one of these situations, the exception being dormant cultivars in A94.

Spring sugar levels mirrored differences in percent stand survival between management systems. In all situations where there were significant differences in stand survival (Tables 39, 41, and 43), except non-dormant cultivars in A94, the management system with the better survival also had higher spring sugar content (Tables 45-47).

Spring starch levels were lower under the seed management system in all situations where there were differences (Tables 45, 46 and 47). This may be due to conversion of starch to soluble sugars during the cold hardening process (Castonguay and Nadeau 1995; Li et al. 1996), resulting in lower spring starch levels in plants which experienced greater cold hardening. Where differences in spring TNC content coincided with differences in stand survival, higher TNC levels (Table 45 and 47) corresponded to better stand survival (Tables 39 and 43). Overall, differences in spring levels of starch and TNC were not consistent between management systems, and did not correspond well to stand survival.

The correspondence between high spring sugar content and increased levels of stand survival is not surprising since sucrose in the main form of available energy from stored carbohydrate (Goodwin and Mercer 1983), and carbohydrate levels are associated with the initiation of spring growth (Chatterton et al. 1977; Brummer and Bouton 1992). Jung and Larson (1972) also stated that the concentration of total soluble sugars (approximately 90% sucrose) is usually closely associated with cold tolerance. The management system under which there is a higher spring sugar content would have an advantage in tolerating spring frosts due to the role of sugar in cold tolerance (Duke and Doehlert 1981; Li et al. 1996), and in the production of spring regrowth. Spring sugar content probably also functions to reduce the manifestation of winter injury symptoms. Readily available energy might encourage rapid spring growth and plant development, thereby increasing resistance to and recovery from factors such as injury from ice encasement, soil heaving and diseases. In this research, winter injury levels were lowest under the management system which resulted in a higher spring sugar content in all situations where there were differences in winter injury (data presented by environment limited to dormant cultivars, Table 34), with the exception of non-dormant cultivars in A94.

In environment A93, there were no differences in spring root carbohydrates between management systems for non-dormant cultivars (Table 47), and there were also no differences in survival (Table 42). None of the non-dormant cultivars survived the winter under either management system, therefore the roots sampled for carbohydrate determination were dead.

The difference in spring root carbohydrate levels between management systems in A93, when contrasted to the complete absence of any differences in fall levels, indicates that fall root carbohydrate content was not an important determinant of winter survival. Factors which influences carbohydrate metabolism may have played a greater role in determining winter survival, and may have included: levels of specific amino acids, proteins, and nutrients, total root mass, overall plant health, plant density, and concentration and activity of enzymes such as endoamylase (Li et al. 1996).

It is also important to note that the carbohydrate content of the roots sampled in spring was probably very indicative of carbohydrate content and composition existing at the end of cold hardening. Starch is converted to sugar during the development of cold tolerance (Li et al. 1996), and the concentration generally increases from October to mid-December (Wilding et al. 1960), and does not decrease markedly from then until new growth occurs in the spring (Li et al. 1996). The relationship of spring sugar content to winter survival may have been the same as the relationship of post-hardening sugar content if roots had also been sampled in mid-December.

Root starch content levels decreased from fall to spring, while root sugar levels increased from fall to spring in all cases except for non-dormant cultivars under forage management in A94, and non-dormant and semi-dormant cultivars managed for seed production and all cultivars managed for forage production in A93. The decrease in starch concentration and the increase in sugar concentration levels observed between fall and spring sampling probably occurred during the cold hardening process. Starch forms the majority of root carbohydrate prior to hardening, and is rapidly converted to sugars as cold tolerance develops (Bula and Smith 1954; Duke and Doehlert 1981; Li et al. 1996). Sugar levels reach a maximum between October (Nelson and Smith 1968) and mid-December (Wilding et al. 1960), coinciding with the decline in root starch concentration (Boyce and Volenec 1992).

Root sugars levels tended to be higher with greater fall dormancy in both fall and spring samples (not determined statistically). This may indicate a difference between cultivars of contrasting fall dormancy in the conversion of starch to sugars during the cold hardening process.

2.4.4 Effect of management system on root size

The average root size (as measured by weight) over four environments (A94, A93, H93 and M94) in spring of year two ranged from two to five times larger under seed management than under forage management (Figure 5). This was also the case within each individual environment (data not presented). Differences in root size between management systems were not surprising due to the differences in seeding rates and row spacing (Table 24). The differences in root size did not directly reflect winter survival, in that root size was greater under the seed management system in all environments, but winter survival was greater under the forage management system in some cases.

Cultivars under the seed management system had larger roots (Figure 5), and would therefore have a greater quantity of carbohydrate available than smaller roots with the same concentration of carbohydrate. This would also be the case for plants with the same percent nitrogen content, but different sized roots. Although they did not propose a reason for the relationship, Schwab et al. (1996) demonstrated a positive relationship between root size and cold tolerance.

Schwab et al. (1996) found that less fall dormant cultivars had larger roots than more dormant cultivars. That pattern was not consistent in this research, as root size within a given dormancy level varied between cultivars (Figure 5). The difference in findings between this research and that of Schwab et al. (1996) may be due to both the number of cultivars examined, the number of environments of tested, and the specific cultivars investigated.

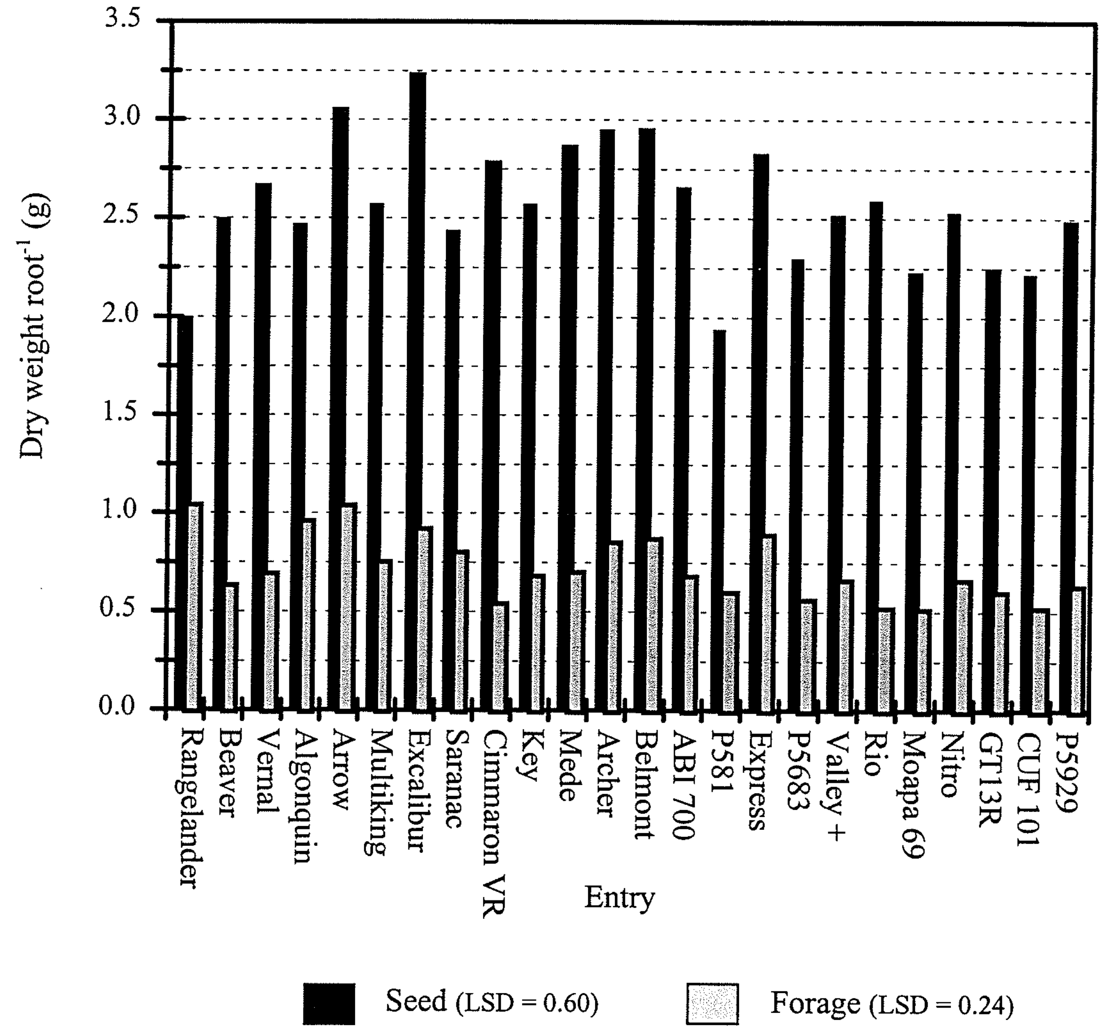

Figure 5. Average weight per root of 24 alfalfa cultivars in spring of year two under two management regimes, over four environments in western Canada.

2.4.5 Seed yield in the year after establishment

Environmental conditions were conducive for alfalfa seed production (mean trial yield ranged from 205 to 301 kg ha^{-1}) in year two for all environments except H93 (52 kg ha^{-1}) (Table 47). In all environments except H93, some cultivars had seed yields in excess of the 1995 to1998 average yield for pedigreed seed production in Manitoba (269 kg ha^{-1}; Manitoba Crop Insurance Corporation, 1999). The low year two yield for H93 was a result of excessive growth, which produced almost complete lodging followed by vegetative regrowth, and most of the seed that had been set was lost prior to harvest. Although the year two seed yields at A94 were above the Manitoba average, seed yield in that environment was limited by drought.

Table 48. Analysis of variance for year two seed yield of 24 alfalfa cultivars over five environments in western Canada.

Environment		Code	Trial Mean	Source	d.f.	MS	F value	
Homewood	1993	H93	52 kg ha^{-1}	Rep	3	4 970	7.65	***
				Cultivar	23	7 047	10.84	***
Arborg	1993	A93	205 kg ha^{-1}	Rep	3	19 076	3.85	*
				Cultivar	14	35 211	7.10	***
Arborg	1994	A94	285 kg ha^{-1}	Rep	3	28 448	5.62	**
				Cultivar	23	93 434	18.47	***
Melfort	1993	M93	301 kg ha^{-1}	Rep	3	10 893	3.38	*
				Cultivar	23	96 954	30.08	***
Melfort	1994	M94	218 kg ha^{-1}	Rep	3	5 760	2.45	NS
				Cultivar	23	21 910	9.31	***

*, **, *** ; Significant at $P \leq 0.05$, 0.01 and 0.001.

Due to the poor winter survival of A93 caused by lack of snow cover, only cultivars with fall dormancy rankings of one to six (excluding cultivar 'P581') remained for evaluation of year two seed yield in this environment. In all other environments seed was harvested from all 24 cultivars planted in the trials, although seed yields of cultivars with fall dormancy levels of eight and nine were low. All cultivars with FD 8-9 (non-dormant) had lower seed yield than all dormant cultivars, with the exception of 'Moapa 69' and 'Nitro' in H93, and 'GT13R' in M94 (Table 52).

Dormant cultivars (FD 1-4) produced the highest seed yields in all environments (Table 52). Previously, only cultivars within this dormancy range were recommended for seed production in western Canada. However, all semi-dormant cultivars (FD 5 and 6) produced seed yields equivalent to at least one cultivar in the dormant group across all environments, with the exception of P581 in H93, and 'ABI 700' and 'Express' in A93.

In H93 and M93 two of the three cultivars with FD 7 (non-dormant) yielded as well as at least one dormant cultivar, while all three cultivars of FD 7 yielded equal or better than at least one dormant cultivar in A94 and M94. These results contradict conventional cultivar recommendations, since cultivars of this fall dormancy classification are normally grown in forage stands in the southern USA.

Table 49. Year two seed yield (kg ha^{-1}) of 24 alfalfa cultivars in five environments across western Canada.

				Environment								
Cultivar	FD[z]	H93[y]		A93		A94		M93		M94	
Rangelander	1	65	de[w]	260	bcd	373	bcd	329	ghi	297	bcd
Beaver	2	124	b	443	a	526	a	547	ab	225	b-i
Vernal	2	57	e	211	d	279	efg	369	e-h	209	f-i
Algonquin	2	65	de	327	b	447	ab	323	ghi	243	b-g
Arrow	3	114	bc	254	bcd	378	bcd	314	hij	302	bc
Multiking	3	91	cd	243	bcd	357	cde	417	def	261	b-f
Excalibur	4	170	a	289	bcd	440	bc	562	a	314	b
Saranac	4	104	bc	301	bc	431	bc	431	cde	297	bcd
Cimmaron VR	4	53	ef	214	d	441	bc	383	efg	267	b-e
Key	4	45	efg	208	d	415	bc	498	abc	375	a
Mede	5	37	e-j	275	bcd	250	fg	420	def	197	ghi
Archer	5	56	ef	273	bcd	420	bc	363	fgh	226	b-i
Belmont	5	53	ef	222	cd	422	bc	483	bcd	256	b-f
ABI 700	6	41	e-h	89	e	302	def	253	j	227	b-h
P581	6	17	g-j	-[x]		160	h	139	k	114	kl
Express	6	26	f-j	40	e	215	gh	290	ij	224	b-i
P5683	7	14	hij	-		236	fgh	121	kl	166	ijk
Valley +	7	16	g-j	-		248	fg	290	ij	196	ghi
Rio	7	39	e-i	-		263	fg	266	ij	225	b-i
Moapa 69	8	15	g-j	-		51	i	105	kl	127	jkl
Nitro	8	21	g-j	-		47	i	122	kl	132	jkl
GT13R	8	9	ij	-		68	i	76	kl	184	hij
CUF 101	9	13	hij	-		48	i	65	l	91	l
P5929	9	7	j	-		27	i	64	l	81	l

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; M93, Melfort 1993; M94, Melfort 1994; H93, Homewood 1993.
x - Cultivar P581 and all cultivars with FD$\geq$7 did not survive the first winter in A93.
w - Cultivar means followed by the same letter are not significantly different at P$\leq$0.05, Fisher's protected LSD.

These seed yields indicated that although reduced winter survival can be expected with cultivars of fall dormancy five to seven, the level of winter survival of some cultivars in this dormancy range was not a limiting factor in achieving year two seed yields equivalent to dormant cultivars. Following the initiation of this research, producers began to routinely grow cultivars of FD 5 and 6, and certain cultivars of FD 7, for seed production in Manitoba and Saskatchewan. This research also indicated that winter survival of cultivars of FD 8 and 9 was often reduced such that year two seed yields were significantly lower than would be obtained from dormant cultivars. Therefore, seed production of these non-dormant cultivars would be risky in western Canada.

Two issues not dealt with by this research are as follows: 1) the cultivars managed for seed production were established without a cover crop, and 2) the potential of causing genetic shifts in seed stands of less dormant cultivars as individual plants are lost to winterkill.

Modifying the seed management system to include establishment under a cover crop might not result in the same findings as this research. The competition from a cover crop could be expected to delay plant development and growth and alter carbohydrate and nitrogen accumulation, as well as root biomass. Depending on the time of removal of a cover crop, its use may serve to either increase or decrease winter survival. S. R. Smith, Jr. (pers. comm.) is investigating the effect of establishment under a cover crop in research implemented in 2000.

Some concern has been expressed that producing seed from semi-dormant alfalfa cultivars in western Canada will produce a genetic shift towards a more fall dormant growth habit via natural selection for more winter hardy plants. However, in the environments investigated, the percent winter kill experienced for cultivars with fall dormancy of five and six ranged from 5 to 44 percent, except in the case of a severe winter in A93 (Table 41). If dealing with a cultivar with a dormancy rating of seven, an equivalent amount of winter kill should not shift the dormancy of the seed produced to more than a six. In the areas where seed of semi-dormant cultivars is currently being marketed, a shift of this magnitude should not create a noticeable difference in cultivar performance. One private breeder remarked that it would be preferable to shift an alfalfa cultivar of FD 7 toward more fall dormancy, rather than less (S. R. Smith, pers. comm.). Smith and Graber demonstrated in 1950 that seed of the cultivar 'Ranger' could be grown outside its region of forage adaptation for one generation of seed increase without genetic change (Smith 1988). In actual practice, there has recently been seed produced in Canada from cultivars of fall dormancy five to seven with no shift in cultivar characteristics (H. Loeppky, pers. comm.).

2.5 SUMMARY

Differences in winter injury and stand survival were not always consistent between management systems. In about half of the environments the cultivars managed for seed production had less injury and better survival under management for seed production than forage production, while in the other half the trend was reversed. However, in environments which experienced severe winter conditions (mainly a lack of snow cover) and overall survival levels were low, stand survival was dramatically better under the seed management system than the forage management system. In contrast, where stand survival was better under forage management than seed management, levels of stand survival were sufficient for stand maintenance under both management systems, and environmental conditions favoured winter survival.

Evaluations of root carbohydrate levels and root biomass indicated that although there was some correspondence between high fall starch and TNC levels and greater stand survival the following spring, fall carbohydrate level and root biomass were not consistent indicators of potential stand survival and winter injury. Spring soluble sugar content of roots seemed to be more closely linked to levels of stand survival than any other measurement of root carbohydrate content in either the fall or the spring.

In some of the environments which had differences in stand survival between management systems, there were large differences in spring root carbohydrate content, but no differences in fall root carbohydrate content. This may indicate that there were differences in plant metabolism between cultivars managed for seed vs. forage production.

Percent root nitrogen concentration was higher under the seed management system than the forage management system in all environments. In the three environments for which both nitrogen content and stand survival were evaluated, all three environments experienced better survival under the seed management system, thus corresponding to high root nitrogen levels.

Winter survival of cultivars with dormancy classification of up to seven was usually high enough to harvest second year seed yields equivalent to at least one of the dormant cultivars. These results suggest that western Canadian producers can successfully produce seed from cultivars in this range, although the risk of winter kill was observed to increase with less fall dormancy.

GENERAL SUMMARY AND CONCLUSIONS

This research evaluated 24 alfalfa cultivars ranging in fall dormancy from dormant to non-dormant under both forage and seed production management systems. Evaluations of yield potential, winter survival, and root carbohydrate and nitrogen content were made within and between these two management systems.

Under the forage management system, one establishment year harvest in mid-August provided no yield advantage to semi- and non-dormant cultivars over that of dormant cultivars. Fall regrowth of semi- and non-dormant cultivars in the establishment year indicated that these cultivars would be advantageous in annual or short-term forage stands due to increased forage production during this period. This increased growth should provide increased nitrogen fixation and forage yield. Using a non-dormant alfalfa cultivar as an annual crop to increase the soil nitrogen contribution over dormant cultivars may become increasingly important as fertilizer prices continue to rise.

Semi-dormant cultivars had greater winter injury and stand reduction than some dormant cultivars in some environments. Non-dormant cultivars had greater injury and stand reduction in all environments. Non-dormant alfalfa cultivars are only suitable for single season forage stands in Manitoba and Saskatchewan due to risk of winterkill, but semi-dormant cultivars provide a useful option for short term stands in areas of this region that receive adequate snow cover.

Spring growth in year two was delayed in cultivars with greater winter injury, but surviving semi- and non-dormant cultivars recovered and exhibited faster regrowth after the first cut and greater fall growth than dormant cultivars. Cultivars with a fall dormancy greater than four had lower year two forage yields than dormant cultivars when only two harvests were possible. In southern environments where three harvests were possible, many cultivars with fall dormancy levels of five to seven yielded as well or better than some of the more dormant cultivars due to greater fall growth. In areas with adequate snow cover and where three cuts are possible, semi-dormant cultivars can produce the same forage yield over a one to two year stand life as dormant cultivars, with the advantage that semi-dormant cultivars would facilitate stand termination.

Percent root nitrogen content was greater under the seed management system than the forage management system, and in three environments for which both nitrogen content and stand survival were evaluated, greater root nitrogen content corresponded to greater stand survival under the seed management system. Improved forage stand survival of semi- and non-dormant cultivars might be possible if they were managed for greater root nitrogen content by delaying harvest and/or reducing planting density. Forage quality and yield would be impacted by this management, and research would need to be conducted to determine the desired balance between forage quality, stand density, winter survival, and forage yield in the establishment year and year two.

The two management systems investigated did not produce consistent differences in root carbohydrate levels. Fall starch and TNC levels were more closely related to stand survival the subsequent spring than fall sugar levels were. High spring sugar levels corresponded to greater stand survival and lower winter injury ratings. Large differences in stand survival between management systems had no corresponding difference in fall carbohydrate content in some environments, indicating that other factors played an important role in determining winter survival.

The effect of management system on winter injury and percent stand survival were not always consistent. However, cultivars had dramatically better stand survival and winter injury under the seed management system in environments which experienced severe winter conditions (mainly a lack of snow cover). When environmental conditions were not severe, stand survival was sometimes greater under the forage system, but differences in survival between systems were not large, and survival levels under either system were adequate for year two seed production. Relative winter injury between cultivars was consistent across management systems in each environment, indicating that it may be possible to quickly evaluate the potential to grow a cultivar for seed production based on survival in a forage test relative to a cultivar for which the survival under seed production management is known. Stand survival of semi- and non-dormants was much higher in these environments than was anticipated for either management system. This indicates the importance of evaluating the winter survival potential of semi- and non-dormant alfalfa cultivars in western Canada, rather than relying on values determined in other environments.

Winter survival of cultivars with fall dormancy classifications up to seven was usually high enough to attain year two seed yields equivalent to those of dormant cultivars, and this research indicated that western Canadian producers can successfully produce seed from cultivars in this dormancy range. This will allow western Canadian producers and seed companies to access more of the world market for alfalfa seed. The potential for use of semi- and non-dormant alfalfa cultivars in annual or short-term forage stands in western Canada also creates the potential that seed of semi- and non-dormant cultivars could be produced in western Canada and sold into a domestic market.

In conclusion, this research indicates that there is potential in western Canada to use semi- and non-dormant alfalfa cultivars for forage production and to produce seed of cultivars up to fall dormancy classification seven.

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Appendix 1. Percent nitrogen of roots in fall of the establishment year and the following spring under two managements in tests established at Arborg, MB in 1993.

		Fall				Spring			
Cultivar	FD[z]	Seed	Forage			Seed		Forage	
Rangelander	1	3.10[y]	2.67	a-e[x]		3.30	a-d	3.21	a
Beaver	2	2.94	2.82	ab		3.47	abc	3.13	a
Vernal	2	2.88	2.57	b-e		3.66	a	2.67	bc
Algonquin	2	2.92	2.55	c-f		3.32	a-d	2.98	ab
Arrow	3	2.82	2.45	ef		3.18	cde	2.58	c
Multiking	3	3.03	2.63	a-e		3.30	a-d	2.48	cd
Excalibur	4	2.87	2.65	a-e		3.38	a-d	2.39	cde
Saranac	4	2.92	2.57	b-e		3.27	bcd	2.46	cd
Cimmaron VR	4[w]	3.12	2.49	def		3.55	ab	2.05	efg
Key	4[w]	3.17	2.30	f		3.43	a-d	2.17	def
Mede	5	3.12	2.49	def		3.26	bcd	2.16	def
Archer	5	2.81	2.46	ef		3.64	a	2.41	cde
Belmont	5	2.75	2.57	b-e		3.53	abc	1.98	fgh
ABI 700	6	2.88	2.83	a		3.08	def	1.73	ghi
P581	6	2.87	2.82	ab		2.72	fgh	1.75	ghi
Express	6	2.99	2.55	c-f		2.82	efg	1.71	ghi
P5683	7	3.06	2.45	ef		2.32	ij	1.73	ghi
Valley +	7	2.84	2.43	ef		2.75	fg	1.88	f-i
Rio	7	2.86	2.55	c-f		2.69	gh	1.89	f-i
Moapa 69	8	3.05	2.61	a-e		1.96	j	1.66	hi
Nitro	8	2.99	2.46	ef		2.25	ij	1.69	ghi
GT13R	8	2.85	2.46	ef		2.20	ij	1.63	hi
CUF 101	9	2.99	2.76	abc		2.38	hi	1.67	ghi
P5929	9	3.09	2.74	a-d		2.44	hi	1.57	i

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - No significant differences between cultivars.
x - Means followed by the same letter are not significantly different at P≤0.05.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 2. Percent nitrogen of roots in fall of the establishment year and the following spring under two managements in tests established at Homewood, MB in 1993.

		Fall				Spring			
Cultivar	FD[z]	Seed		Forage		Seed		Forage	
Rangelander	1	2.94	a[y]	2.36	b-f	3.55	a-e	3.05	c-k
Beaver	2	2.89	ab	2.25	efg	3.68	ab	3.00	g-k
Vernal	2	2.76	a-f	2.23	fg	3.28	d-h	2.95	h-k
Algonquin	2	2.67	c-h	2.15	g	3.25	fgh	2.94	h-k
Arrow	3	2.67	c-h	2.27	efg	3.33	c-h	2.83	k
Multiking	3	2.89	ab	2.37	b-f	3.47	a-f	2.91	jk
Excalibur	4	2.77	a-f	2.30	c-g	3.57	a-d	2.96	h-k
Saranac	4	2.81	a-e	2.28	efg	3.31	d-h	3.00	g-k
Cimmaron VR	4[x]	2.52	hij	2.25	efg	3.28	d-h	3.07	e-j
Key	4[x]	2.62	e-i	2.29	d-g	3.27	e-h	3.08	e-j
Mede	5	2.59	f-i	2.34	c-f	3.11	h	2.93	ijk
Archer	5	2.78	a-f	2.32	c-g	3.41	b-g	3.15	c-i
Belmont	5	2.53	g-j	2.26	efg	3.30	d-h	3.06	e-j
ABI 700	6	2.67	c-h	2.53	b	3.28	d-h	3.21	c-g
P581	6	2.55	g-j	2.36	b-f	3.19	fgh	3.16	c-h
Express	6	2.77	a-f	2.28	efg	3.28	d-h	3.28	cde
P5683	7	2.39	j	2.48	bc	3.19	fgh	3.13	d-j
Valley +	7	2.66	c-h	2.47	bcd	3.35	c-h	3.19	c-g
Rio	7	2.72	b-g	2.40	b-f	3.40	b-h	3.26	c-f
Moapa 69	8	2.49	hij	2.54	b	3.48	a-f	3.36	c
Nitro	8	2.84	abc	2.75	a	3.68	ab	3.95	a
GT13R	8	2.45	ij	2.43	b-e	3.12	gh	3.34	cd
CUF 101	9	2.63	d-i	2.54	b	3.62	abc	3.65	b
P5929	9	2.82	a-d	2.77	a	3.75	a	3.62	b

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - Means followed by the same letter are not significantly different at $P \leq 0.05$.
x - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 3. Percent nitrogen of roots in fall of the establishment year under two managements in tests established at Melfort, SK in 1993.

		Fall		
Cultivar	FD[z]	Seed	Forage	
Rangelander	1	2.57[y]	2.08	b-g[x]
Beaver	2	2.69	1.95	d-g
Vernal	2	2.51	1.91	fgh
Algonquin	2	2.50	1.96	d-g
Arrow	3	2.38	1.65	h
Multiking	3	2.52	1.95	d-g
Excalibur	4	2.44	2.03	b-g
Saranac	4	2.35	1.96	d-g
Cimmaron VR	4[w]	2.51	1.92	e-h
Key	4[w]	2.60	2.21	b-e
Mede	5	2.51	1.82	gh
Archer	5	2.49	2.06	b-g
Belmont	5	2.52	1.94	d-h
ABI 700	6	2.50	1.96	d-g
P581	6	2.63	2.01	b-g
Express	6	2.39	1.88	gh
P5683	7	2.56	2.20	b-f
Valley +	7	2.64	2.27	bc
Rio	7	2.61	2.30	ab
Moapa 69	8	2.63	2.23	bcd
Nitro	8	2.84	2.59	a
GT13R	8	2.59	2.26	bc
CUF 101	9	2.86	1.99	c-g
P5929	9	2.76	2.30	ab

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - No significant differences under seed management.
x - Means followed by the same letter are not significantly different at $P \leq 0.05$.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 4. Year two winter injury of 24 alfalfa cultivars managed for seed production over four environments in western Canada.

		Environment								
Cultivar	FD[z]	A94S[y]		M93S		M94S		H93S	A93S	
Rangelander	1	1.50[x]	gh[w]	1.00	g	3.16	i	1.00	1.00	h
Beaver	2	1.75	fgh	1.00	g	3.25	ghi	1.00	1.00	h
Vernal	2	1.75	fgh	1.25	fg	3.43	f-i	1.00	1.75	fg
Algonquin	2	1.25	h	1.00	g	3.60	d-i	1.00	1.00	h
Arrow	3	2.50	de	1.00	g	3.55	e-i	1.00	1.50	gh
Multiking	3	2.25	ef	1.25	fg	3.59	d-i	1.00	2.00	efg
Excalibur	4	2.00	efg	1.00	g	3.20	hi	1.00	2.50	cde
Saranac	4	1.75	fgh	1.00	g	3.71	c-h	1.00	1.75	fg
Cimmaron VR	4[v]	2.50	de	1.50	efg	3.89	c-f	1.00	3.00	c
Key	4[v]	2.25	ef	1.75	ef	3.78	c-g	1.00	2.75	cd
Mede	5	3.50	bc	1.75	ef	3.95	c-f	1.00	3.00	c
Archer	5	2.25	ef	1.50	efg	3.86	c-f	1.00	2.25	def
Belmont	5	2.50	de	1.25	fg	3.89	c-f	1.00	3.00	c
ABI 700	6	3.00	cd	1.50	efg	3.88	c-f	1.00	4.00	b
P581	6	3.75	b	3.25	c	4.16	abc	1.00	5.00	a
Express	6	3.50	bc	1.75	ef	3.93	c-f	1.00	5.00	a
P5683	7	3.50	bc	3.25	c	3.90	c-f	1.00	4.75	a
Valley +	7	3.25	bc	2.50	d	4.11	bcd	1.00	4.75	a
Rio	7	3.25	bc	3.50	c	3.79	c-g	1.00	4.75	a
Moapa 69	8	5.00	a	4.25	ab	4.56	ab	1.00	5.00	a
Nitro	8	4.75	a	4.25	ab	4.25	abc	1.00	5.00	a
GT13R	8	4.75	a	3.75	bc	4.03	b-e	1.00	5.00	a
CUF 101	9	4.50	a	4.50	a	4.69	a	1.00	4.75	a
P5929	9	5.00	a	4.50	a	4.69	a	1.00	5.00	a

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; M94, Melfort 1994; H93, Homewood 1993; A93, Arborg 1993.
x - Winter injury; 1 = no injury, 5 = dead.
w - Cultivar means followed by the same letter are not significantly difference at $P \leq 0.05$.
v - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 5. Year two stand survival (percent) of 24 alfalfa cultivars managed for seed production over four environments in western Canada.

		Environment									
Cultivar	FD[z]	A94S[y]		M94S		H93S		A93S		M93S	
Rangelander	1	85	abc[x]	100	a	85	b-g	69	a	98	ab
Beaver	2	86	ab	100	a	91	ab	69	a	99	a
Vernal	2	84	abc	99	ab	86	a-f	64	a	93	a-d
Algonquin	2	89	a	100	a	89	a-d	73	a	98	ab
Arrow	3	76	bc	100	a	84	c-g	49	bc	95	a-d
Multiking	3	79	abc	100	a	88	a-e	51	b	93	a-d
Excalibur	4	79	abc	100	a	86	a-f	41	bc	95	a-d
Saranac	4	86	ab	100	a	88	a-e	51	b	98	ab
Cimmaron VR	4[w]	78	abc	100	a	86	a-f	25	e	93	a-d
Key	4[w]	76	bc	100	a	86	a-f	25	e	86	a-d
Mede	5	50	de	94	abc	91	ab	26	de	85	bcd
Archer	5	76	bc	98	abc	91	ab	38	cd	96	abc
Belmont	5	74	c	100	a	93	a	21	ef	95	a-d
ABI 700	6	61	d	98	abc	89	a-d	11	fg	91	a-d
P581	6	34	f	86	abc	83	d-h	0	g	46	ef
Express	6	41	ef	95	abc	86	a-f	3	g	84	cd
P5683	7	51	de	90	abc	88	a-e	1	g	44	f
Valley +	7	59	d	80	c	90	abc	1	g	83	d
Rio	7	59	d	96	abc	86	a-f	1	g	59	e
Moapa 69	8	6	g	44	de	83	d-h	0	g	21	g
Nitro	8	10	g	49	d	80	fgh	0	g	18	gh
GT13R	8	16	g	81	bc	86	a-f	0	g	25	g
CUF 101	9	11	g	41	de	79	gh	3	g	8	h
P5929	9	5	g	30	e	76	h	0	g	5	h

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - A94, Arborg 1994; C94, Carman 1994; M94, Melfort 1994; H93, Homewood 1993; A93, Arborg 1993.
x - Cultivar means followed by the same letter are not significantly difference at P≤0.05.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 6. Year three stand survival (percent) of 24 alfalfa cultivars managed for seed production in two environments in western Canada.

Cultivar	FD[z]	A93S		H93S	
Rangelander	1	70	a	68	a-d
Beaver	2	63	a	70	abc
Vernal	2	57	ab	64	b-e
Algonquin	2	69	a	75	abc
Arrow	3	38	cd	61	cde
Multiking	3	46	bcd	64	b-e
Excalibur	4	45	bcd	61	cde
Saranac	4	52	bc	74	abc
Cimmaron VR	4[w]	39	cd	65	a-d
Key	4[w]	31	d	70	abc
Mede	5	19	ef	68	a-d
Archer	5	38	cd	65	a-d
Belmont	5	32	de	79	a
ABI 700	6	11	f	46	fgh
P581	6	–[y]		63	b-d
Express	6	1	g	39	ghi
P5683	7	–		75	abc
Valley +	7	–		73	abc
Rio	7	–		76	ab
Moapa 69	8	–		55	def
Nitro	8	–		50	efg
GT13R	8	–		64	b-e
CUF 101	9	–		33	hi
P5929	9	–		29	i

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - No cultivars with FD>6, nor P581, survived after spring of year two.
x - Means followed by the same letter are not significantly different at $P \leq 0.05$.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 7. Year three seed yield (kg ha^{-1}) of 24 alfalfa cultivars in two environments in western Canada.

Cultivar	FD^{z}	A93S		H93S	
Rangelander	1	234	cde	77	e-i
Beaver	2	317	a	154	a
Vernal	2	243	bcd	128	abc
Algonquin	2	296	ab	135	abc
Arrow	3	218	c-f	137	ab
Multiking	3	204	c-g	112	bcd
Excalibur	4	179	efg	132	abc
Saranac	4	261	abc	161	a
Cimmaron VR	4^{w}	220	c-f	109	b-e
Key	4^{w}	174	fg	135	abc
Mede	5	235	cde	126	abc
Archer	5	204	d-g	100	c-f
Belmont	5	147	gh	127	abc
ABI 700	6	112	h	109	b-e
P581	6	$-^{y}$		48	hij
Express	6	36	i	66	f-i
P5683	7	-		81	d-h
Valley +	7	-		84	d-g
Rio	7	-		108	b-e
Moapa 69	8	-		57	g-j
Nitro	8	-		43	ij
GT13R	8	-		51	g-j
CUF 101	9	-		30	j
P5929	9	-		49	g-j

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - No cultivars with FD>6, nor P581, survived in spring of year two.
x - Means followed by the same letter are not significantly different at $P \leq 0.05$.
w - Cimmaron VR and Key were initially entered with fall dormancy ratings of 5 and 6, respectively.

Appendix 8. Root carbohydrate content (mg g^{-1}) of nine alfalfa cultivars managed for forage production in fall of the establishment year and spring of year two at Homewood, MB from 1993 to 1994 (H93F).

		Fall					Spring				
Cultivar	FD[z]	Sugar		Starch		TNC[y]	Sugar		Starch	TNC	
Rangelander	1	122	a[x]	209	d	331[w]	172	a	87	259	ab
Vernal	2	107	ab	265	bc	372	143	b	105	249	ab
Arrow	3	111	ab	266	bc	377	154	ab	103	257	ab
Saranac	4	110	ab	246	cd	356	155	ab	98	253	ab
Belmont	5	94	bc	285	abc	379	156	ab	130	286	a
ABI 700	6	87	c	285	abc	372	114	c	129	243	b
P5683	7	59	d	321	a	380	115	c	137	253	ab
Moapa 69	8	48	d	328	a	376	81	d	140	221	bc
CUF 101	9	50	d	313	ab	378	82	d	110	192	c

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - TNC, Total Non-structural Carbohydrates.
x - Cultivar means followed by the same letter are not significantly difference at P≤0.05.
w - No significant cultivar differences.

Appendix 9. Root carbohydrate content (mg g^{-1}) of nine alfalfa cultivars managed for seed production in fall of the establishment year and spring of year two at Homewood, MB from 1993 to 1994 (H93S).

		Fall						Spring				
Cultivar	FD[z]	Sugar		Starch		TNC[y]		Sugar		Starch		TNC[w]
Rangelander	1	94	a[x]	277	d	371	a	160	bc	58	c	218
Vernal	2	70	bc	343	c	413	c	175	ab	103	b	277
Arrow	3	64	bcd	365	bc	429	abc	184	a	96	b	280
Saranac	4	76	b	346	c	420	b	177	ab	101	b	278
Belmont	5	57	cd	393	ab	450	ab	183	a	109	b	293
ABI 700	6	53	d	382	bc	435	ab	182	a	98	b	280
P5683	7	68	bc	393	ab	449	ab	159	bc	169	a	328
Moapa 69	8	37	e	425	a	456	a	145	c	158	a	281
CUF 101	9	34	e	426	a	460	a	146	c	146	a	293

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - TNC, Total Non-structural Carbohydrates.
x - Cultivar means followed by the same letter are not significantly difference at $P \leq 0.05$.
w - No significant cultivar differences.

Appendix 10. Root carbohydrate content (mg g^{-1}) of nine alfalfa cultivars managed for forage production in fall of the establishment year and spring of year two at Arborg, MB from 1993 to 1994 (A93F).

		Fall			Spring				
Cultivar	FD[z]	Sugar	Starch	TNC[x]	Sugar		Starch		TNC
Rangelander	1	97[y]	305	401	112	a	115	d	227
Vernal	2	54	347	401	39	b	173	c	212
Arrow	3	71	365	436	44	b	177	c	221
Saranac	4	74	340	414	34	bc	196	bc	230
Belmont	5	76	323	399	17	cd	229	ab	246
ABI 700	6	52	352	404	4	d	257	a	262
P5683	7	63	352	415	0	d	239	a	239
Moapa 69	8	62	345	407	3	d	265	a	269
CUF 101	9	62	330	392	4	d	241	a	246

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - No significant cultivar differences.
x - TNC, Total Non-structural Carbohydrates.
w - Cultivar means followed by the same letter are not significantly difference at P≤0.05.

Appendix 11. Root carbohydrate content (mg g^{-1}) of nine alfalfa cultivars managed for seed production in fall of the establishment year and spring of year two at Arborg, MB from 1993 to 1994 (A93S).

		Fall					Spring				
Cultivar	FD^z	Sugar		Starch	TNC^y	Sugar		Starch		TNC	
Rangelander	1	130	a^x	298^w	394	167	a	63	d	230	cd
Vernal	2	100	b	343	420	158	a	119	c	276	ab
Arrow	3	73	c	394	467	126	b	178	b	304	a
Saranac	4	62	c	398	470	125	b	128	c	253	bc
Belmont	5	71	c	365	436	128	b	148	bc	277	ab
ABI 700	6	61	c	360	421	60	c	185	b	245	bcd
P5683	7	74	c	331	416	5	d	172	b	216	d
Moapa 69	8	71	c	352	423	1	d	300	a	301	a
CUF 101	9	67	c	353	420	11	d	265	a	275	ab

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - TNC, Total Non-structural Carbohydrates.
x - Cultivar means followed by the same letter are not significantly difference at $P \leq 0.05$.
w - No significant cultivar differences.

Appendix 12. Root carbohydrate content (mg g^{-1}) of nine alfalfa cultivars managed for forage production in fall of the establishment year and spring of year two at Arborg, MB from 1994 to 1995 (A94F).

		Fall						Spring					
Cultivar	FD[z]	Sugar		Starch		TNC[y]		Sugar		Starch		TNC	
Rangelander	1	107	a[x]	324	c	432	d	173	a	88	g	262	f
Vernal	2	81	b	393	b	474	c	156	a	161	ef	317	cde
Arrow	3	89	b	408	b	487	bc	154	a	141	f	295	e
Saranac	4	87	b	398	b	485	bc	164	a	159	ef	323	cde
Belmont	5	80	b	413	b	493	abc	163	a	184	de	347	bc
ABI 700	6	50	c	413	b	472	c	105	b	210	cd	315	de
P5683	7	53	c	460	a	513	ab	105	b	236	c	341	bcd
Moapa 69	8	44	c	475	a	519	a	1	c	356	b	356	b
CUF 101	9	24	d	482	a	507	ab	1	c	402	a	402	a

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - TNC, Total Non-structural Carbohydrates.
x - Cultivar means followed by the same letter are not significantly difference at $P \leq 0.05$.

Appendix 13. Root carbohydrate content (mg g^{-1}) of 24 alfalfa cultivars managed for seed production in fall of the establishment year and spring of year two at Arborg, MB from 1994 to 1995 (A94S).

		Fall						Spring					
Cultivar	FD[z]	Sugar		Starch		TNC[y]		Sugar		Starch		TNC	
Rangelander	1	103	a[x]	274	d	377	cd	125	a	76	f	201	d
Vernal	2	77	ab	309	d	386	cd	120	ab	120	ef	240	cd
Arrow	3	56	bc	320	cd	376	d	124	a	134	de	259	c
Saranac	4	78	ab	339	cd	416	bcd	123	ab	145	cde	268	bc
Belmont	5	63	b	317	cd	380	cd	120	ab	183	bc	303	ab
ABI 700	6	27	cd	408	bc	435	bcd	106	bc	238	a	345	a
P5683	7	27	cd	459	ab	486	ab	91	c	222	ab	313	a
Moapa 69	8	11	d	510	a	521	a	16	d	242	a	258	c
CUF 101	9	15	d	438	ab	453	abc	21	d	229	ab	250	c

z - FD, fall dormancy rating of 1 (dormant) to 9 (non-dormant).
y - TNC, Total Non-structural Carbohydrates.
x - Cultivar means followed by the same letter are not significantly difference at $P \leq 0.05$.

Appendix 14. Pesticides used for weed and insect control and dessication in alfalfa trials managed for forage and seed production in six environments in western Canada from 1993-1995.

Pesticide	Trade Name	Common Name	Chemical Name	Env.[z]	Application Date/Timing
Pre-emergent herbicide	Treflan EC	trifluralin	∝,∝,∝-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine	All	pre-plant
Post-emergent herbicides	Pursuit	imazethapyr	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridine carboxylic acid	C94 H93	24 July 1994 mid June 1993
	Pardner	bromoxynil	3,5-dibromo-4-hydrobenzonitrile	A94	early June 1994
	Embutox 625	2,4-DB	4-(2,4-dichlorophenoxy)butyric acid	M94	14 June 1994
	Poast	sethoxydim	2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one	A94	early June 1994
Insecticides [y]	Cygon	dimethoate	O,O-dimethyl S-[2-(methylamino)-2-oxoethyl] phosphorodithioate	M93	late June 1994
	Malathion	malathion	O,O-dimethyl phosphorodithioate of diethyl mercaptosuccinate	H93	6 July 1994
	Dylox	trichlorfon	dimethyl (2,2,2-trichloro-1-hydroxyethyl) phosphonate	H93	20 June 1994
Desiccants [y]	Reglone	diquat	6,7-dihydrodipyrido(1,2-∝:2', 1'c) pyrazidinium	M94 M93	26 Sept 1995 28 Sept 1994
	Harvest	glufosinate	(±)2-amino-4-(hydroxymethylphosphinyl) butanoic acid	H93 A93 A94	26 Sept 1993 18 Sept 1994 25 Sept 1993 19 Sept 1995 19 Sept 1994 31 Aug 1995

z - Environments in which pesticides were used. C94, Carman 1994; H93, Homewood 1993; A94, Arborg 1994; M94, Melfort 1994; M93, Melfort 1993; A93, Arborg 1993.

y - applied only to seed trials