UNIVERSITY OF ALBERTA

Direct Seeding of Alfalfa into Russian Wildrye and Crested Wheatgrass Pastures in Southwestern Saskatchewan

by

Michael P. Schellenberg

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science in Plant Science.

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The undersigned certify that they have road, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Direct Seeding of Alfalfa into Russian Wildrye and Crested Wheatgrass pastures in Southwestern Saskatchewan** submitted by Michael P. Schellenberg in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

Many hectares of grassland in the Canadian prairies are in less than good condition. Standard cultivation and reseeding methods, used to improve production increase the erosion risk, seedling stress, and temporarily remove the area from production. This study was initiated to examine factors affecting alfalfa establishment after direct seeding into sod, in semiarid southwestern Saskatchewan.

The research consisted of three experiments utilizing a full factorial random block design. A greenhouse experiment was initiated to determine competitive ability of two grasses (Russian wildrye *Psathyrostachys juncea* (Fisch.) Nevskii cv. Swift and crested wheatgrass *Agropyron sibiricum* (Willd.) Beauv. cv Nordan) and two alfalfa germplasms (*Medicago sativa* ssp. *sativa* (L.) Lesins & Lesins 'Rangelander' and *M. sativa* ssp. *falcata* Arcengeli 'Mf3713'), and the importance of root and shoot competition. In a field experiment, the benefits to alfalfa establishment of cutting Russian wildrye roots, adjacent to seeded alfalfa rows, to a depth of 15 cm were examined. Another field experiment examined the effect of grass root cutting and four widths of glyphosate suppression of crested wheatgrass on alfalfa establishment.

In the greenhouse experiment, Russian wildrye was the more competitive grass with a 15% greater yield than crested wheatgrass and a 40% reduction in alfalfa yield. 'Rangelander' was the more competitive alfalfa producing approximately 40% more dry matter. Shoot competition adversely affected alfalfa establishment more than root competition.

Both alfalfa germplasms established equally well in the field in 1989. 'Rangelander' outyielded 'Mf3713' in plots established in 1990 in the Russian wildrye pastures. 'Mf3713' crowns produced greater etiolated growth than those of 'Rangelander' after repeated harvests. Cutting grass roots adjacent to alfalfa seedlings had no effect on alfalfa establishment when compared to not cutting grass roots.

All suppression treatments of crested wheatgrass increased

seedling survival 60 to 100% over no suppression, depending on the year. This in turn resulted in +100% greater yields. Suppression of crested wheatgrass by glyphosate improved alfalfa establishment the most when the alfalfa was sodseeded within a 50 cm wide glyphosate treated band and if sufficient soil moisture was available.

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1. Introduction

Rangelands are defined as "land characterized by native vegetation ... suitable for grazing and / or browsing. It includes lands revegetated naturally or artificially to provide forage cover" (Range Term Glossary Committee 1974). Grasslands (approximately 30% of the world's land surface), deserts, forests and cropland utilized by grazing animals are included in the above definition. Rangelands occupy approximately 47% of the world's land area.(Stoddart et al. 1975)

Rangeland condition is arrived at by comparing the current plant community and its vigour to the estimated original pristine climax community (Stoddart et al. 1975). Range condition is divided into four classes: excellent (76-100% similarity to climax), good (51-75%), fair (26-50%) and poor (0-25%). In a recent assessment of nonfederal rangelands in the United States, Joyce (1989) reported 4% excellent, 31% good, 47% fair and 17% poor. Smoliak (1978) found Alberta range conditions somewhat better: excellent 13%, good 44%, fair 29% and 14% poor. In Saskatchewan, the 3 million acres of grazing land controlled by federal and provincial government have declined in productivity due to overgrazing (Malik et al. 1989). Unpalatable plant species have increased, and soil fertility has declined suggesting a need for improvement or renovation.

Pasture improvement or renovation, to improve dry matter and desirable species productivity , has been defined as partial or complete destruction of the sod, plus liming, fertilizing and seeding as required to establish desirable forage plants (Van Keuren et al. 1985). Eight essential parameters for renovation were identified by Van Keuren et al. (1985); 1) species selection, 2) site selection, 3) vegetation control, 4) climatic control, 5) predator control, 6) seedbed preparation, 7) seeding methods and 8) time of seeding.

In the past, renovation usually meant establishment of a completely new vegetation cover by seeding into soil after existing vegetation had been destroyed by cultivation (Vallentine 1980, Van Keuren et al. 1985). More recently, seeding into living, established swards (sod-seeding, direct seeding) has been practiced. Charles (1962) listed the following countries practicing direct seeding: Scotland, Wales, subhumid USA, Australia and New Zealand. Since then research into direct seeding methodologies has increased to include the semi-arid plains of Canada (Waddington 1989), semi-arid plains of the United States (Hewitt and Berdahl 1984, Hewitt and Onsager 1988), the maritime environment of Eastern Canada (Kunelius and Campbell 1984, 1986), and the hill country of Czechoslovakia (Hrazdira 1989).

Van Keuren et al. (1985) defined sod-seeding as "the placement of seed into the soil of existing pasture." Sod-seeding has an advantage over complete seedbed preparation by cultivation when one or more of the following situations applies: 1) erosion hazard is high as on sandy soils and slopes, 2) preparation of the complete seedbed is impractical due to rocky or hilly land, 3) the purpose is to modify rather than replace the existing plant stand (Vallentine 1980).

The advantages of sod-seeding are the result of: 1) a more consolidated seed bed (Bellotti and Blair 1989b), 2) reduced erosion (Haggar 1985, Holland and Tesar 1981, Waddington and Bowren 1976, Vallentine 1980), 3) reduced soil moisture loss (Haggar 1985, Vallentine 1980), 4) improved infiltration and soil moisture retention (Vallentine 1980), 5) improved seedling protection from the elements by the remaining vegetative cover (Vallentine 1980, Dowling et al. 1971), 6) limited grazing may be possible during the establishment year so there is not a complete loss of production (Mooso 1989, Vallentine 1980, Van Keuren et al. 1985), 7) a reduced weed problem (Van Keuren et al. 1985), 8) ultimately increased forage quantity and quality (Provenza and Richards 1984) and 9) a more economical use of time, energy and labour (Bellotti and Blair 1989a, Vallentine 1980) achieved by elimination of cultivation operations.

To successfully establish a forage by seeding into the existing sod the following must be done: (1) remove or substantially reduce existing and competing vegetation, (2) prepare a suitable microenvironment for seedling establishment, (3) ensure firm soil below the seed to promote moisture movement to it and loose soil above for ease of emergence, and (4) leave mulch on the soil surface to reduce erosion, conserve moisture and improve the microenvironment (Herbel 1983).

Environmental conditions coupled with competition from neighbouring plants directly affect seedling establishment (Zajicek et al. 1986) at a very early stage of development (Campbell and Swain 1973). Fenner (1985) went so far as to state "competition from neighbouring plants is the greatest single hazard faced by colonizing seedlings." Competition between plants in the existing sward and the newly introduced seedlings must be altered, at least temporarily, to the benefit of the colonizing seedlings if they are to establishment.

Competition occurs among the various components of the sward for light, moisture, space and nutrients (Van Keuren et al. 1985). Determining which of these factors is most important is extremely difficult (Harper 1977, Fowler 1988b). Shading (light competition) and moisture (root competition) have been given the most attention. Wilkinson and Gross (1964) concluded from a greenhouse pot study with ladino clover seeded in orchardgrass sod, that light and moisture appeared to be critical factors in clover establishment. With high soil moisture and special techniques to prevent shading by orchardgrass, clover establishment was successful. Root competition reduced clover dry matter production primarily by causing plant moisture stress. Groya and Schaeffer (1981) noted from their study of alfalfa seeded into glyphosate-treated Kentucky bluegrass (Poa pratensis L.), smooth bromegrass (Bromus inermis Leyss.) and quackgrass (Agropyron repens L.) sods that competition for both light and moisture must be controlled to ensure legume establishment. Waddington (1989) concluded that competition for light and moisture by established vegetation must be reduced for establishment of sod-seeded alfalfa in eastern Saskatchewan.

The importance of the role that root competition plays may change with stage of growth. Martin and Field (1984) found that root competition played a more important role in the earlier stages of growth of Trifolium repens grown in boxes with Lolium perenne. In later stages, shoot and root competition had similar effects. Once the introduced plants were established, shoot competition became more important. Vandermeer (1989) in his studies of intercropping noted that; 1) during initial stages of growth seedlings are so small that no competition exists, 2) when nutrient depletion zones become well established due to continued growth of the seedlings, root competition occurs, and 3) when above-ground canopies begin to overlap and photosynthesis is modified to accommodate the reduced light environment, competition at the canopy level occurs.

When plants compete for light, at least one of them experiences a decrease in light quantity and quality. This can cause a variety of growth responses. Santhirasegaram and Black (1968) noted that growth of clover undersown in wheat was linearly related to the amount of light available. As shading increased, clover vigour and the amount of nodulation on roots by rhizobia decreased (Evers 1989). With alfalfa, root mass decreased with decreasing light intensity and shoot mass increased (Cooper 1967). Kalmbacher and Martin (1980) observed that when more light penetrated through a bahiagrass (Paspalum notatum Flugge.) canopy to emerging legume (Aeschynomene americana) seedlings, legume stands were better and pasture quality higher.

Light under an established canopy is rich in far-red light (Salisbury and Ross 1985, Smith 1982) which causes changes in seedling morphology: increased internode elongation, decreased branching and leaf production (Caldwell 1987, Casal et.al. 1987, Salisbury and Ross 1985, Smith 1982), increased petiole length, reduced leaf area, and increased stem dry weight (Smith 1982). In grasses, tiller extension, leaf and sheath length increased in a simple hyperbolic relationship to the amount of far-red light added to sunlight (Casal et al. 1987).

Competition for light is considered more important in mesic environments (Campbell and Swain 1973, Groya and Schaeffer 1981). Competition for other factors, with soil moisture the more prominent, may have a greater importance in other environments (Harper 1977, Santhirasegaram and Black 1968). Fowler (1986), concluded that competition for water is highly important in arid and semiarid regions. Evans (1973) stated "in early stages of establishment, competition for nutrients and water is likely to be of greater significance than competition for light". A significant reduction in competition for water by the established vegetation is required if sod-seeding is to be successful (Waddington 1989).

The ability of a plant to successfully compete for available soil moisture will be influenced by the size and speed of development of its root system. Stevenson (1967) postulated that when root systems are crowded, each root interferes with the water supply of nearby roots, reducing water intake and growth of the entire plant. Harper (1977) stated "the greater the amount of leaf growth before plants come in contact with each other, the more extensive the root system and the less likely the plant is to suffer from drought." This suggests the key for survival under drought conditions is the development of an extensive root system. Evans (1973) stated "an early requirement after germination is rapid root penetration to the deeper soil layers, which are less susceptible to rapid drying out than the surface layer". Cook and Ratcliff (1985) noted that in south-eastern Queensland, Australia, root competition played a more important role than shoot competition for establishment of Siratro (Macroptilium atropurpureum) and Green Panic (Panicum maximum var. triglochume) in an existing native grassland dominated by Speargrass (Heteropogon contortus). Caldwell (1987) stated that root competition is more pronounced than shoot competition in a tightly packed population of plants.

The under ground environment in pastures is highly competitive. The bulk of roots under pastures and crops are found in the uppermost 20 to 30 cm (Weaver and Clements 1938, Evans 1978). McCannaughay and Bazzaz (1991) stated "grass swards often have very high rooting densities that effectively exploit all below ground space." Gordon et al. (1989) found, with Quercus douglasii Hook & Arn. of grasses establishment in annual swards, fibrous grass roots were more competitive than the tap-roots of the forbs.

Competitive dominance in the soil environment may occur by a variety of means. Roots of established plants will exclude roots of introduced plants. Bookman and Mack (1982), determined that established plants of Poa pratensis L. excluded Bromus tectorum L. seedlings. Jeangros and Nosberger (1990) noted that an established sward of Lolium perenne L. was able to limit Rumex obtusifolius L. growth by root competition, mainly for the nitrogen. Turkington (1990) grew clones of Trifolium repens L. in boxes containing Dactylis glomerata L., Holcus lanatus L. , and Lolium perenne L. for 43 weeks. After harvesting, dead and decaying grass root systems reduced leaflet length, petiole length, internode length, stolon length, stolon number, number of ramets and shoot dry weight of T. repens. Turkington ranked the grasses for their deleterious effects on the growth of T. repens as follows: Dactylis >Lolium >Holcus >control. Turkington et al. (1988) noted L. perenne indirectly influenced the growth of their neighbouring T. repens by their direct effect on soil microorganisms, particularly Rhizobium trifolii L.

Both morphology and growth rates of root systems differ among plant species. These differences may determine the ability of particular species to exploit environments successfully (Gregory 1987). Shallower-rooted species must have a greater competitive ability to compensate for the extra nutrients available to deeper-rooting plants (Berendse 1979). Species growing together may avoid competition by actively absorbing at different depths in the soil (Caldwell and Richards 1983).

Legumes and grasses have differing abilities to gain access to different nutrients. Grasses, for example, have a mass of fibrous roots near the surface giving them greater assess to nutrient nitrate accumulated near the soil surface (Caldwell and Richards 1983) and are therefore considered the aggressor for nitrogen (Chamblee 1972). In contrast, legumes are the aggressors for phosphorus (Chamblee 1972) due to their deeper root systems gaining access to the deep and narrowly distributed phosphorus (Caldwell and Richards 1983). These differing abilities of resource extraction occur not only between legumes and grasses but also within the families. Goodman and Collison (1982) noted that T. repens was absorbing P^{32} at different depths than L. perenne They also noted differences between individual cultivars of the two species. Eissenstat and Caldwell (1988) noted that Agropyron desertorum (Fisch.) Schult. extracted water more rapidly from the soil profile than A. spicatum (Pursch) Scribn. & Sm. due to its equal but finer root biomass.

When competing against established plant, seedlings are at a disadvantage due to their undeveloped competitive mechanisms. Ross and Harper (1972) noted "dominance by neighbours may be felt very early in the life of the individual". Competition may be avoided if the seedling emerges in a 'safe site' (Harper 1977). These safe sites could be the result of subtle features of soil topography. Hamrick and Lee (1987) found that the position of the seed in relation to topography can have a dramatic effect on germination and seedling establishment. Germination, survival and establishment of Carduus nutans L. were optimized in micro-habitats with reduced evaporation. These micro-habitats were created with cracks or moderately irregular surface topographies with a light covering of litter.

An important type of microhabitat that allows for establishment of seedlings in natural plant communities is the 'gap'. Fowler (1988a) studied the establishment of Aristida longiseta (Steud.) Vasey and Bouteloua rigidiseta (Steud.) Hitchc. in a Texan grassland and concluded "the effects of aggregation in favourable microsites outweighed the effects of competition among these plants". Goldberg (1987), in a study of seedling emergence and survival in undisturbed and experimentally disturbed vegetation of two multisuccessional fields, stated that the probability of establishment from seed of perennials such as Aster pilosus Willd., Trifolium repens, T. pratense L., Achillea millefolium L., and Potentilla recta L. would be low to rare without the presence of gaps of 10 cm or larger. Increasing gap size had a positive effect on survivorship, growth and production for colonizing annuals in a Poa pratensis L. field in Illinois (McConnaughay and Bazzaz 1990) and Solidago ssp. (Golberg and Werner 1983).

Although gaps ease competition between the existing sward and the seedling they do not eliminate competition among seedlings. Mithen et al. (1984) noted that with decreasing "available area", as defined by Thiessen polygons, death of greenhouse grown Lapsana communis L. occurred more rapidly. Ross and Harper (1972) stated "the factor most influencing its (the seedling) growth rate is the density of seedlings already emerged". They added that a seedling was affected by a large number of neighbours, not just one.

When moisture being is limited, periods of growth would be expected to correspond to periods when moisture is available. Currie et al. (1989) noted for semi-arid Montana range a strong correlation between herbage yield and precipitation in the previous fall (September, October) and spring (March, April, May). In field trials at Ballantrae, New Zealand, Barker et al. (1988) noted that the establishment of Dactylis glomerata and Trifolium repens in pasture following the suppression of resident vegetation by paraquat and glyphosate was linearly related to rainfall in the first one and two weeks following seeding, but unrelated to rainfall before sowing or three weeks after sowing.

Alfalfa establishment in competition with existing grass swards is not always successful, especially when soil moisture is deficient (Groya and Sheaffer 1981, Martin et al. 1983, Kreuger and Vigil 1979). In New South Wales, Australia, moisture stress was the most significant contributor to seedling loss of Medicago sativa, Trifolium subterranean, Lolium perenne and Phalaris tuberosa (Campbell and Swain 1973). In Saskatchewan, Waddington (1989) noted that seedling survival could be maintained only by frequent precipitation events. He suggested the frequency and intensity of precipitation events needed would depend on soil texture. For warm season grasses, the first wet-dry period is the most critical to survival (Frasier et.al. 1984).

In Palmerston North, New Zealand, Evans (1978) suggested that deeper soil layers are important to plant survival during times of drought. He also stated that nutrient availability is dependent on water availability. Evans grew alfalfa with Dactylis glomerata and Lolium perenne. The alfalfa's ability to draw water from depths of 150 cm ensured a flow of nutrients as long as both moisture and nutrients were available from the greater depths. The alfalfa's demonstrated deep rooting characteristic provided a competitive advantage over the shallower rooted grasses D. glomerata and L. perenne. Researchers have found that lack of surface moisture may not be the only growth limiting factor under drought conditions. Garwood and Williams (1967) noted that grass growth was severely depressed when all water available to plants in upper soil layers was exhausted even though subsoil moisture was adequate to maintain transpiration at high rates. They demonstrated that when nutrients were supplied to deeper soil layers, grass growth resumed.

In pastures, herbicides may be used to manipulate and rapidly change plant populations while leaving the soil surface undisturbed (Van Keuren et al. 1985). For example, thinning native rangeland consisting of 90% blue grama grass (Bouteloua gracilis) with 4.5 kg ha^{-1} of glyphosate applied to 30 cm wide strips alternating with 15 cm wide untreated strips resulted in a 37% forage yield increase, 67% more animal days of winter grazing and a doubling of seed yields (McGinnies 1984). Suppression of the existing sward by herbicide application can also improve the establishment of sod-seeded seedlings. Hagood (1988) noted a direct linear relationship between control of tall fescue (Festuca elatior L.) and alfalfa establishment and yield.

For a herbicide to be of benefit for sod-seeding it must 1) control a wide spectrum of undesirable plants, 2) effectively kill the entire plant including vegetatively reproducing parts, 3) dissipate rapidly after the desired herbicidal effect (Vallentine 1980, Van Keuren et al. 1985), 4) be harmless to livestock, and 5) be cost effective compared to tillage (Van Keuren et al. 1985). Factors which may prevent success, include 1) excessive dead mulch and litter, 2) control of the resident plant population may be greatly affected by drought and 3) weed infestation may occur from a soil seed bank (Vallentine 1980). Also, allelopathic compounds can be released from decaying vegetative material and inhibit the establishment of new plant species from seed (Hagar 1985).

In a review of pasture and meadow renovation, Van Keuren et al. (1985) listed a number of herbicides utilized for sod-seeding, the most effective of which were those that fully suppressed the grass sward. Paraquat and glyphosate have produced the best results, with glyphosate the more effective (Belanger and Winch 1985, Haggar 1985, Malik and Waddington 1990, Trimmer and Linscott 1985, Vogel et al. 1983, Waddington 1989). Other studies have shown paraquat to be more effective than dalapon (Belanger and Winch 1985, Watkins et al. 1971),and for establishment of sod-seeded birdsfoot trefoil and alfalfa in a bromegrass and kentucky bluegrass pasture in southern Ontario glyphosate, paraquat and dalapon to be more effective than fluazifop-butyl and mefluidide (Belanger and Winch 1985).

The advantage of glyphosate lies in the following features: 1) rapid neutralization on adsorption to soil constituents, 2) immobility in soil and 3) ready degradation by fungal microflora (Tortensson 1985). Waddington and Bowren (1976) noted that glyphosate had no residual effects in contrast to 2,4-Dichlorophenoxyacetic acid (2,4-D) and methyl sulfanilylcarbamate (asulam). On the other hand, Salazar and Appleby (1982) noted that both paraquat and glyphosate damaged seeds of several grasses and legumes seeds when applied directly to them.

The degree or extent of suppression of the resident vegetation has not been defined clearly for all situations. Suppression is not always needed. Bowes found that suppression of a bluegrass sward was unnecessary when seeding alfalfa (Anonymous 1990). Anderson and Delaney (1979) found that alfalfa established best with no herbicide when interseeded in wet hay meadows. In the same study they noted that Garrison creeping foxtail (Alopecurus arundinaceus Poir.) successfully established without herbicide when seeded on March 31 seeding but required a banded glyphosate treatment when seeded on May 23. In this experiment, treatments included a control, and glyphosate applied at a rate of 3.4 kg ai ha $^{-1}$ both broadcast and in 20 cm bands.

Under a variety of environmental conditions, some degree of sward suppression was needed. Vallentine (1980) suggested the width required was dependent on the vigour of the existing stand, soil moisture content and forage species being interseeded: wider strips are needed for more competitive sods and for drier sites where competition for moisture is high. He also suggested that a vegetation control width of 15 to 20 cm was appropriate for alfalfa interseeded into cool season grasses which had been overgrazed, and a width of 30 to 40 cm for native grasses. When they used tillage to control resident vegetation, Smoliak and Feldman (1979) found that the wider the tilled strip the better the establishment of Russian wildrye in native prairie in southeastern Alberta. Total suppression was best of all. Other workers have learned that seedling establishment is not impossible at narrower widths. In the orchardgrass pastures of Pennsylvania, Byers and Templeton (1988) found that glyphosate sprayed at 1.7 kg ha $^{-1}$, to suppress the resident vegetation, in 10.2 cm wide bands spaced 10.2 cm apart resulted in less alfalfa dry matter than if applied to the entire plot. In the Atlantic region of Canada, Kunelius and Campbell (1986) studied the establishment of sod-seeded alfalfa at two sites with timothy (Phleum pratense L.)-dominated swards. They noted a broadcast application of paraquat prior to sod-seeding usually increased alfalfa dry matter yields. Waddington (1989) suggested that there was no advantage for a strip wider than 40 cm for establishing sod-seeded alfalfa in a variety of pastures located within Saskatchewan. The exceptions for the need of suppression had non-limiting moisture. Anderson and Delaney (1979) noted a difference between species for width requirements and sowing dates; earlier sowing dates required no suppression. It could be postulated that the earlier dates resulted in seedling establishment because of the reduced or non-competitive environment present earlier in the spring. If this were so then some amount of suppression is required for all situations in which competition exists between the existing sward and the introduced seedlings. The amount of suppression required depends on plant species and environmental conditions.

Nitrogen and phosphorus fertilization during the establishment year was of no benefit for alfalfa (Dowling et al. 1971, Malik and Waddington 1990), white clover (Cullen 1970, 1966), siratro and green panic (Cook and Ratcliff 1985) establishment when sod-seeded. The addition of fertilizer decreased the presence of white clover (Rais et al. 1989) although nitrogen fertilization was beneficial the year following seeding (Delaney et al. 1984).

Herbel (1983) noted two factors that must be taken into consideration when choosing the type of forage to seed: 1) the potential of the site and 2) whether there are species locally or otherwise available that may be more productive or better able to meet requirements than the plants already present. Introduced plant species have been successful in increasing productivity. Smoliak and Feldman (1978) stated that grazing introduced forage stands, as complementary pastures, had increased livestock gains three- to six-fold over native stands alone.

Charles (1962) produced the following list of recommended plant species for sod-seeding in different parts of the world; 1)continental Europe - Trifolium repens , 2) Britain - Lolium perenne, 3) New Zealand - Trifolium repens, Dactylis glomerata, and Phleum pratense, 4) Eastern Canada - Festuca rubra, Bromus inermis and Melilotus ssp. and for areas with more xeric conditions, F. rubra. To this list for the more xeric conditions can be added Medicago sativa and Melilotus ssp.

Legumes are used most often for direct seeding because they fix nitrogen, thus reducing the need for applications of nitrogen fertilizer (Holland and Tesar 1981, Nyren et al. 1979, Mooso 1989). Clovers have been the legume of choice for sod-seeding in more mesic climates (Charles 1962, Kunelius and Narasimhalu 1983, Kunelius and Campbell 1984, Graffis 1973), whereas alfalfa (Medicago ssp.) provides the best results for arid and semi-arid regions (Frame and Harkness 1987, Leach 1978, Malik and Waddington 1990, McGinnies and Townsend 1983, Anonymous 1989, Waddington 1989). In Iowa, Holland and Tesar (1981) estimated fixation to be 75 kg ha $^{-1}$ of N in the year following establishment of alfalfa in a pasture. This leading to a two- to three-fold increase in the yield of grass pastures and hayfields. Hrazdira (1989) noted similar increases in clover biomass in Czechoslovakia. Kreuger and Vigil (1979) obtained a 30 to 40% increase in dry matter yield from native rangeland following the addition of alfalfa to the forage mixture.

Dubbs (1975) found alfalfa the most competitive and highest yielding when in combination with crested wheatgrass and Russian wildrye in Montana. Jefferson and Lawrence (1988) stated that the creeping-rooted varieties of alfalfa were persistent in the Swift Current area where M. sativa var. falcata was found to be more drought tolerant than M. sativa var. sativa (Anonymous 1989). Berdahl et al. (1989) concluded, from a study of 25 alfalfa cultivars interseeded into rangeland near Mandan, North Dakota, that the cultivars and experimental strains with a high proportion of falcata parentage were better adapted to interseeding in semiarid rangeland. The reasons they suggested for greater adaptability included 1) plant spread by root proliferation, 2) broad crown development, 3) dormancy during midsummer drought and 4) slow, decumbent regrowth. Bittman et al. (1991) found that the genotype 'ScMf3713', six years after establishment in alfalfa-smooth brome mixed stands at Pathlow, Saskatchewan yielded more alfalfa, and had lower weed and smooth bromegrass yields than varieties containing a higher proportion of ssp sativa.

A further benefit of adding alfalfa to the sward is increased crude protein (Kreuger and Vigil 1979, McGinnies and Townsend 1983) which can increase beef production by up to 35% (Kreuger and Vigil 1979). Hervey (1960) cited an increase of 65% in lamb production during the third year of grazing when alfalfa and crested wheatgrass had been seeded into Wyoming native sod.

In their review of alfalfa environmental physiology, Bula and Massengale (1972) reported the following characteristics for alfalfa: 1) seedling emergence and growth was minimal under soil and air temperatures below 10 °C or above 35 °C, 2) the most rapid and vigorous seedling emergence occurs when daily mean air and soil temperatures are near 25 °C, 3) alfalfa grown in a warm regime (33 °C day/17 °C night) grows faster and reaches 10% bloom in half the time of plants growing in a cool regime (24 °C/4 °C), 4) available soil moisture greatly influences growth of alfalfa seedlings, 5) growth of both tops and roots of legume seedlings is reduced by increased moisture stress, 6) once established, the alfalfa plant obtains approximately 46% of its moisture from the top 60 cm of its root zone, 7) alfalfa seedlings do not tolerate low light intensities and 8)under low light conditions, root development is affected more than shoot development. The temperature and light requirements listed above indicate that seedling emergence will likely occur after grasses are actively growing, which would put the alfalfa seedlings at a competitive disadvantage. Low soil moisture would further handicap alfalfa seedlings in a competitive growing environment. Once established, alfalfa would have a competitive advantage because of its ability to withdraw soil moisture from below the depth at which most grass roots are found, assuming moisture is present at the lower depth.

Sod-seeding is not confined to the Legumes; grasses are also utilized. Bellotti and Blair (1989a) working in New Zealand, sod-seeded perennial ryegrass into a pure white clover stand in order to extend grazing into the dry season. Other grasses which have been utilized in various sod-seeding studies include Dactylis glomerata, Phleum pratense, Poa pratensis and Festuca rubra L. Grasses are considered by some to be easier to establish than legumes using no-tillage methods (Van Keuren et al. 1985).

The amount of seed required for a satisfactory stand varies with species. Herbel (1983) suggested a target of 125 to 250 living plants m^{-2}, but cautioned that an excessive amount of seed would result in increased intra- and/or interspecific competition. Vallentine (1980) confirmed that a higher seeding rate reduces the number of survivors per 100 viable seeds planted. Schaeffer and Swanson (1982) found that increasing the seeding rate for red clover to more than recommended rates was of no benefit.

The recommended rate for complete reseeding with alfalfa is 4 kg ha^{-1} in Saskatchewan (Gayton 1990). A rate of up to 1 kg ha^{-1} was recommended for interseeding purposes by Vallentine (1980). Scheaffer and Swanson (1982) found that a seeding rate of 17.6 kg ha^{-1} when sod-seeding alfalfa produced increased yields in fields with very competitive swards. Waddington (1989) used a rate of 200 seeds m^{-1} of row for sod-seeding in Saskatchewan, twice the recommended rate.

Decker and Taylor (1985) found emergence to be no more than a third of sown seed, with only 50% of these surviving the first year. Waddington (1989) noted that a 10% catch resulted in good stands. Sheehy (1989) stated that adequate N (41 kg ha^{-1} yr^{-1}) for grazing purposes in Great Britain was provided when 10% of the crop surface area was in legumes.

Vallentine (1980) stated that sod-seeding should occur on the same date as seeding into cultivated land. Herbel (1983) stated that the most desirable time to seed is directly prior to the season of the most reliable rainfall.

Seeding in spring is usually the best time for a number of plant species in several areas of the world. In Atlantic Canada, late-April to mid-June seeding resulted in successful establishment of sod-seeded alfalfa in a timothy sward (Kunelius and Campbell 1986). In New Zealand, spring overseeding of alfalfa in semi-arid tussock grasslands produced better results than fall seeding (Musgrave 1976). Zajicek et al. (1986) reported that for native forbs, better growth was obtained by seeding in spring; the best seeding date varying with the specific forb. Spring seeding is recommended for Saskatchewan with late fall the second best time (Kilcher 1961).

A variety of plant species are seeded in fall, in a number of areas of the world. In Ontario, fall seeding of birdsfoot trefoil produced better results than spring seeding (Watkins et al. 1971). In northern Saskatchewan on grey-wooded soils with a pasture mix of <u>Bromus inermis</u> L., <u>Poa pratensis</u>, and <u>Festuca rubra</u>, legumes sod-seeded in fall germinated earlier in spring, thus taking advantage of spring moisture (Malik and Waddington 1990). Trimmer and Linscott (1985) reported superior establishment of <u>Trifolium pratense</u> seeded in fall in <u>Dactylis glomerata</u> and <u>Poa pratensis</u> sods for the same reasons. October seeding is better than September seeding for alfalfa in tall fescue pastures of North Carolina (Rogers et al. 1983). The later date ensures that no fall germination will occur, thereby eliminating the possibility of seedling winter kill.

Where herbicides are utilized to suppress resident vegetation, seeding date must be delayed to follow herbicide application. The response to herbicides occurs in three stages 1) direct action of the herbicide on the sward, 2) sward decomposition during which residues toxic to germinating seeds occur in the soil and 3) end of activity. Seeds should germinate at the end of stage two (Charles 1962). Adverse affects have been noted following herbicide application to the existing sward. Dowling and Linscott (1983) found decomposition of a glyphosate-killed _Agropyron repens_ L. sward produced allelopathic effects that limited alfalfa seedling numbers. Eltun and Wakefield (1984) attributed substances from grasses (_Phleum pratense_, _Poa pratensis_, and _Dactylis glomerata_) treated with glyphosate (1.5 kg ha^{-1}) with inhibiting alfalfa seedling numbers and growth. They also reported the longer the period following application of glyphosate to timothy sod, up to 28 days, the better the alfalfa yields.

Experiments to determine the delay required between glyphosate application and seeding have produced a wide range of results. Establishment was best with an interval between spraying and seeding of 3 days (Moshier and Penner 1978), 2 to 3 weeks (Delaney et al. 1984), 28 days (Haggar 1985, Welty et al. 1981), and 35 days for surface-sown pasture species (Campbell 1974). Byers and Templeton (1988) stated no effect was evident for delayed seeding. Possible invasion of the treated area by undesirable plants must also be considered. Waddington and Bowren (1976) found in the gray-wooded soil zone of Saskatchewan a period greater than 2 weeks between spraying and seeding resulted in weed invasion and increased competition for the sown seedlings.

The optimum season for herbicide application varies with the herbicide used. In Rosemount, Minnesota, Martin et al. (1983) found, for sod-seeding alfalfa, dalapon was most effective if applied to a mixed stand of smooth bromegrass, quackgrass and Kentucky bluegrass in April. Mueller-Warrant and Koch (1983) noted at Durham, New Hampshire, fall and spring applications of paraquat were equally effective in suppressing quackgrass sod prior to sod-seeding alfalfa, but the spring application resulted in higher alfalfa yields due to reduced weed competition. In Portage la Prairie, Manitoba Bowes and Friesen (1967) found that a spring application of paraquat followed by spring seeding of alfalfa into the suppressed Kentucky bluegrass pastures, resulted in the best stands of alfalfa. Wolf et al. (1989) found alfalfa sod-seeded in spring, into a mixed Festuca arundinacea Schreb. and D. glomerata sod, following a fall paraquat application established better than where no paraquat was applied. Mueller-Warrant (1981), in New York, found that an early May glyphosate application and a late May alfalfa seeding into the suppressed alfalfa stands was best. An early fall glyphosate application on a pasture of mixed grasses (bromegrass, Kentucky bluegrass and red fescue) with late fall seeding of alfalfa and cicer milkvetch provided satisfactory results in the Melfort area of Saskatchewan (Malik and Waddington 1990).

For successful establishment, seed placement is critical. For best results, the seed must be covered (Bellotti and Blair 1989b, Waddington 1989, Taylor et al. 1972) as opposed to surface seeded. A number of different seeders were able to place the seed correctly (Waddington 1989).

Pest preference is a factor when choosing a plant species or cultivar.

In the mesic northeastern U.S., slugs (Derocerus spp., Arion spp.) and clover root curculio (Sitonia hispidulus (F.)) have been a problem for establishment of alfalfa and red clover (Byers et al. 1985, Byers and Templeton 1988). Slug control greatly increased chances of successful establishment of sod-seeded plant species (Dowling 1981, Dowling and

Linscott 1985, Bahler et al. 1987).

In the more xeric western prairie region of North America, grasshoppers are often the dominant pest. Grasshoppers have prevented alfalfa seedling establishment in Saskatchewan (Waddington 1989). Melanoplus spp. are the dominant grasshopper inflicting the greatest damage to forbs and grasses in the Stavely and Coalhurst areas of Alberta (Hardman and Smoliak 1982). Hewitt and Onsager (1988) stated that the extent of damage to alfalfa depended on the species of grasshopper present. In their study, Melanoplus sanguipes populations increased in plots where Artemisia tridentata Nutt. was removed and alfalfa and cicer milkvetch was interseeded. For example, grasshoppers (Melanoplus ssp.) prefer the alfalfa cultivar 'Roamer' over other cultivars (Hewitt and Berdahl 1984, Hewitt et al. 1982).

Utilization of insecticides has been beneficial for seedling establishment. Rogers et al. (1983) noted that application of carbofuran removed insects and significantly increased yields of sod-seeded ladino clover. In a second study, they found insect control was required for September sod-seeded alfalfa into tall fescue swards in eastern U.S. (Rogers et al. 1985).

Other pests reducing the success of seedling establishment include seed harvesting ants (Campbell and Swain 1973) and rabbits (Rumbaugh and Pedersen 1979). Roundy et al. (1985) noted that infrequent grazing by black-tailed jackrabbits (Lepus californicus) can slightly increase seedling survival in a dry year but heavy grazing results in stand failure. The slight increase in seedling survival under light grazing was attributed to the decrease in leaf surface area available for evapotranspiration.

Competition from invading weeds can also affect establishment. Smoliak and Feldman (1979) noted that removal of 50% of the vegetation resulted in significant increases in growth of native grass, but also of undesirable forbs, and woody species such as Artemisia frigida Willd.

which persisted for several years. Bahler et al. (1987) stated that weeds must be controlled for successful alfalfa establishment in stubble.

Grazing the pasture prior to sod-seeding can be beneficial or detrimental, depending on timing, intensity and site climatic conditions. Heavy grazing has been of benefit to establishment when done immediately before or after sowing to suppress the existing sward and remove competition (Cullen 1966, 1970, Rayburn et al. 1980, Tesar 1980, Holland and Tesar 1985). Once seedlings emerge, they become the preferred forage for livestock (Vallentine 1980, Waddington 1989) and grazing becomes detrimental. On mesic sites light grazing may be tolerated (Vallentine 1980) when grazing occurs above seedling height.

Objectives

The purpose of this research was to examine methods of suppressing competition from existing pasture vegetation to allow establishment, by direct seeding, of two alfalfa germplasms. Pastures, into which the alfalfa germplasms were seeded, were dominated by either Russian wildrye (Psathyrostachys juncea (Fisch.) Nevskii in Komarov) in rows spaced at 90 cm or a solid stand of crested wheatgrass (Agropyron sibiricum (Willd.) Beauv.) (Moss 1983). These are the most common Eurasian introduced grasses in southwestern Saskatchewan.

The methods examined were: 1) killing a desired width of existing grass sward by applying 2.2 kg ha^{-1} of glyphosate and 2) eliminating living grass roots under the seeded area by severing them to a depth of 15 cm. In the Russian wildrye the effect of cutting grass roots on one or both sides of the seeded alfalfa and existing grass rows was examined. In the crested wheatgrass, the effects on alfalfa establishment of several widths of the glyphosate sprayed strips were examined along with root cutting at the edge of the surviving grass.

All experiments compared Medicago sativa ssp. falcata Arcengeli

'Mf3713' a drought and cold-hardy, non-creeping-rooted selection, with *M*. *sativa* ssp. *sativa* (L.) Lesins & Lesins 'Rangelander' a creeping-rooted selection of mixed ssp. *sativa*-*falcata* parentage (Quiros and Bauchan 1988).

2. Materials and Methods

2.1 Greenhouse Competition Study: Alfalfa seedlings established in Russian Wildrye or Crested Wheatgrass Swards

In order to examine 1) the competitive ability of two alfalfa seedling germplasms in Russian wildrye and crested wheatgrass swards, 2) the competitive effect of the grasses on the alfalfa seedlings, and 3) the effect of shoot or root competition on the alfalfa's ability to establish in the grass swards, a three factorial randomized block design (Appendix A) with 6 replicates was used. The factors were: 1) 2 grass species - Russian wildrye (cv. Swift) and crested wheatgrass (cv. Nordan), 2) 2 alfalfa germplasms - 'Rangelander' and 'Mf3713', and 3) 4 types of competition - root competition only, shoot competition only, both root and shoot competition and no competition.

Pots, 30 cm in diameter and 25 cm deep, were filled with a mixture of three parts greenhouse soil; two parts peatmoss and one part vermiculite. The treatment eliminating root competition, had a 7 cm diameter by 21 cm long plastic cylinder placed in the centre of the soil to prevent grass root growth within the centre core. The same size of cylinder was in the centre of the pot above the soil to prevent shoot competition. The above ground cylinder was perforated to allow air circulation.

Grasses were sown in each pot at a rate of 17.2 kg ha^{-1} (day 0)and the pots placed on a greenhouse bench at a temperature of 20 °C beneath high-intensity sodium lighting (16 hours of light 789 $\mu Em^{-2}s^{-1}$), and watered to saturation every second day.

Additional seed was sown one week later (day 8) in any gaps to obtain a solid stand and ensure root competition.

When the grass seedlings were at the 2 to 3 leaf stage, day 30, glyphosate was applied to the centre 38.5 cm^2 at a rate of 2.0 kg ai ha^{-1} in 100 l water using a 7 cm diameter cylinder over the nozzle of the applicator to insure a circular pattern.

Eleven days after the glyphosate application (day 41) a string of incandescent lights of 582 $\mu E\ m^{-2}\ s^{-1}$ intensity (zeta ratio 0.7337) were added to supplement the near red portion of the spectrum obtained from high intensity sodium lighting of 345 $\mu E\ m^{-2}\ s^{-1}$ intensity (zeta ratio 1.626). The incandescent lights were turned on 10 minutes prior to the sodium lights, to better simulate the natural light spectrum. A zeta ratio of 1.500 was obtained when both sets of lights were on with an intensity of 788 $\mu E\ m^{-2} s^{-1}$. The zeta ratio and light intensities were obtained using a Licor LI-1800 spectroradiometer.

On day 79 the grass was clipped to a height of 2.5 centimetres and nitrogen was applied at a rate of 100 kg ha^{-1}.

On day 88, the soil pH was taken in the centre of the pots using an Accutronics pH90 pH computer.

On day 89, alfalfa inoculated with Rhizobium meliloti was seeded into the glyphosate-treated centres of the pots at a rate of 12 seeds per pot. When the spade leaf was fully open, the alfalfa seedlings were thinned to three per pot. The grass was clipped to a height of 5.0 cm seven days after seeding the alfalfa (day 96). Pots were treated with a fungicidal solution of 0.25% oxine benzoate applied as a drench once a week for four weeks to prevent alfalfa seedling damping off.

Thirty-two days after seeding the alfalfa (day 121), light intensity was measured at the top of the alfalfa seedling canopy and at soil level in the centre of the pots.

Seventy-four days after the seeding of the alfalfa (day 163), alfalfa and grass shoots were harvested to a height of 2.5 cm The alfalfa was at approximately 10% bloom. Data on grass shoot height, number of alfalfa plants, alfalfa plant height, number of alfalfa leaves per pot and leaf area of the alfalfa per pot were taken at this time. The leaf areas were measured with a Licor leaf area machine. All samples were dried in an oven at a temperature of 65 °C for a minimum of 48 hours and weighed.

A second harvest and measurements took place fifty-four days after the first (day 217). All measurements were taken as in the first harvest. In addition, the alfalfa roots were harvested, dried and weighed.

2.2 Field Experiments

The field experiments were located at the Agriculture Canada Research Station, Swift Current, Saskatchewan (sections 16 and 28, range 14 township 15 west of the third meridian) (Figure 1).

Sections 16 and 28 soils are Orthic Brown Chernozems, loam in texture, of the Swinton association (Ayres et al. 1985) (Appendix D). Section 16 soil is a slightly stony dissected loess. Section 28 soil is a moderately to very stony dissected moraine. Wind erosion can become serious during periods of prolonged drought, and water erosion can be a serious problem when runoff occurs (Mitchell et al. 1962).

Swift Current is located in a semi-arid area region "characterized by light rainfall and high evaporation" (Gove 1986). Mean annual precipitation is 360 mm with the greatest proportions falling in fall and spring. June is the only month receiving greater than 50 mm of rainfall. The Precipitation:Evaporation ratio for Swift Current is 0.5 (Smoliak et al. 1990). The plant available water holding capacity of the Swinton silt loams surrounding Swift Current has been estimated as 200 mm to a depth of 120 cm (DeJong and Shields 1988, Shields and Sly 1984). Shields and Sly (1984) report an aridity index of 300 mm (the amount the perennial crop demand for water exceeds that which is available) for the area immediately southeast of Swift Current.

Meteorological data were obtained from records maintained at the Agriculture Canada Swift Current Research Station. The weather station is located on section 16, approximately 500 meters south of the field experiments in the same section (Figure 1). The data were obtained following standard Environment Canada Methods (Weather Services Directorate 1992).

Weekly totals of precipitation and potential evaporation, average temperature and average minimum and maximum air temperatures were obtained over the growing season (May 1 to September 30) for the years 1989 and 1990. The 30 year average data, were obtained from site records. Measurements of potential evaporation used a U.S. Weather Bureau Class A pan, and were limited in early spring and late fall due to ice formation in the pan. The potential evaporation was subtracted from the precipitation to provide a better understanding of the climatic stress encountered by the seedlings.

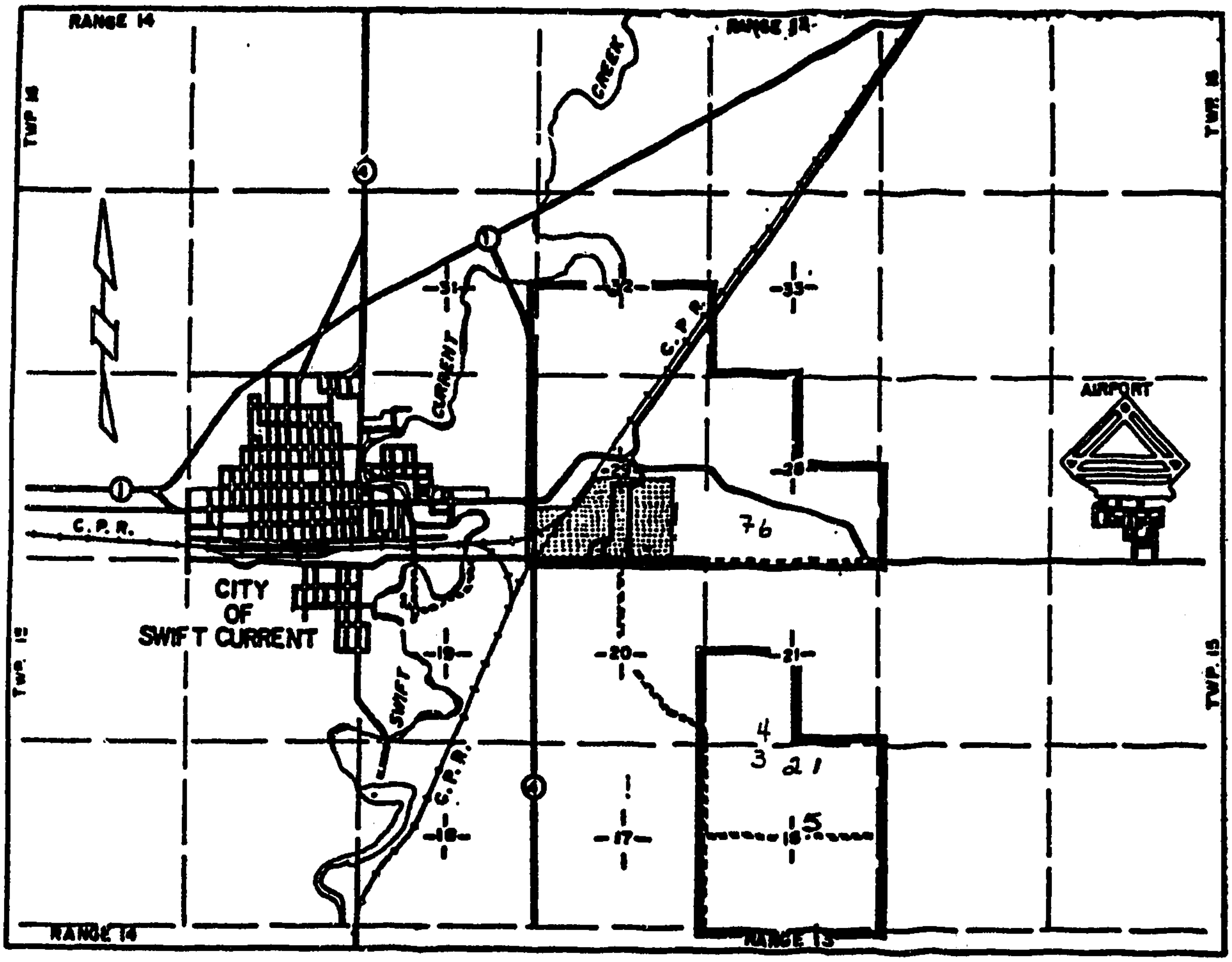


Figure 1: Location of field study sites on Swift Current Research Station. 1 - site 1 seeded in 1989, 2 - site 2 seeded in 1989, 3 - site 1 seeded in 1990, 4 - site 2 seeded in 1990, 5 - weather station, 6 - 1989 Russian wildrye study, 7 - 1990 Russian wildrye study. (courtesy of Agriculture Canada, Swift Current Research Station)

2.2.1 Effect of Spray Width and Reduced Root Competition on Alfalfa Establishment in Crested Wheatgrass Stands

In order to examine the effects on alfalfa establishment of 1) killing established crested wheatgrass to various distances from the seeded alfalfa row, 2) reducing crested wheatgrass competition by severing any roots invading the area of dead grass around the seeded row, and 3) seeding two distinctly different alfalfa germplasms, a three factorial randomized block design (Appendix A) with four replicates was used for all four sites. The factors were: 1) alfalfa germplasms - Rangelander and MF3713, inoculated with R. meliloti; 2) root cutting or no root cutting and 3) width of glyphosate treatment - no application, 25 cm width, 50 cm width and 75 cm width. At all sites the individual plots were 3 meters wide by 8 meters long running north and south. Blocks were separated by a 2 meter path.

Two sites on the Agriculture Canada Swift Current Research Station section 16 were used. Site 1 was a solid stand of 30+ year old crested wheatgrass with a slight northerly slope. The area had been cut for hay most years since establishment. Site 2 was approximately 500 meters northwest of Site 1. The 1989 experiment at site 2 was on a thin stand of crested wheatgrass and large mats of little clubmoss (Selaginella densa Rydb.) and low prairie everlasting (Antennaria aprica Greene). Previously, the area had been cut for hay each year. The 1990 experiment at site 2 was adjacent to the 1989 experiment but was on a solid crested wheatgrass stand with a northeasterly slope and had been grazed by cattle at various stocking rates and times until 1988.

In 1989, glyphosate was applied at 2.2 kg ai ha^{-1} to an experiment at each site on May 9-10. Strips not completely killed were resprayed two weeks later.

Roots were cut to a depth of 15 cm at both edges of the 50 cm and 75 cm width sprayed strips May 29-30, 1989 utilizing an experimental paraplow with 1 m diameter cutting disks. The 25 cm width was knifed to the same depth using flat spades. The control plots were knifed with a width of 50 cm. The blade or spade was run down both sides of the sprayed strips.

The alfalfa was seeded, at a rate of 100 seeds m^{-1}, in the centre of the killed grass strips or the centre of the control plots, on June 1, 1989 utilizing a self propelled press drill plot seeder with offset disks followed by packers seeder.

The experiments were repeated in 1990 at each site. The experiments were sprayed May 17, roots severed May 30-June 1 and alfalfa seeded June 3.

A Campbell Pacific Nuclear Model 503 Hydroprobe calibrated for Research station soils, with a source strength 1.85 GBq and BF_3 detector with a surface adaptor (Chanasyk and Naeth, 1988) was used to monitor surface (0-15 cm) soil moisture. The same equipment was used without the surface adapter to obtain soil profile moistures for depths of 0-50 cm at 10 cm increments. Surface measurements were made on an approximately biweekly basis, weather and equipment availability permitting. Profile measurements were made occasionally, at site 1 only, using access tubes placed in the alfalfa row.

The neutron meter with surface adapter was calibrated by taking 30 soil cores with a diameter of 7.5 cm, to a depth of 15 cm from site 1 during the 1989 growing season. Gravimetric water (moisture g^{-1} soil) and bulk densities (D_B = Weight of soil/Volume of soil) were used to obtain % volume values which in turn were used with the corresponding neutron meter values to obtain the calibration equation:

```
Corrected     Actual
Volumetric =  Volumetric * 6.80 + 8.16
Reading       Reading
```

r = 0.94
prob>F 0.0001.

Light measurements were taken in mid-June of the establishment year and prior to spring harvest of the second year of growth with a Licor model Li-188 quantum meter. Readings were taken from 11:00 h to 14:00 h to obtain readings when the sun was at its zenith.

Three one-meter strips within each plot, were staked and alfalfa plants counted two weeks after seeding and again in late August to early September of the establishment year. The percentage of plants counted in spring and surviving until fall was calculated:

% Survival = (Fall number m^{-1} / Spring number m^{-1})*100.

The average stage of development of alfalfa seedlings was recorded twice a week until the third leaf emerged. Because the stage of development varied within each plot, the stage of the majority of the seedlings was used as the estimate.

Alfalfa plant height measurements were taken on August 24, 1989, July 4, 1990 in the 1989 experiments and September 5 in the 1990 experiments.

On September 11, 1989 alfalfa, grass, and weeds were cut separately at ground level from a 1.0 by 0.5 m quadrat placed across the centre of the plot using sickles. The same procedure was followed in 1990 except that a 2.0 by 1.0 m quadrat was used. The plant material was harvested on July 5, 1990 for the 1989 experiments and September 11 for the 1990 experiments.

For all grass dry matters an adjusted value was calculated to detect any increased grass growth in the area not killed. For the 75 cm sprayed:

Adjusted Value = (dry matter from remaining 25 cm * 4).

Similar calculations were used for 50 and 25 cm wide bands.

On October 22-23, 1990, three alfalfa plant crowns and roots per plot were excavated from experiment established in 1989 at site 1 using a backhoe . The backhoe was utilized because of the extreme difficulty of removing 15 cm of intact alfalfa crowns and roots from drought-hardened soil. The excavated crowns and roots were washed within 24 hours to remove soil, planted in 10 cm diameter by 25 cm deep plastic pots filled with medium-textured vermiculite, and placed in growth rooms with a constant temperature of 20°C, a relative humidity of 80% and no source of light. The etiolated growth was harvested every second week until no growth occurred (McKenzie et al. 1988). All plant material was oven-dried at a temperature of 100°C for a minimum of 24 hours and then weighed.

2.2.2 The Effect of Reduced Root Competition on Alfalfa Establishment in a Russian Wildrye Stand

In order to examine the effect on alfalfa establishment of 1) reducing Russian wildrye competition by severing any roots invading the area of dead grass around the seeded row, and 2) seeding two distinctly different alfalfa germplasms, a two factorial randomized block design with 4 replicates was used(Appendix A). Each plot consisted of four Russian wildrye rows, 0.9 m apart and 10 m long with the long axis east-west; with a 5 m pathway separating blocks, of which the centre two rows received the root cutting treatment and the outside two acted as guards. The factors were: 1) alfalfa germplasm -Rangelander and MF3713, seeded between the centre two grass rows and 2) root cutting pattern. In 1989 the Russian wildrye roots were cut on one side of one grass row adjacent to the seeded alfalfa (Figure 2A), one side of both grass rows adjacent to the seeded alfalfa (Figure 2B) and a control (no roots cut). In the 1990 experiment two additional root cutting treatments were added: roots cut on both sides of one grass row adjacent to the seeded alfalfa (Figure 2C) and on both sides of both grass rows adjacent to the seeded alfalfa row (Figure 2D).

The 1989 and 1990 experiments were located in section 28, on Swinton loam. The site used in 1989 had a slight westerly slope whereas the nearby 1990 site had a northeasterly slope. Russian wildrye and alfalfa were cross-seeded in 0.9 m row spacings in fall 1977. Cattle grazed from 1979 until 1988 at various stocking rates and dates. The alfalfa winter-killed in 1985; and crested wheatgrass has invaded the space between the Russian wildrye rows. The area between the Russian wildrye rows was sprayed with

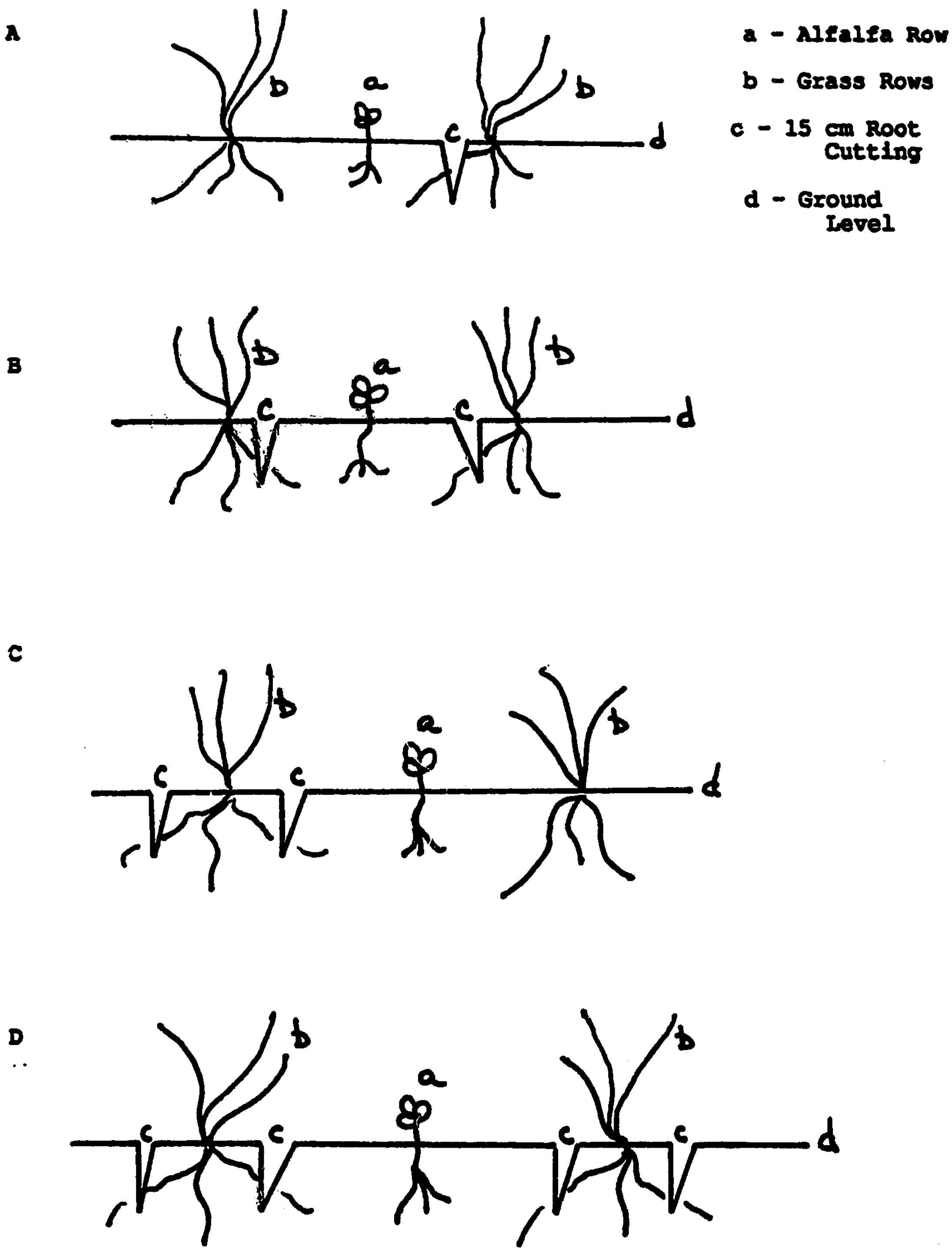


Figure 2: Russian wildrye root cutting treatments A) roots cut on one side of alfalfa row, B) roots cut on both sides of alfalfa row, C) roots cut on both sides of grass row on one side of alfalfa row and D) roots cut on both sides of grass rows on both sides of alfalfa row.

2.2 kg ai ha^{-1} of glyphosate to remove the crested wheatgrass prior to applying the treatments.

In the experiment started in 1989 roots were cut to a depth of 15 cm on May 29, utilizing the paraplow previously described. In the experiment started in 1990 the roots were cut on May 30 to the same depth using a flat spade. On June 1, 1989 and June 3, 1990 the alfalfa seed was inoculated with R. meliloti and seeded immediately, at a rate of 100 seeds m^{-1} down the centre of the space between the centre 2 grass rows, with the plot seeder previously described.

On August 11, 1989 when soil moisture in the top 10 cm dropped below the permanent wilting point, additional water was provided by a single flooding of the plots to simulate a 2.5 cm precipitation event.

Surface soil moisture (0-15 cm) was monitored on a bi-weekly basis, weather and equipment availability permitting, using the same site-calibrated Campbell Pacific Nuclear Model 503 Hydroprobe and surface adapter described above.

The same procedure as described for the crested wheatgrass experiment was used to obtain the following calibration equation for the Russian wildrye sites:

$$\text{Corrected Volumetric Reading} = \text{Actual Volumetric Reading} * 2.34 + 2.15$$

$r = 0.90$
prob. $F < 0.0001$.

Light measurements were taken in mid-June of 1989 and prior to spring harvest 1990 with a Licor model Li-188 quantum meter. Readings were taken from 11:00 h to 14:00 h to obtain readings when the sun was at its zenith.

Alfalfa plant counts, heights and development times were taken as described for the crested wheatgrass experiment.

The plots were harvested with sickles on September 21, 1989 and July 11, 1990 for plots established in 1989. Plots established in 1990 were harvested on September 11, 1990. Alfalfa was harvested by clipping a 1 m length of row near the centre of the plot at a height of 2.5 cm. One m from each grass row adjacent to the alfalfa was harvested at the same height, with the vegetative material from the two grass rows being bulked. Areas damaged by mice, Richardson's ground squirrels or deer were avoided.

2.3 Data Analysis

All climatic data were analyzed for differences between 1989 and 1990 and between the years and the 30 year average by calculating Student's t Test with the assumption of unequal variance (Steel and Torrie 1980).

Because precipitation follows a Poisson distribution (Branson et al. 1981, Yevjevich 1972) the square root of the values were used for analysis (Steel and Torrie 1980).

All statistical analyses of experimental data were performed using the SAS GLM procedure (SAS Institute Inc. 1990). The F statistic was used to determine significance at $P < 0.05$. Analysis of variance was performed utilizing the following hypotheses: $H_0 : \delta^{21}=\delta^2{}_2$, $H_1 : \delta^2{}_1 \neq \delta^{22}$ for all single sources variance, $H_0 : (ab)_{ij} = 0$, $H_1 : (ab)_{ij} \neq 0$ for all 2 way interactions, $H_0 : (abc)_{ijk} = 0$ and $H_1 : (abc)_{ijk} \neq 0$ for all 3 way interactions where a, b, and c equal the effects of the single sources of variance and $_i = (1,2 \ldots n)$, $_j = (1,2 \ldots m)$ and $_k = (1,2 \ldots o)$ (Montgomery 1984).

Orthogonal contrasts were used for planned comparisons (Appendix A) to test differences between factors (Fitter 1988). Polynomial contrasts (Appendix A) were used to test relationships between the differing widths of glyphosate application for the effect of spray width and reduced root competition alfalfa establishment in crested wheatgrass stands (Steel and Torrie 1980). The linear polynomial contrast tested for a linear response between the 25 cm and 75 cm widths. The quadratic polynomial contrast tested for the quadratic or second-degree response (nonlinear response or lack of fit to a linear response) of the three width treatments. The factors and hypotheses (Montgomery 1984) used for each contrast are found in Appendix A.

3. RESULTS

3.1 Greenhouse Competition Study: Alfalfa Seedlings Established in Russian Wildrye or Crested Wheatgrass Swards

As indicated in tables in Appendix B, interactions were only occasionally significant. Therefore only the main effects are discussed.

Table 1: The effect of Russian wildrye and crested wheatgrass, 74 days after seeding the alfalfa, on alfalfa seedling growth, and grass production.

Material Harvested	Russian wildrye	Crested wheatgrass
Number of alfalfa leaves/plant	8.10	12.52
Alfalfa leaf area (cm^2/plant)	6.87	11.31
Alfalfa shoot dry matter (g/plant)	0.04	0.09
Grass plant height (cm)	16.96	20.27
Grass shoot dry dry matter (g/plant)	19.54	19.29

At the first harvest, after 74 days of alfalfa growth, Russian wildrye appeared to suppress alfalfa growth more than crested wheatgrass, although the differences were not significantly different (Table 1). Alfalfa produced 35% fewer leaves, 39% less leaf area and 56% less shoot dry matter. The Russian wildrye plants tended to be shorter but produced similar levels of shoot dry matter as the crested wheatgrass (Table 1).

By the second harvest 128 days after seeding alfalfa, Russian wildrye had suppressed alfalfa growth significantly ($P<0.05$) more than did crested wheatgrass (Figure 3). Alfalfa root dry matter production of 0.09 g of roots per alfalfa plant was equally affected by both grasses.

Table 2: Russian wildrye and crested wheatgrass shoot dry matter yields for the second harvest 128 days after seeding alfalfa.

Species	Grass Shoot Dry Matter	
	g/pot	g/alfalfa plant
Russian wildrye	5.25	2.23
Crested wheatgrass	4.46	2.52
Significance	*	ns

(* = significant difference for P<0.05, ns = not significant P<0.05)

Russian wildrye produced significantly more shoot dry matter per pot than did crested wheatgrass, but the amounts were not statistically different on a per alfalfa plant basis, averaging 2.4 g of shoot dry matter per alfalfa plant (Table 2).

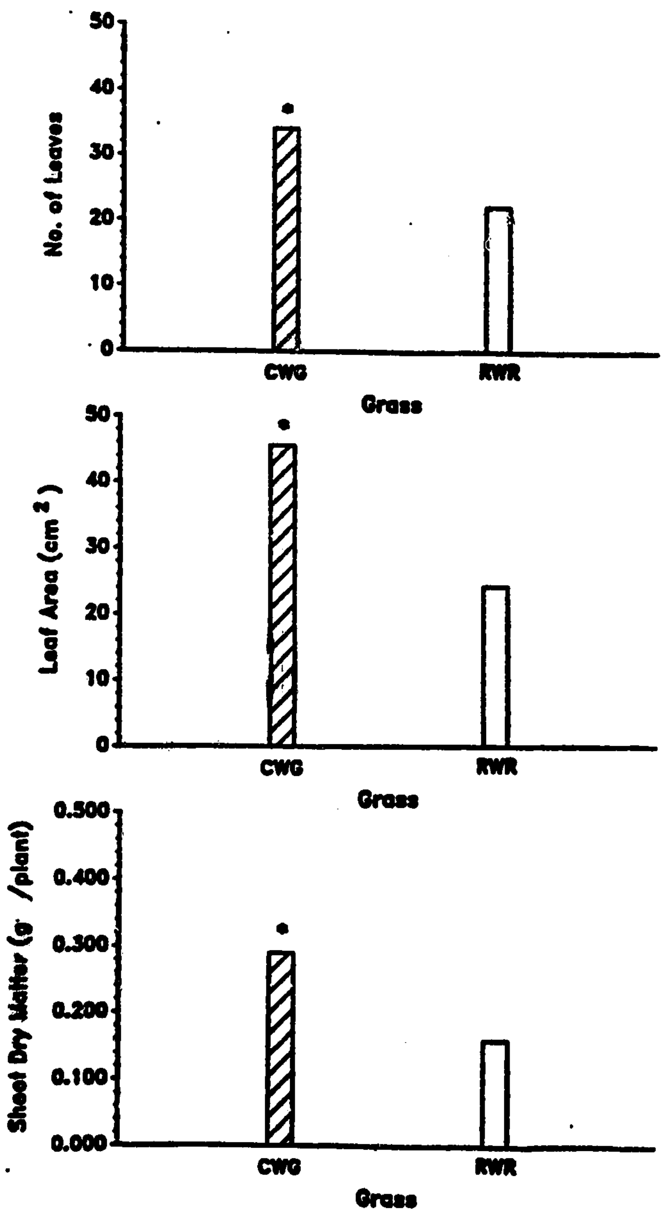
Rangelander alfalfa tended to produce more leaves, more leaf area and greater shoot dry matter than Mf3713 for the second harvest (Table 3), although differences were not statistically significant.

The alfalfa germplasms had no significant effect on grass production for the first harvest (Table 3). The grass plants attained an average height of 18.6 cm and an average shoot dry matter production of 19.4 g per pot.

Rangelander alfalfa outyielded Mf3713 alfalfa for the second harvest. Mf3713 produced 45% fewer leaves, 50% less leaf area, 47% less shoot dry matter and 55% less root dry matter than Rangelander alfalfa (Figure 4).

Grass shoot production was not affected by differences in alfalfa germplasm (Table 4). However a significant effect was noted for grass production on a per alfalfa plant basis. Pots with Rangelander had 30% less grass shoot production than pots with Mf3713.

There was significantly less alfalfa growth in pots where alfalfa and grass shoots competed than in pots where alfalfa and grass roots competed for the first harvest (Table 5). In pots where alfalfa and grass roots competed, the alfalfa had 60% more leaves, 66% more leaf



<u>Figure 3</u>: Russian wildrye and crested wheatgrass effect on alfalfa seedling leaves, leaf area and shoot dry matter for the second harvest, 128 days after alfalfa was seeded. (* = significant difference for P<0.05).

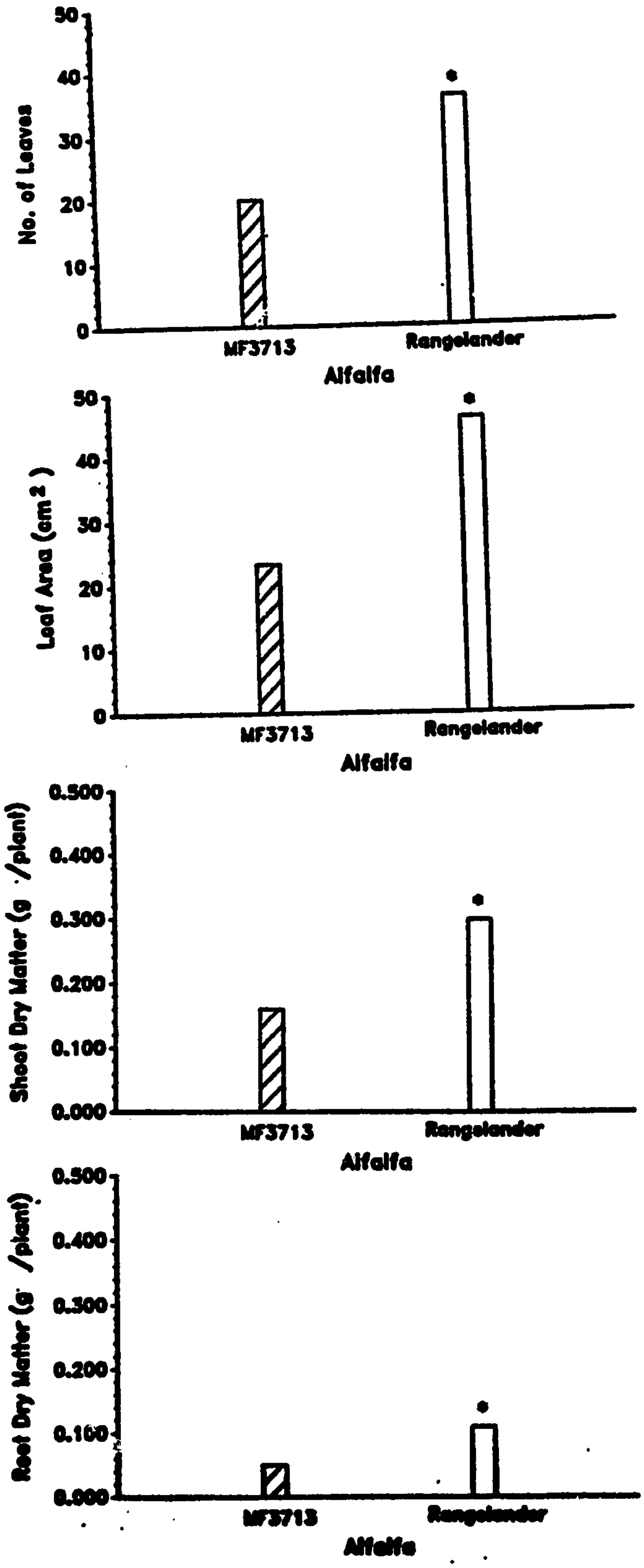
Table 3: Alfalfa germplasm effect, 74 days after growth, on alfalfa leaf numbers, leaf area, and shoot dry matter, and grass plant height and shoot dry matter.

Material Harvested	Alfalfa Germplasm	
	Rangelander	Mf3713
Number of alfalfa leaves/plant	12.8	7.9
Alfalfa leaf area (cm^2/plant)	11.5	6.7
Alfalfa shoot dry matter (g/plant)	0.09	0.04
Grass height (cm)	19.1	18.1
Grass shoot dry matter (g/pot)	19.0	20.0

Table 4: Alfalfa germplasm effect on grass shoot production 128 days after alfalfa was seeded in the grass swards.

Alfalfa	Grass Shoot Dry Matter	
	g/pot	g/alfalfa plant
Mf3713	4.75	2.77
Rangelander	4.96	1.97
Significance	ns	*

(* = significant for P<(0.05), ns = not significant for P<(0.05)).



<u>Figure</u> <u>4</u>: Alfalfa germplasm (Rangelander and Mf3713) differences for number of leaves, leaf area, shoot and root dry matter yields, 128 days after alfalfa was seeded in grass swards. (* = significant for $P<0.05$).

area and 75% more shoot dry matter significantly more than where alfalfa and grass shoots competed (Figure 5, Table 5). In pots where grass and alfalfa did not compete, the grass had significantly less shoot dry matter than with other competition treatments, even though the grass was taller (Table 6, Figure 6). Where alfalfa and grass roots competed the grass grew taller and when its shoots also competed with alfalfa shoots produced 15% more dry matter.

Table 5: Contrast results for competition effect on measured alfalfa growth parameters; number of leaves, leaf area, and shoot dry matters for the first harvest (Figure 5).

Competition Present	No. of Leaves/plant	Leaf Area (cm^2/plant)	Shoot Dry Matter (g/plant)
n vs r,s,b	NS	NS	NS
b vs r,s	NS	NS	NS
r vs s	S	S	S
CV (%)	202.9	124.8	143.8

competition present: n = none, b = both shoot and root, r = root, s = shoot; CV = coefficient of variation
S = significant for $P<0.05$, NS = not significant for $P<0.05$

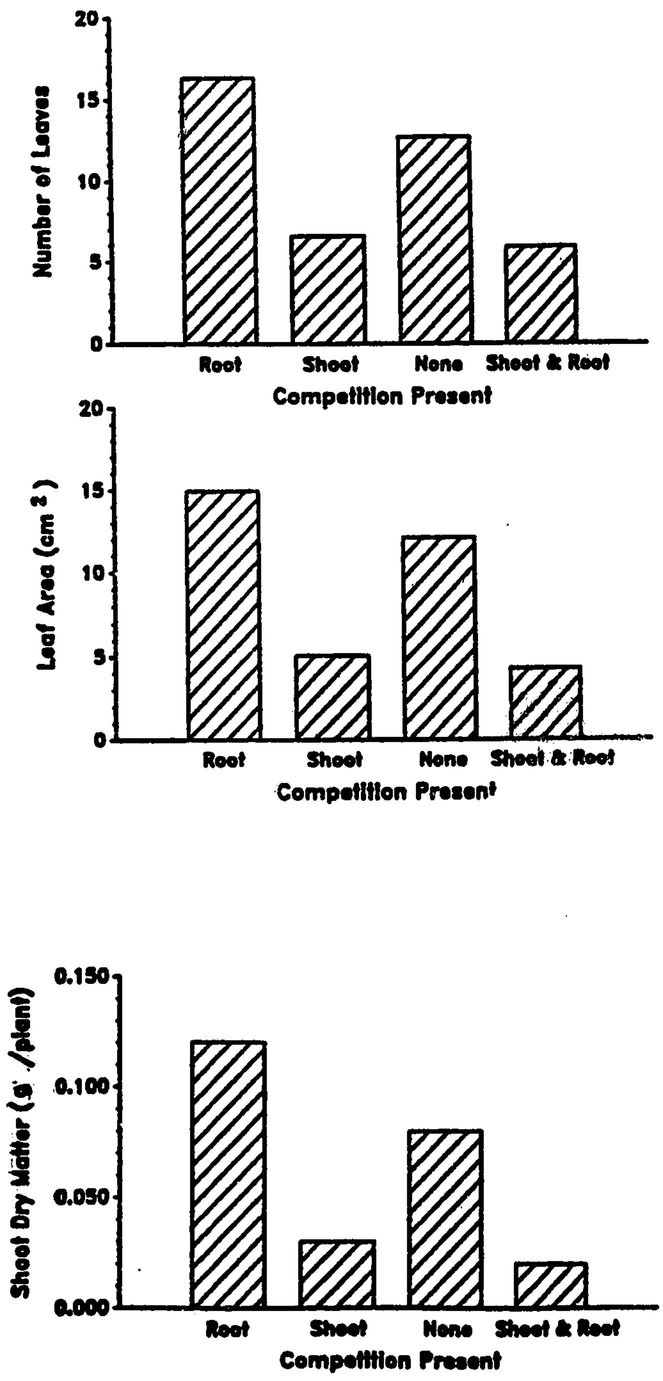


Figure 5: The effect of the presence of root, shoot, both root and shoot, and no competition on alfalfa leaf number, leaf area and shoot dry matter for the first harvest 74 days after alfalfa was seeded.

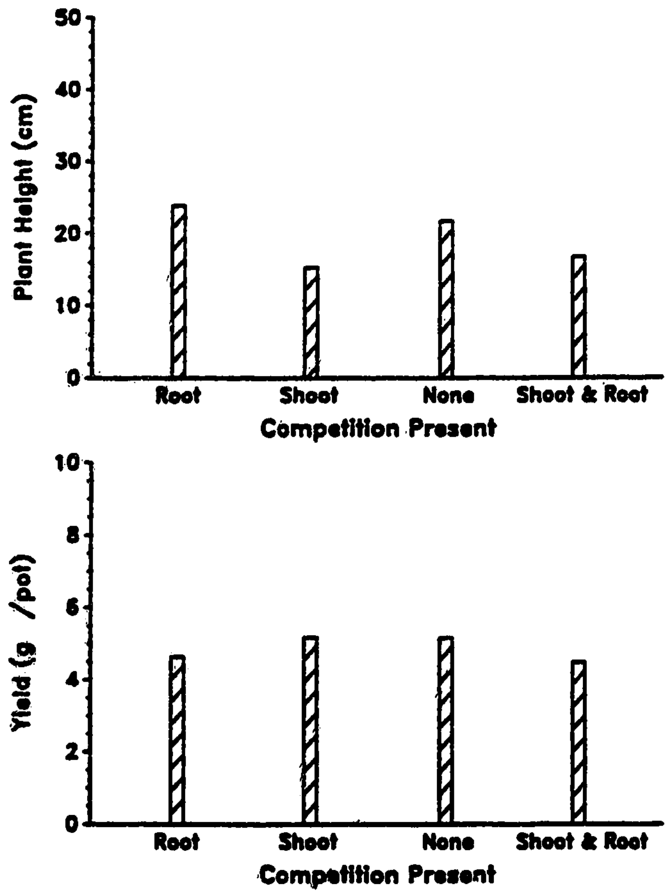


Figure 6: The effect of the presence of root, shoot, both root and shoot, and no competition on grass plant height and shoot dry matter yield for the first harvest.

Table 6: Contrast results for competition effect on grass plant height and shoot dry matter (Figure 6) for the first harvest, 74 days after alfalfa was seeded into grass swards.

Competition Present	Plant Height (cm)	Shoot Dry Matter (g/pot)
n vs r,s,b	S	S
b vs r,s	NS	NS
r vs s	S	S
CV (%)	20.1	49.7

competition present: n = none, b = both shoot and root, r = root , s = shoot ; S = significant for P<0.05, NS = not significant for P<0.05.

Table 7: Contrast results for competition effect on measured alfalfa growth parameters; number of leaves, leaf area, shoot and root dry matters for the second harvest (Figure 7).

Competition Present	No. of Leaves /plant	Leaf Area (cm^2/plant)	Shoot Dry Matter (g/plant)	Root Dry Matter (g/plant)
n vs r,s,b	NS	NS	NS	NS
b vs r,s	NS	NS	NS	NS
r vs s	S	NS	S	S
CV (%)	120.3	143.3	80.9	109.5

Competition present: n = none, b = both shoot and root, r = root, and s = shoot; S= significant for P<0.05, NS= not significant for P<0.05.

Alfalfa had significantly less shoot dry matter and fewer leaves, and less leaf area (but not significantly), where alfalfa and grass shoots competed for 128 days, than where roots competed (Table 7, Figure 7). At the second harvest the type of competition between alfalfa and grass did not affect grass shoot dry matter yields (Table 8).

Table 8: Effect on grass dry matter yields of type of competition between alfalfa seedlings and established grass, 128 days after seeding alfalfa.

Type of Competition Present	Grass Shoot Dry Matter	
	g/pot	g/alfalfa plant
Root	4.64	2.16
Shoot	5.18	2.48
None	5.15	2.46
Shoot & Root	4.48	2.41
CONTRAST		
n vs b,r,s	NS	NS
b vs r,s	NS	NS
r vs s	NS	NS
CV (%)	34.9	67.2

Competition present: n = none, b = both shoot and root, r = root, and s = shoot; NS = not significant for P<0.05.

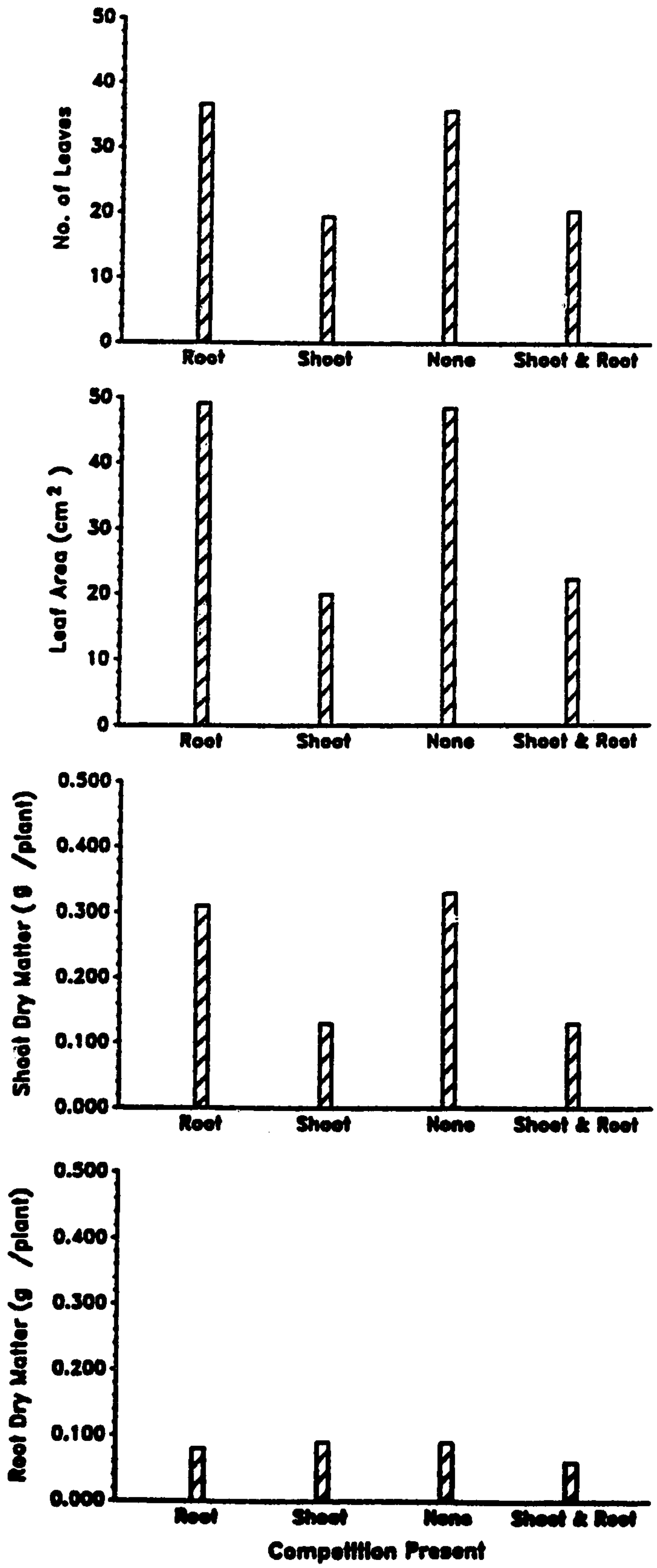


Figure 7: Effect of type of competition on number of leaves, leaf area, shoot and root dry matter yield of alfalfa, for the second harvest 128 days after the alfalfa was seeded.

The average light intensities at ground level were 1332 μEm^{-2} sec^{-1}, and at the top of the alfalfa canopy were 1636 μEm^{-2} sec^{-1}, with an average difference of 304 μEm^{-2} sec^{-1}. No significant differences between grass species were found 90 days after seeding grass (Table 9). No significant differences between alfalfa germplasms were found (Table 10).

The soil pH for pots with Russian wildrye (pH 7.8) was significantly more acidic than that observed for crested wheatgrass (pH 7.9) (Table 9). The soil pH was 7.8 for both alfalfa germplasms.

Table 9: Effect of grass species on light intensity readings for ground level, top of the alfalfa canopy and the difference, taken 32 days after seeding alfalfa (90 days after seeding grass) and soil pH readings taken 88 days after seeding grass.

	Light Intensity (μEm^{-2} sec^{-1})			
Grass	Soil Level	Top of Canopy	Difference	Soil pH
Crested Wheatgrass	1304	1639	335	7.9
Russian Wildrye	1360	1632	272	7.8
CV (%)	16.0	22.9	121.4	3.9
Significance	ns	ns	ns	*

* = significant, n = not significant for $P<0.05$.

Table 10: Effect of alfalfa germplasms on light intensity readings for ground level, top of the alfalfa canopy and the difference, taken 32 days after seeding alfalfa (90 days after seeding grass) and soil pH readings taken 88 days after seeding grass.

	Light Intensity (μEm^{-2} sec^{-1})			
Alfalfa	Soil Level	Top of Canopy	Difference	Soil pH
Mf3713	1359	1668	308	7.8
Rangelander	1301	1592	293	7.8
CV (%)	16.0	22.9	121.4	3.9

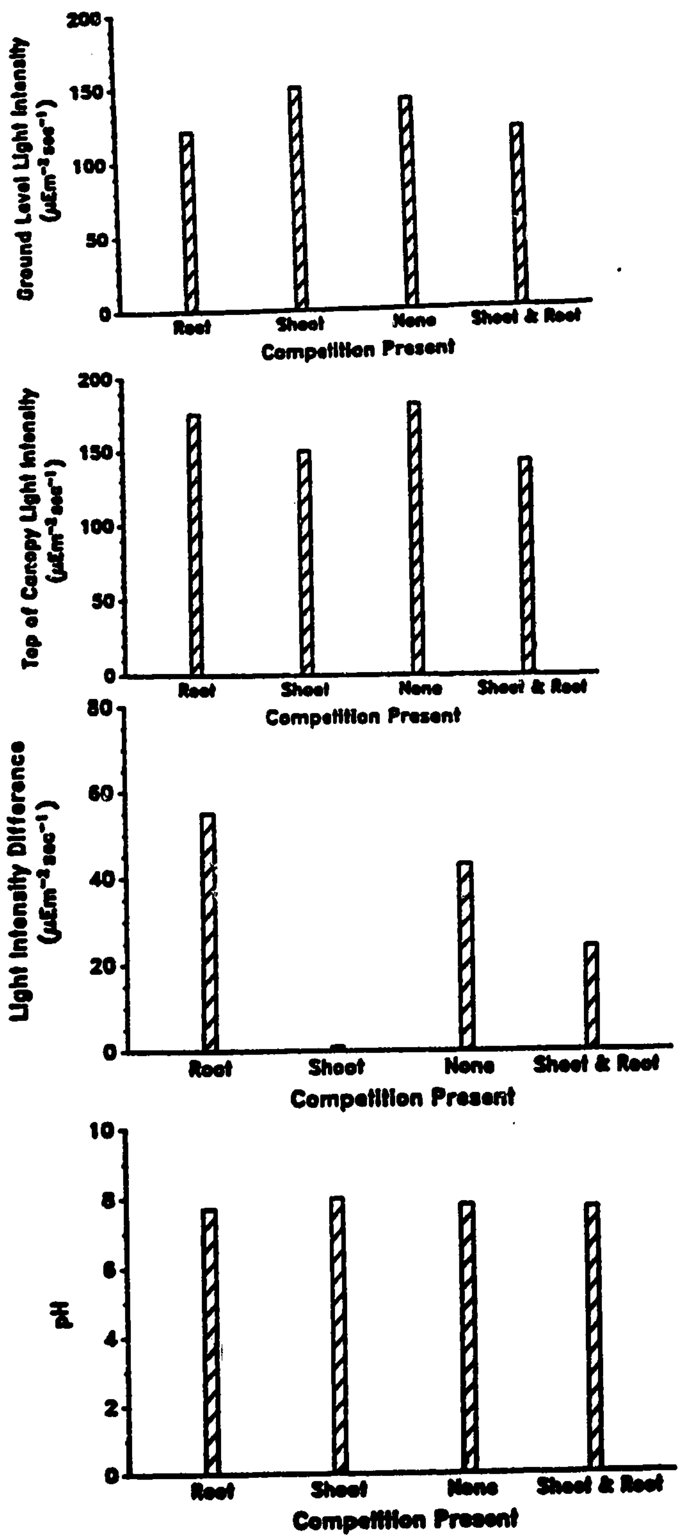
Preventing shoot competition between alfalfa and established grass resulted in a significant increase in light intensity at the soil surface. Also light intensity at the soil surface was less where only alfalfa and grass roots competed than where only their shoots competed (Figure 8, Table 11). Light intensity at the top of the alfalfa canopy had significant differences between all treatments. The following ranking resulted: shoot and root competition < shoot competition < root competition < no competition. Root competition between alfalfa and grass significantly reduced light transmission (30%) through the alfalfa canopy more than did combined root and shoot competition which in turn reduced light transmission (20%) significantly more than shoot competition. Root competition alone reduced light transmission significantly more than shoot competition.

Soil pH readings were more basic in the alfalfa root zone where grass roots were excluded (Figure 8, Table 11).

Table 11: Contrast results for differences between competition treatments for light intensity readings at ground level, top of the alfalfa canopy and the difference between the two, taken 32 days after alfalfa seeded (90 days after grass seeded), and soil pH readings taken 88 days after the grass was seeded. (Figure 8)

	Light Intensity (μEm^{-2} sec^{-1})			
Contrast	Ground Level	Top of Canopy	Difference	Soil pH
n vs b,r,s	S	S	NS	S
b vs r,s	NS	S	S	NS
r vs s	S	S	S	S
CV (%)	16.0	22.9	121.4	3.9

S = significant, NS = not significant for $P<0.05$, b = both root and shoot competition present, r = root competition present, s = shoot competition present, n = no competition present.



<u>Figure</u> <u>8</u>: Light intensity observations at ground level, top of the alfalfa canopy, and the difference between the two taken 32 days after alfalfa was seeded (90 days after grass was seeded) and soil pH readings taken 88 days after grass was seeded for the various root and shoot competition treatments between alfalfa and grass.

3.2 The Effect of Spray Width and Reduced Root Competition on Alfalfa Establishment in Crested Wheatgrass

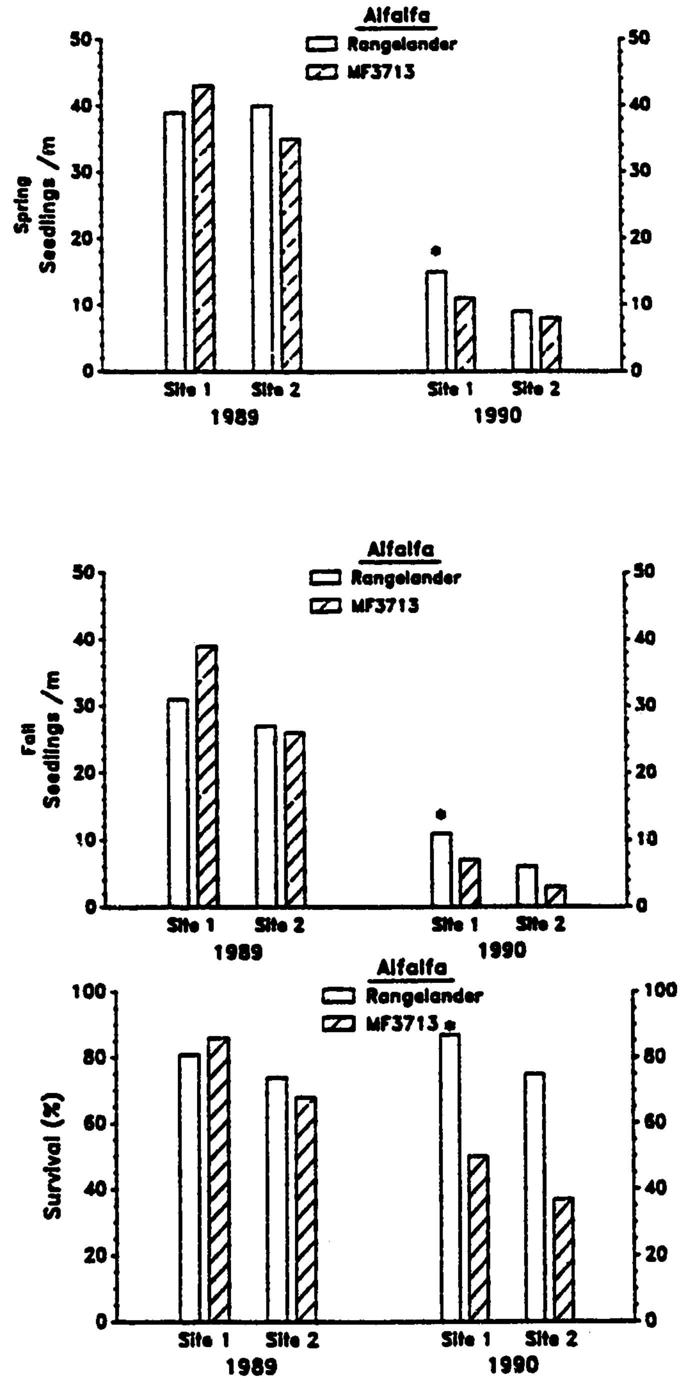
3.2.1 Number of Alfalfa Seedlings and Development Time

For the seeding year 1989 no significant differences were detected between Mf3713 and Rangelander alfalfa germplasms, although there seemed to be more Mf3713 alfalfa than Rangelander alfalfa seedlings at site 1 (Figure 9). The average results for both sites and both alfalfa germplasms were 1) 39 plants m^{-1} on July 15, 1989, 2) 31 plants m^{-1} on August 23, 1989 and 3) 77% of the plants survived to fall. In 1990, the spring and fall seedling counts and survival rates were lower than in 1989. There were more seedlings of Rangelander alfalfa than of Mf3713, and a higher percentage of them survived to fall. Only the results from site 1 showed significant differences. Rangelander alfalfa plots had 27% more seedlings on June 16, 1990, and 36% more seedlings on September 4, 1990 than Mf3713 alfalfa. Thirty-seven per cent more plants survived to fall in Rangelander plots than in Mf3713 plots.

No significant differences were detected between alfalfa germplasms for the time required to reach the true three leaf stage of growth (Table 12). In 1989 the average time to reach this stage was 31 days compared to 27 days in 1990.

The application of glyphosate had a strongly positive effect on the plant counts and survival of the alfalfa seedlings to the fall of the seeding year (Table 13, Figure 10). Spring seedling numbers were 10-66% lower and fall seedling numbers were 76% lower in plots without a glyphosate application. Alfalfa seedlings failed to survive to fall when seeded in 1990 without a glyphosate application.

There was a linear relationship between the width of the crested wheatgrass area controlled by glyphosate and seedling numbers and per-cent of seedlings surviving to fall. The wider the area controlled, the



<u>Figure 9</u>:Mf3713 and Rangelander alfalfa germplasm effects on spring (July 15, 1989 and June 16, 1990) and, fall (August 23, 1989 and September 4, 1990) seedling numbers m-1 and % plants surviving to fall for 1989, and 1990 when seeded into established crested wheatgrass. (* - significant for P<0.05).

Table 12: Mf3713 and Rangelander alfalfa germplasm effects on development time to reach the three leaf stage for seeding years 1989 and 1990 in crested wheatgrass.

Year	Site	Mf3713	Rangelander	CV (%)
1989	1	29	29	9.8
	2	32	33	13.4
1990	1	36	35	9.6
	2	17	18	70.4

more alfalfa seedlings survived. The trend was significant for site 2 seeded in 1989 and for both sites seeded in 1990 (Table 13, Figure 10).

The application of glyphosate shortened the time required for the alfalfa seedlings to reach the three true leaf stage (Figure 11, Table 14). The plots without a glyphosate application had development times which were 5 to more than 20 days longer. For three of four sites, a linear relationship between the width of the crested wheatgrass area controlled by glyphosate existed for time to reach the three true leaf stage.

For the seeding year 1989, cutting crested wheatgrass roots had no effect on the number of alfalfa seedlings (Table 15). On July 15, 1989 there were 39.5 alfalfa plants m^{-1} averaged across both sites, while on August 23, 1989 there was a average of 30.8 alfalfa plants m^{-1}. The average survival percentage for plants was 76.8%.

In the seeding year 1990, fewer alfalfa seedlings emerged. Plots in which the crested wheatgrass roots had been cut had eleven alfalfa seedlings m^{-1} for site 1, and six for site 2 at the second harvest. Plots where grass roots were not cut had only seven alfalfa seedlings m^{-1} for site 1, and three for site 2. The survival percentage of alfalfa seedlings was also higher for site 1 (67%) than site 2 (52%). Site 2 showed a similar trend to site 1 but results were extremely variable.

No differences were evident between plots where grass roots were or were not cut for the time required for alfalfa to reach the three true leaf stage of development . In 1989 the alfalfa seedlings required

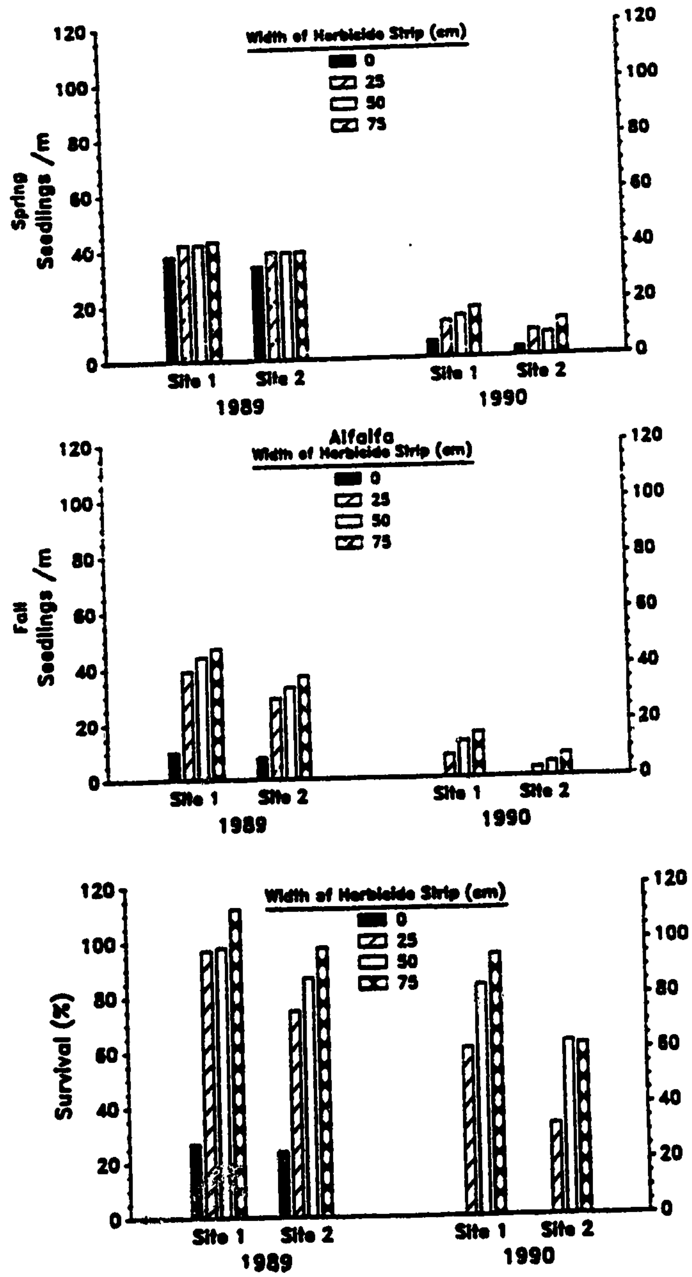


Figure 10: The effect of width of crested wheatgrass area controlled by glyphosate on spring plant counts m^{-1} (July 15, 1989 and June 16, 1990), fall plant counts m^{-1} (August 23,1989 and September 5, 1990) and per cent plants surviving until fall count for seeding years 1989 and 1990 (Table 13).

Table 13: Contrast results for the effect of width of crested wheatgrass area controlled by glyphosate on spring plant counts m^{-1} (July 15, 1989 and June 16, 1990), fall plant counts m^{-1} (August 23,1989 and September 5, 1990) and per cent plants surviving until fall for seeding years 1989 and 1990 (Figure 10).

			Contrasts			
			Glyphosate application vs	Trend in Width of Control		
Year	Site	Date Counted	none	Linear	Quadratic	CV (%)
1989	1	July 15	NS	NS	NS	27.9
		Aug 23	S	NS	NS	45.2
		% Survival	S	NS	NS	39.0
	2	July 15	S	NS	NS	30.0
		Aug 23	S	S	NS	40.8
		% Survival	S	S	NS	29.4
1990	1	June 16	S	S	NS	50.2
		Sept 5	S	S	NS	58.0
		% Survival	S	S	NS	33.4
	2	June 16	S	NS	S	78.7
		Sept 5	S	S	NS	83.2
		% Survival	S	NS	NS	271.7

S - significant for P<0.05, NS - not significant for P<0.05.

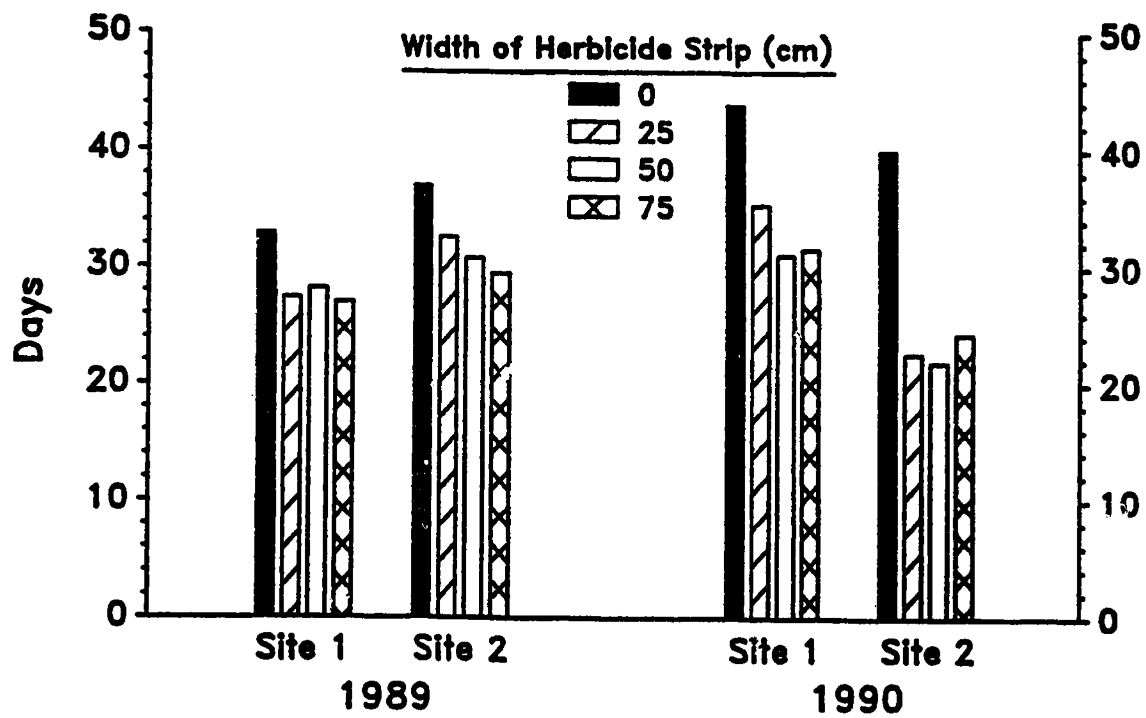


Figure 11: The effect of width of crested wheatgrass area controlled by glyphosate on time required for alfalfa seedlings to reach the three true leaf stage of development for seeding years 1989 and 1990.

Table 14: Contrast for the effect of width of crested wheatgrass area controlled by glyphosate on time required for alfalfa seedlings to reach true three leaf stage of development for seeding years 1989 and 1990 (Figure 11).

	1989		1990	
Contrast	Site 1	Site 2	Site 1	Site 2
Glyphosate application vs none	S	S	S	S
Linear	S	S	S	NS
Quadratic	NS	NS	S	NS
CV (%)	9.8	13.4	9.6	70.4

S - significant, NS - not significant for $P<0.05$

Table 15: The effect of cutting crested wheatgrass roots, to a depth of 15 cm adjacent to glyphosate application strips, on spring plant counts m^{-1} (July 15, 1989 and June 16, 1990), fall plant counts m^{-1} (August 23,1989 and September 5, 1990) and per cent plants surviving until fall for the seeding years 1989 and 1990.

Year	Site	Date Counted	Roots Cut	Roots Not Cut	CV (%)
1989	1	July 15	37	45	27.9
		Aug 23	31	39	45.2
		% Survival	78	88	39.0
	2	July 15	39	37	30.0
		Aug 23	27	26	40.8
		% Survival	72	69	29.4
1990	1	June 16	14	12	50.2
		Sept 5	11*	7	58.0
		% Survival	67*	52	33.4
	2	June 16	8	8	78.7
		Sept 5	6*	3	83.2
		% Survival	75	37	271.8

* - significant for $P<0.05$

an average of 30.7 days while in 1990 they required 26.5 days.

3.2.2 Vegetative Growth

Alfalfa seeded in 1989 reached an average height of 16.4 cm at site 1 and 10.8 cm at site 2 for the establishment year. In the following year the alfalfa plants, grew to an average height of 30.8 cm at site 1. There were no significant differences ($P<0.05$) between alfalfa germplasms (Table 16).

Rangelander plants (16.8 cm) seeded in 1990 were 40% taller than Mf3713 (12.0 cm) plants by July 4.

Table 16: Differences between Mf3713 and Rangelander germplasms for plant height (cm) measured on August 24, 1989 and July 4, 1990 for alfalfa seeded in 1989 and September 5, 1990 for alfalfa seeded in 1990.

Site	Date	Mf3713	Rangelander	CV (%)
1	August 24, 1989	16.7	16.3	41.6
	July 4, 1990	31.1	30.4	20.0
2	August 24, 1989	11.3	10.3	41.6
	July 4, 1990 (inadequate sample)			
1	September 5, 1990	16.8*	12.0	42.2

* - significant for $P<0.05$

Alfalfa germplasms had no effect on alfalfa, grass, weed or total dry matter yields for plots seeded in either 1989 or 1990 (Tables 17 and 18).

Differences between sites for the same seeded year were evident. Site 2 seeded in 1989 had average grass dry matter yields approximately 60% less than site 1. Alfalfa and weed dry matter yields also showed a similar trend but only in the year of seeding (Table 17). Site 2 seeded in 1990 had grass dry matter yields a third higher than site 1 but considerably lower alfalfa dry matter yields (Table 18).

Rangelander alfalfa produced twice the etiolated growth of Mf3713 alfalfa for the first harvest (0.12 g vs 0.06 g) 14 days after transplanting (Figure 12). With successive harvests Rangelander alfalfa regrowth steadily decreased. Mf3713 equalled Rangelander at the second harvest and produced significantly more in the remaining three harvests. The total dry matter yields were not significantly different.

At both sites in both years, plant height was positively corre-

Table 17: Differences between Mf3713 and Rangelander germplasms for dry matter yields (g m-2) obtained on September 21, 1989, and July 11, 1990 for alfalfa seeded in 1989.

			Yield (g m^{-2})		
Date	Site	Harvested Material	Mf3713	Rangelander	CV (%)
Sept.21 1989	1	Adjusted Grass Yields	93.5	75.4	41.5
		Actual Grass Yields	53.4	46.1	37.4
		Alfalfa	8.6	7.8	70.3
		Weeds	13.0	25.3	179.7
		Total	71.7	71.7	31.5
Sept. 21 1989	2	Adjusted Grass Yields	31.6	23.8	75.2
		Actual Grass Yields	19.5	15.1	66.9
		Alfalfa	3.1	4.2	108.6
		Weeds	6.1	9.6	134.5
		Total	27.5	27.4	44.0
July 11 1990	1	Adjusted Grass Yields	173.6	169.4	14.3
		Actual Grass Yields	147.3	142.7	15.0
		Alfalfa	28.1	25.9	42.4
		Weeds	0.0	0.2	599.7
		Total	175.4	168.9	13.3
July 11 1990	2	Adjusted Grass Yields	57.2	57.5	52.1
		Actual Grass Yields	48.6	48.6	52.1
		Alfalfa	34.4	33.6	73.2
		Weeds	17.3	16.6	60.9
		Total	100.3	98.8	31.0

* - significant for P<0.05.

Table 18: Differences between Mf3713 and Rangelander germplasms for dry matter yields (g m^{-2}) obtained on September 11,1990 for alfalfa seeded in 1990 in crested wheatgrass.

Date	Site	Harvested Material	Mf3713	Rangelander	CV (%)
Sept. 11	1	Adjusted Grass Yields	218.8	209.4	25.6
		Actual Grass Yields	109.4	104.7	25.3
		Alfalfa	4.1	5.2	97.0
		Weeds	0.8	3.3	275.3
		Total	114.3	113.5	25.2
Sept. 11	2	Adjusted Grass Yields	378.5	327.3	36.2
		Actual Grass Yields	182.1	161.1	23.6
		Alfalfa	1.2	2.6	22.5
		Weeds	5.6	4.0	270.6
		Total	166.3	188.9	22.6

* - significant for P<0.05.

lated with the width of strips killed by glyphosate.

Plant growth a year after seeding was taller than in the previous fall but followed the same trend. Differences were easily visible to the eye (Figure 13).

When harvested from a constant area, grass dry matter had a negative correlation with increasing width of grass suppression (Figure 14, Table 20). For example, plots from site 1 seeded in 1989 had the following yields: 78.2 g m^{-2} for no glyphosate application, 56.1 g m^{-2} for a glyphosate application width of 25 cm, 37.2 g m^{-2} for glyphosate application width of 50 cm and 27.6 g m^{-2} for a glyphosate application width of 75 cm. The application of glyphosate also resulted in positive correlations between increasing width of grass suppression and alfalfa and weed dry matter yields. For example, alfalfa dry matter yields from site 1 plots seeded in 1989 had the following yields: 0.5 g m^{-2} for no glyphosate application, 5.1 g m^{-2} for a glyphosate application width of 25 cm, 13.3 g m^{-2} for glyphosate application width of 50 cm and 14.8 g m^{-2} for a glyphosate application width of 75 cm. The same trends were

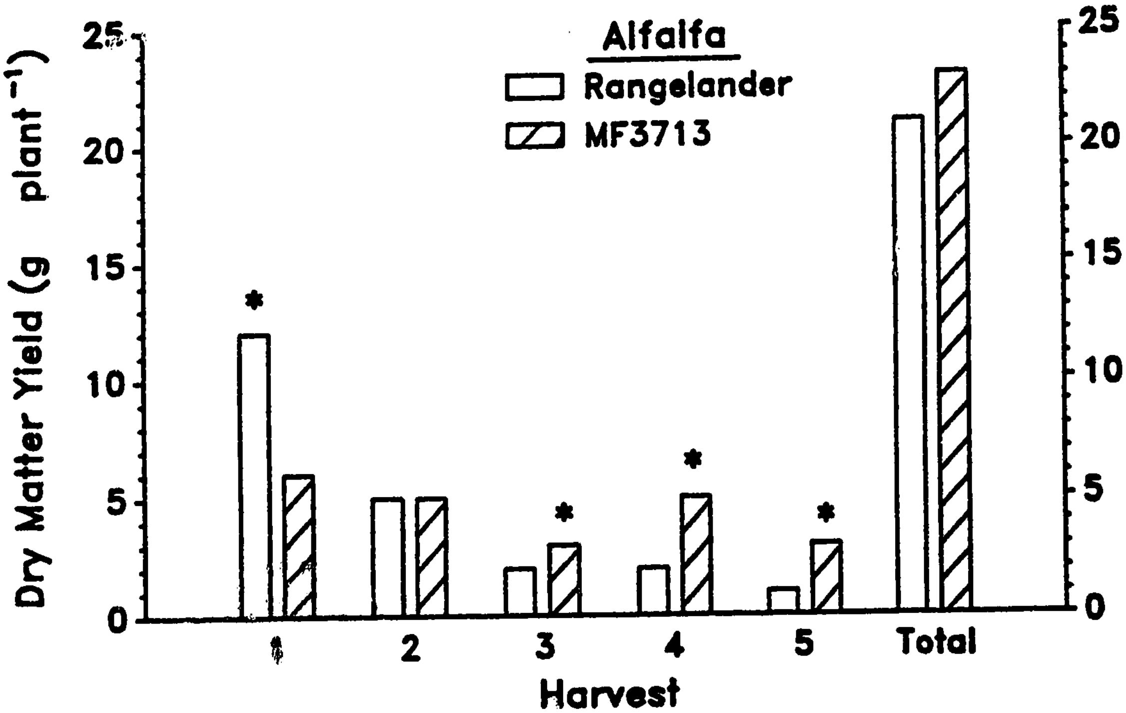


Figure 12:Rangelander and Mf3713 germplasm effect on five successive harvests ($x10^{-2}$), spaced two weeks apart, for alfalfa plants removed from the field October 15, 1990, a year and four months after seeding. (* - significant for $P<0.05$)

Table 19: The effect of width of crested wheatgrass area controlled by glyphosate on plant height (cm) measured on August 24, 1989 and July 4, 1990 for alfalfa seeded in 1989 and September 5, 1990 for alfalfa seeded in 1990.

Glyphosate Application Width (cm)	Height (cm) Site 1 1989 Aug. 24 1989	Site 1 1989 July 4 1990	Site 2 1989 Aug. 24 1989	Site 1 1990 Sept. 5 1990
0	4.8	22.5	3.3	0.0
25	15.9	27.8	9.8	10.3
50	19.4	35.5	13.9	22.4
75	25.9	37.4	16.4	25.6
CONTRASTS				
Glyphosate Application vs None	S	S	S	S
Linear trend Controlled Width	S	S	S	S
Quadratic trend Controlled Width	NS	S	NS	S
CV (%)	41.6	20.0	41.6	42.2

S - significant, NS - not significant for P<0.05.

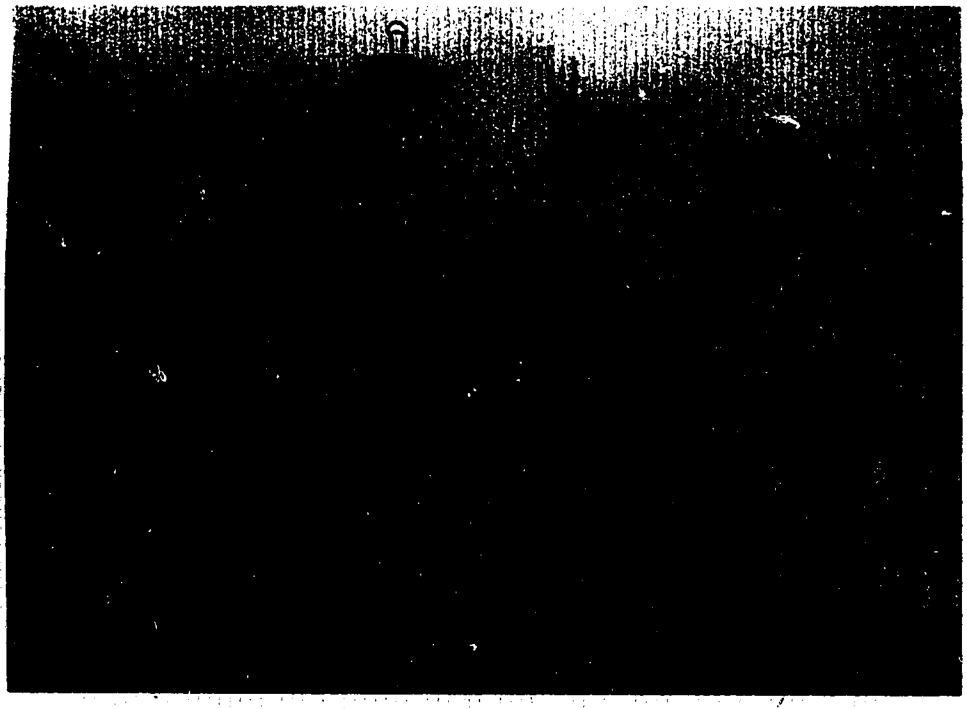


Figure 13a: Growth on July 4, 1990 of Mf3713 alfalfa, seeded in June 1989, in a plot with no glyphosate application. The lines on the stake are one centimetre apart.

Figure 13b: Growth on July 4, 1990 of Mf3713 alfalfa, seeded in June 1989, in a plot with a glyphosate application width of 25 cm. The lines on the stake are one centimetre apart.

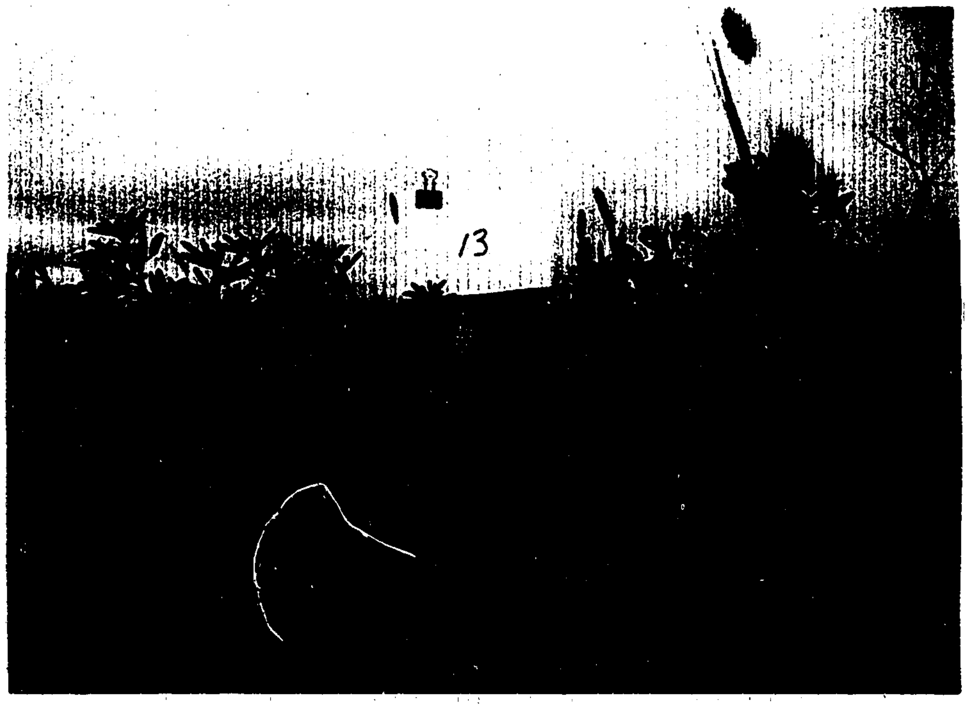


Figure 13c: Growth on July 4, 1990 of Mf3713 alfalfa, seeded in June 1989, in a plot with a glyphosate application width of 50 cm. The lines on the stake are one centimetre apart.

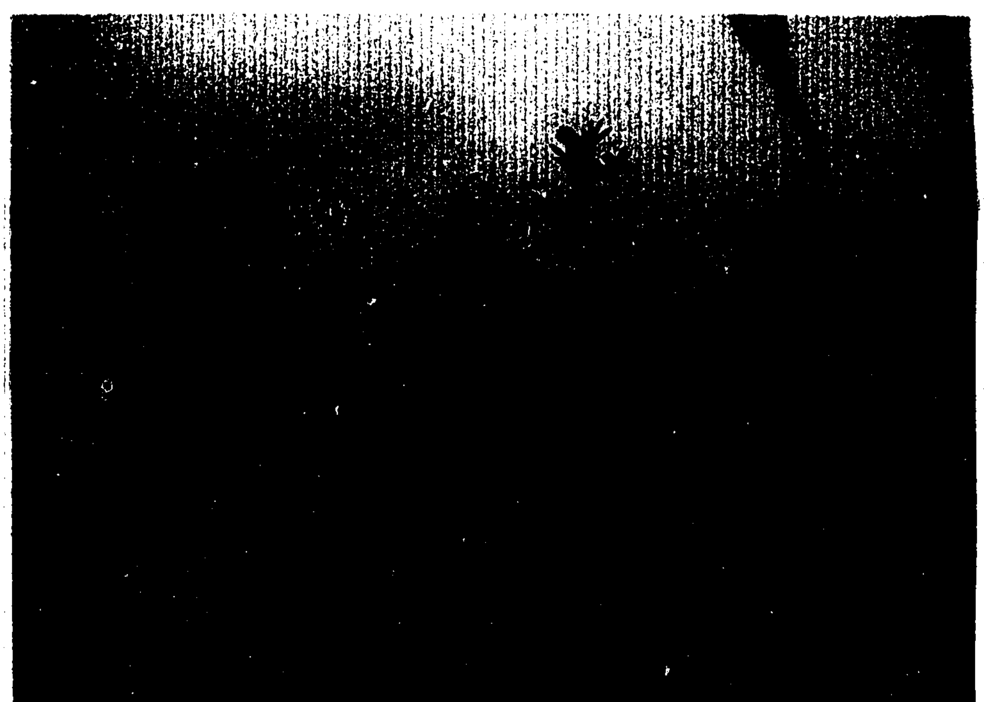


Figure 13d: Growth on July 4, 1990 of Mf3713 alfalfa, seeded in June 1989, in a plot with a glyphosate application width of 75 cm. The lines on the stake are one centimetre apart.

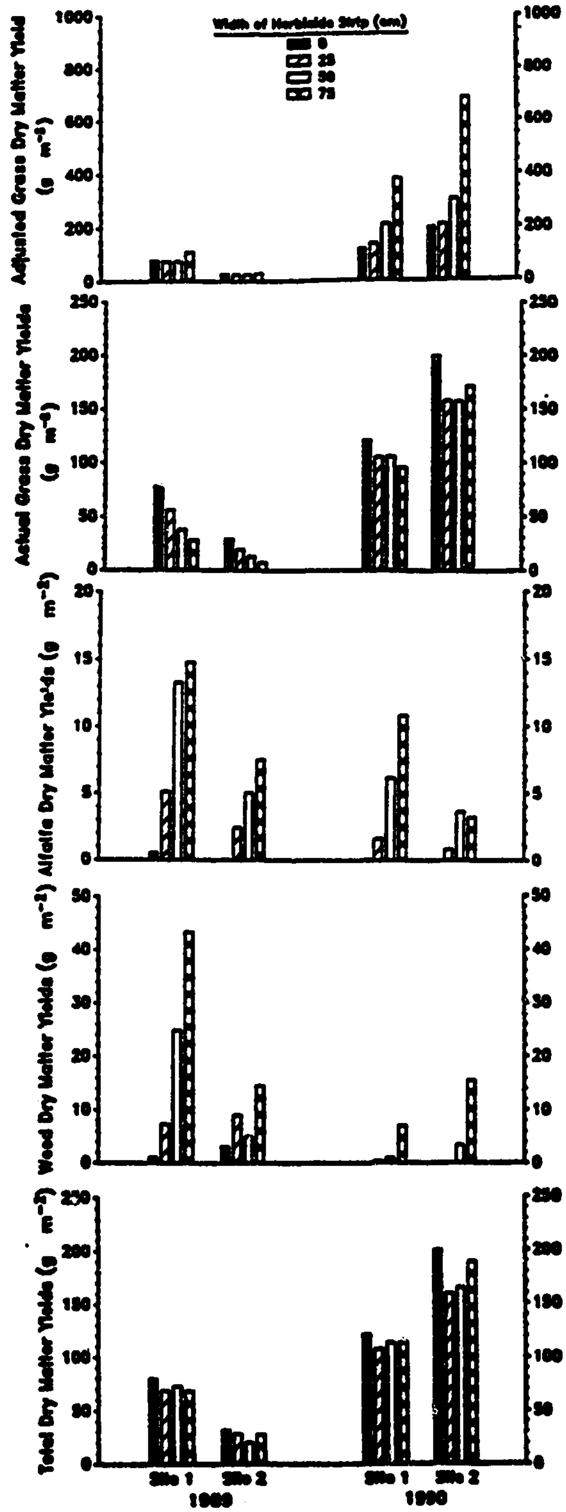


Figure 14: The effect of width (0cm, 25 cm, 50 cm, 75 cm) of glyphosate application on actual grass, adjusted grass, alfalfa, weed and total dry matter yields (g m^{-2}) on September 21, 1989 for the seeding year 1989 and September 11, 1990 for the seeding year 1990

Table 20:Orthogonal contrast for the effect of width of glyphosate application on actual grass, adjusted grass, alfalfa, weed and total dry matter yields (g m^{-2}) on September 21, 1989 for the seeding year 1989 and September 11, 1990 for the seeding year 1990 (Figure 14).

			Contrasts			
			Glyphosate vs	Trend in Width of Control		
Date	Site	Material Harvested	None	Linear	Quadratic	CV(%)
Sept.21 1989	1	Adjusted Grass	NS	S	NS	41.5
		Actual Grass	S	S	NS	37.4
		Alfalfa	S	S	NS	70.3
		Weeds	S	S	NS	179.7
		Total	NS	NS	NS	31.5
	2	Adjusted Grass	NS	NS	NS	75.2
		Actual Grass	S	S	NS	66.9
		Alfalfa	S	S	NS	108.6
		Weeds	S	NS	S	134.5
		Total	NS	NS	NS	44.0
Sept.11 1990	1	Adjusted Grass	S	S	S	25.6
		Actual Grass	S	NS	NS	25.3
		Alfalfa	S	S	NS	97.0
		Weeds	NS	S	NS	275.3
		Total	NS	NS	NS	25.2
	2	Adjusted Grass	S	S	S	36.2
		Actual Grass	S	NS	NS	23.6
		Alfalfa	S	S	NS	22.5
		Weeds	NS	S	NS	270.6
		Total	S	S	NS	22.6

S - significant, NS - not significant for P<0.05.

evident in both years for both sites.

There was a significant linear relationship between the width of the crested wheatgrass area controlled by glyphosate and alfalfa dry matter yields for all 4 sites (Figure 14, Table 20). Similar trends were observed for all dry matter yields, but not all trends were statistically significant.

Grass dry matter yields adjusted for the killed area showed no significant differences (P<0.05) between plots with or without a glyphosate application for sites established in 1989 (Figure 14, Table 20). On sites established in 1990, adjusting grass yields to reflect the actual area not suppressed, resulted in a positive correlation with increasing width of grass suppression which suggested an increase in production for the area in which grass was not suppressed.

Experiments started in 1990 had more grass growth than those started in 1989 and they tended to have less alfalfa and weeds (Figure 14).

In spring of 1990, the experiments started in 1989 the same growth trends were observed as in fall of 1989 (Figure 15, Table 21). The differences between the two harvests were 1) almost complete suppression of weeds at site 1 while at site 2 weeds increased, 2) grass and alfalfa dry matter yields increased (alfalfa was present in solid stands), 3) plots without a glyphosate application no longer had higher actual grass yields than plots with a glyphosate application, and 4) a positive correlations existed between the adjusted grass dry matter yield at site 1 and increasing width of grass suppression.

The application of glyphosate to control the crested wheatgrass had a positive effect on etiolated growth of alfalfa. The narrowest treatment width (25 cm) resulted in a significant increase in etiolated growth over plants from the control plots (Figure 16, Table 22). The total etiolated growth for plots with no glyphosate application was 0.08 g plant^{-1}, compared to 0.17 g plant^{-1} with a glyphosate application width of 25 cm. There was a significant linear relationship between the width of crested wheatgrass area controlled by glyphosate and alfalfa etiolated growth for harvest 2, 4, 5, and total yield. Etiolated growth increased as width of control increased.

Plots in which crested wheatgrass roots were cut tended to have taller alfalfa plants than plots where roots were not cut but differences reached significance in plots established at site 1 in 1990 (Table 23).

In the same experiment, alfalfa produced 6.2 g dry matter m^{-2} where grass roots were cut and 3.2 g dry matter m^{-2} where they were not cut. There were no clear trends in any dry matter yields for the other

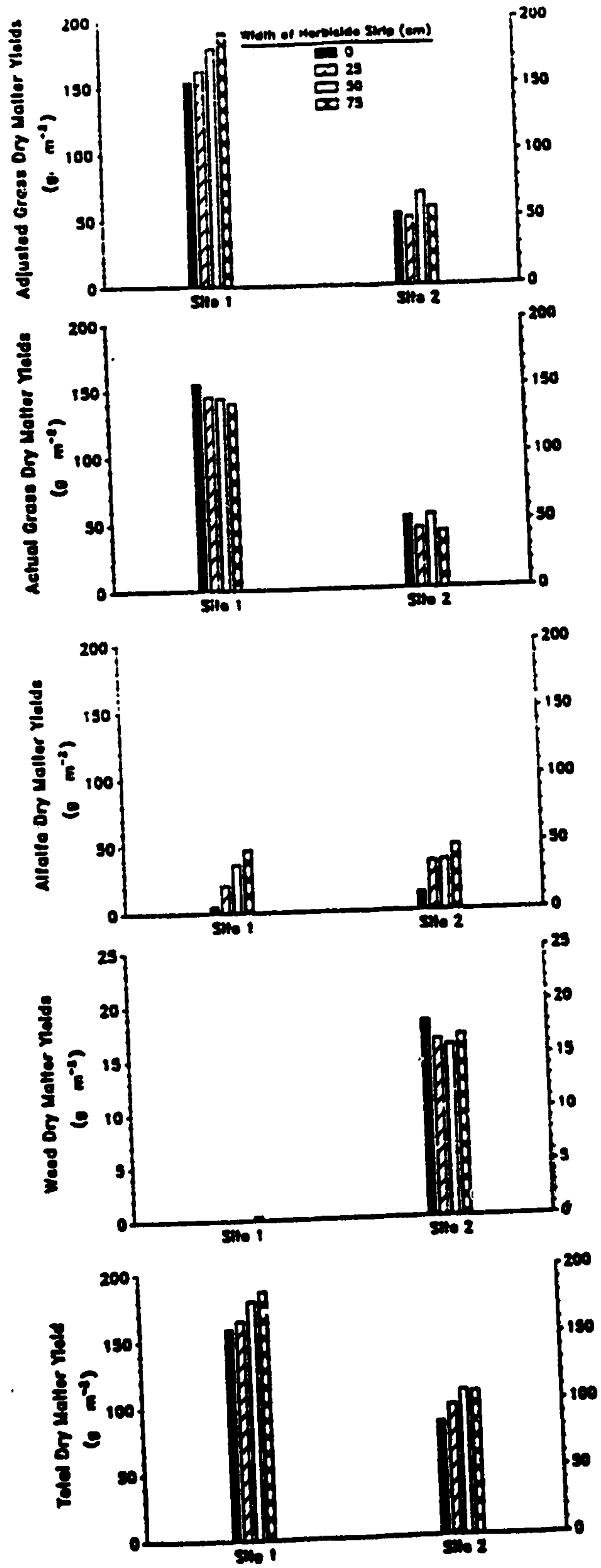


Figure 15: The effect of width (0cm, 25 cm, 50 cm, 75 cm) of glyphosate application on adjusted grass, actual grass, alfalfa, weed and total dry matter yields (g m^{-2}) on July 11, 1990 for the seeding year 1989.

Table 21:Orthogonal contrasts for the effect of width of crested wheatgrass area controlled by glyphosate on adjusted grass, actual grass, alfalfa, weed and total dry matter yields (g m^{-2}) taken on July 11, 1990 for the seeding year 1989 (Figure 15).

			Contrasts			
			Glyphosate Application vs None	Trend in Width of Control		
Date	Site	Yield		Linear	Quadratic	CV(%)
July 11 1990	1	Adjusted Grass	S	S	NS	14.3
		Actual Grass	NS	NS	NS	15.0
		Alfalfa	S	S	NS	42.4
		Weeds	NS	NS	NS	599.7
		Total	S	S	NS	13.3
	2	Adjusted Grass	NS	NS	NS	52.1
		Actual Grass	NS	NS	NS	52.2
		Alfalfa	S	NS	NS	73.2
		Weeds	NS	NS	NS	60.9
		Total	S	NS	NS	31.0

S - significant, NS - not significant for P<0.05.

Table 22:Orthogonal contrast for the effect of width of glyphosate application effect on five successive harvests, spaced two weeks apart, of etiolated growth alfalfa plants removed from the field October 15, 1990, a year and four months after seeding.(Figure 16)

	Contrast			
Harvest	Glyphosate Application vs None	Linear	Quadratic	CV (%)
1	S	NS	NS	89.8
2	S	S	NS	78.7
3	S	NS	NS	101.7
4	S	S	NS	92.5
5	S	S	NS	143.4
Total	S	S	NS	70.6

S - significant, NS - not significant for P<0.05.

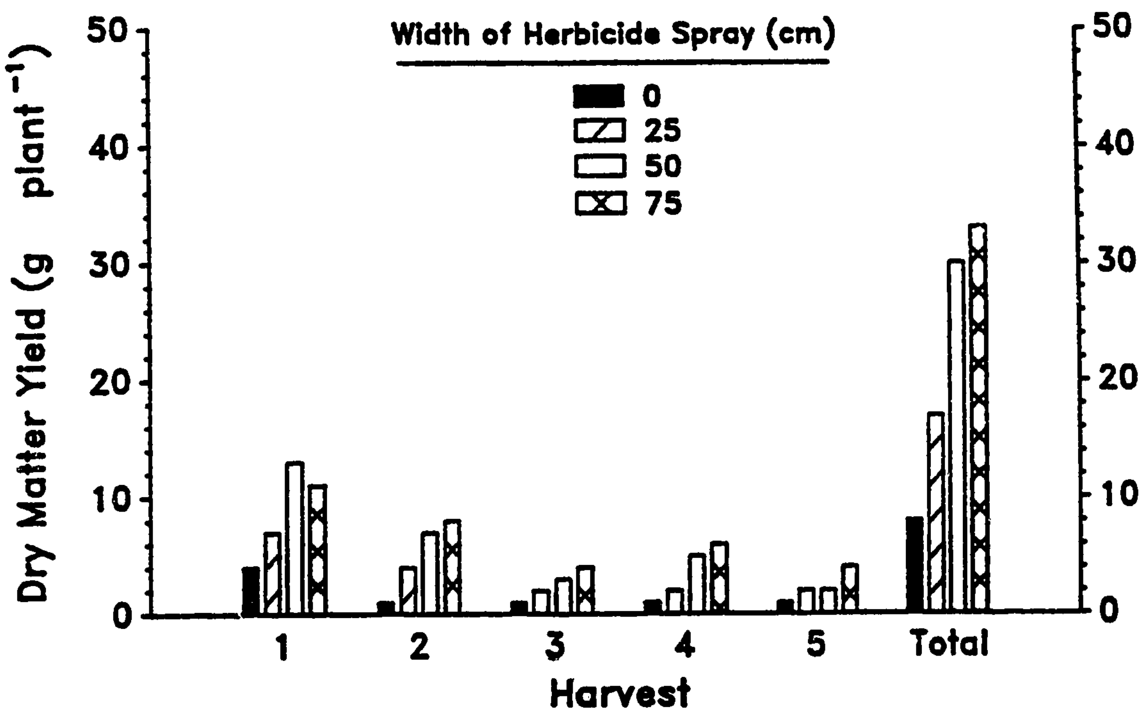


Figure 16: The effect of width (0cm, 25 cm, 50 cm, 75 cm) of glyphosate application on five successive harvests (x10^{-2}), spaced two weeks apart, from alfalfa plants removed from the field October 15, 1990, a year and four months after seeding.

Table 23: The effect of cutting crested wheatgrass on alfalfa height measured on August 24, 1989 and July 4, 1990 for plants seeded in 1989 and September 5, 1990 for alfalfa seeded in 1990.

Date	Site	Roots Cut	No Roots Cut	CV
		cm		%
Aug 24 1989	1	17.1	15.8	41.6
	2	11.1	10.6	41.6
July 4 1990	1	31.2	30.3	20.0
Sept 5 1990	1	17.3*	11.7	42.2

* - significant for P<0.05.

sites, harvests and establishment years or for etiolated alfalfa growth.

3.2.3 Light Intensity

No significant differences were detected between Mf3713 and Rangelander alfalfa germplasms for light intensity measurements (Appendix B). Typical intensities are those measured on July 3, 1990 at site 1 seeded in 1989. Light levels at ground level were 824 and 810 $\mu E\ m^{-2}\ s^{-1}$ respectively, at the top of the alfalfa canopy 1528 $\mu E\ m^{-2}\ s^{-1}$ for both, and for Mf3713 and Rangelander absorption by the canopy 703 and 617 $\mu E\ m^{-2}\ s^{-1}$ respectively.

In both establishment years, light intensity readings at ground level were significantly ($P<0.05$) higher in plots where glyphosate had been applied, and light intensity increased linearly with width of glyphosate application (Figure 16, Table 24) but the trend was only significant at site 1. There was no such trend at ground level on July 3, 1990, for plots seeded in 1989: plots with no glyphosate application had the highest light intensity (1064 $\mu E\ m^{-2}\ s^{-1}$) although not significantly ($P<0.05$) so (Table 25).

Cutting crested wheatgrass roots resulted in no significant ($P<0.05$) differences between light intensities (Appendix B).

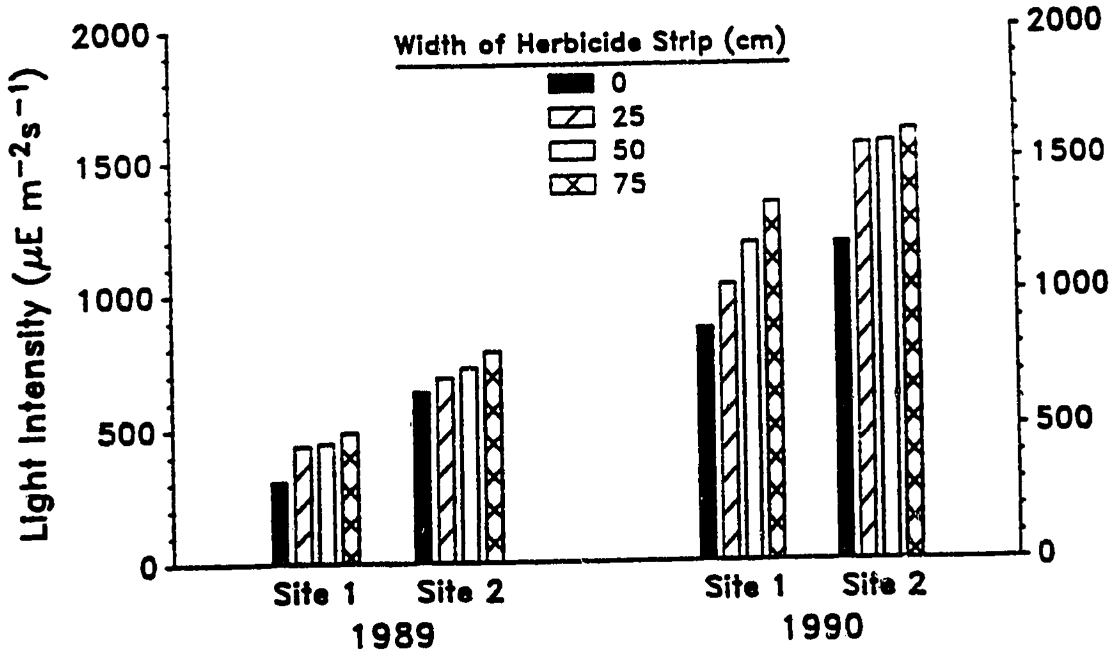


Figure 17: The effect of glyphosate application width (0, 25, 50, 75 cm) on light intensity ($\mu E\ m^{-2}\ s^{-1}$) measurements taken at ground level. The measurements were taken June 23,1989 for plots seeded in 1989 and August 3, 1990 for plots seeded in 1990.

Table 24: Orthogonal contrasts for the effect of glyphosate application width on light intensity ($\mu E\ m^{-2}\ s^{-1}$) measurements taken at ground level on June 23, 1989 for plots seeded in 1989 and August 3, 1990 for plots seeded in 1990 (Figure 17).

		Contrasts			
		Glyphosate Application vs None	Trend in Width of Control		
Date	Site		Linear	Quadratic	CV (%)
June 23 1989	1	S	S	NS	16.0
	2	S	NS	NS	20.4
Aug 3 1990	1	S	S	NS	26.3
	2	S	NS	NS	12.3

S - significant for P<0.05, NS - not significant for P<0.05.

Table 25: Contrast results for the effect of glyphosate application width on light intensity ($\mu E\ m^{-2}\ s^{-1}$) at ground level, top of the alfalfa canopy, and the difference between them, taken on July 3, 1990 for plots seeded in 1989.

	Light Intensities ($\mu E\ m^{-2}\ s^{-1}$)		
	Ground Level	Top of Alfalfa Canopy	Difference
Glyphosate Application Width (cm)			
0	1064	1560	536
25	624	1486	862
50	958	1486	459.1
75	822	1607	785
Contrasts			
Glyphosate Application vs None	NS	NS	NS
Trend in Width of Control			
Linear	NS	NS	NS
Quadratic	NS	NS	NS
CV (%)	46.9	19.1	51.2

NS - not significant for P<0.05.

3.2.4 Soil Moisture

The only significant differences between alfalfa germplasms occurred on June 20 and June 27, 1989. Plots seeded with Mf3713 alfalfa germplasm had volumetric surface soil moisture readings of 31.6 and 24.4% compared to 31.1 and 23.7% where Rangelander alfalfa germplasm was seeded.

In most cases the application of glyphosate resulted in increased surface soil moisture (Figures 18-21, Tables 26- 29). The application of glyphosate had little effect on surface soil moisture on June 10, 1990, the year following the seeding of site 1. Another notable exception occurred with the September 27, 1989 reading for site 1. The plots with no glyphosate applied had a surface soil moisture of 28.2% significantly more than 27.5%, the average for plots with a glyphosate application.

In general, surface soil moistures tended to increase with increasing width of crested wheatgrass control area (Figure 18 to 21, Table 26 to 29). For example the surface soil moisture on August 14, 1990 for site 2 seeded in 1990 were: no control 16.2%, crested wheatgrass control width of 25 cm - 17.4%, width 50 cm - 19.0% and width 75 cm - 19.1%. The higher amounts of water, in plots where crested wheatgrass was controlled with glyphosate, were observed in late summer as non-dormant crested wheatgrass plants adjacent to the strips (Figure 21).

For sites 1 and 2 seeded in 1989, August 8, 1989, had the lowest surface soil moistures with average values of 12.9% and 3.0% respectively. Site 1 moisture was just above the volumetric wilting point of 11% for one year old alfalfa seedlings (Cutforth et al. 1991), while site 2 moisture was well below this value. The lowest average surface soil measurements for sites 1 (13.4%) and 2 (17.9%), seeded in 1990 occurred on September 7.

Severing roots resulted in only two significant differences in the 25 times that measurements were taken (Appendix B, Table B.3.47 -

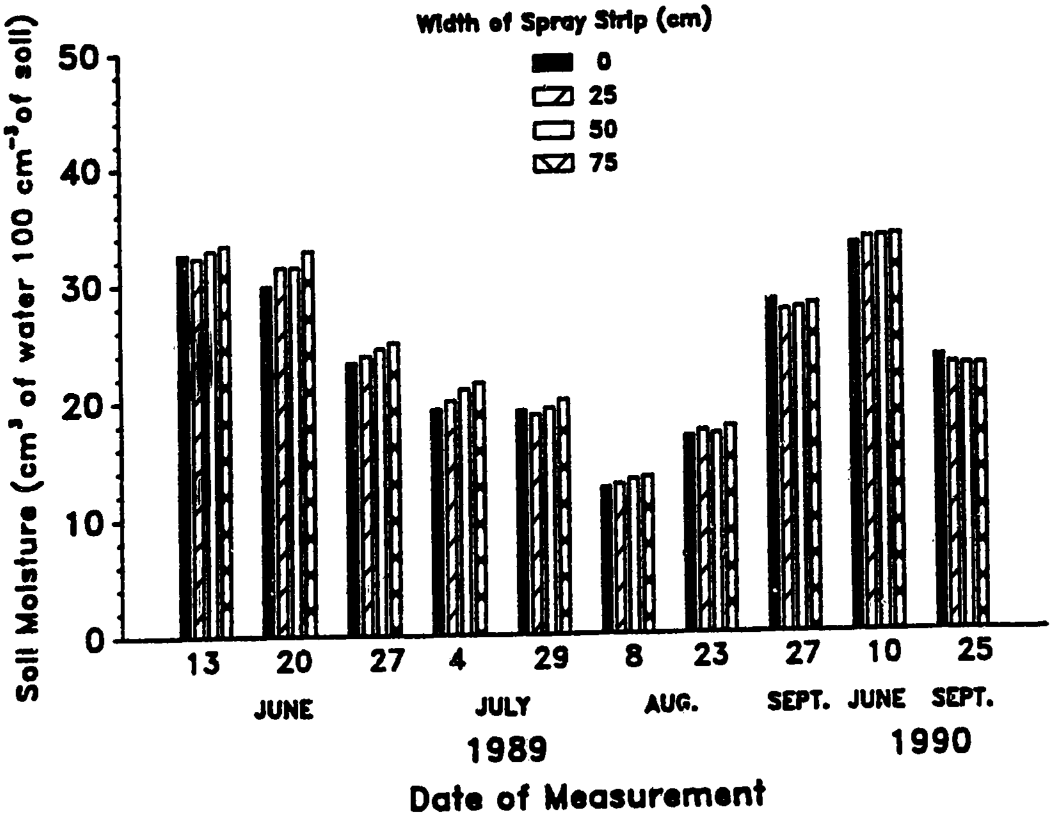


Figure 18: The effect of width of crested wheatgrass controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe with surface adapter, for site 1 seeded in 1989.

Table 26: Contrast results for the effect of width of crested wheatgrass controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 1 seeded in 1989 (Figure 18).

	Contrast			
		Trend in Width of Control		
Date	Glyphosate Application vs None	Linear	Quadratic	CV (%)
June 13 1989	NS	NS	NS	6.1
June 20 1989	S	S	NS	4.6
June 27 1989	S	S	S	8.1
July 4 1989	S	S	NS	5.3
July 29 1989	NS	S	NS	7.3
Aug 8 1989	S	S	NS	6.0
Aug 23 1989	NS	NS	NS	5.5
Sept 27 1989	S	NS	NS	5.2
June 10 1990	NS	NS	NS	3.5
Sept 25 1990	S	NS	NS	3.7

S - significant for P<0.05, NS - not significant for P<0.05.

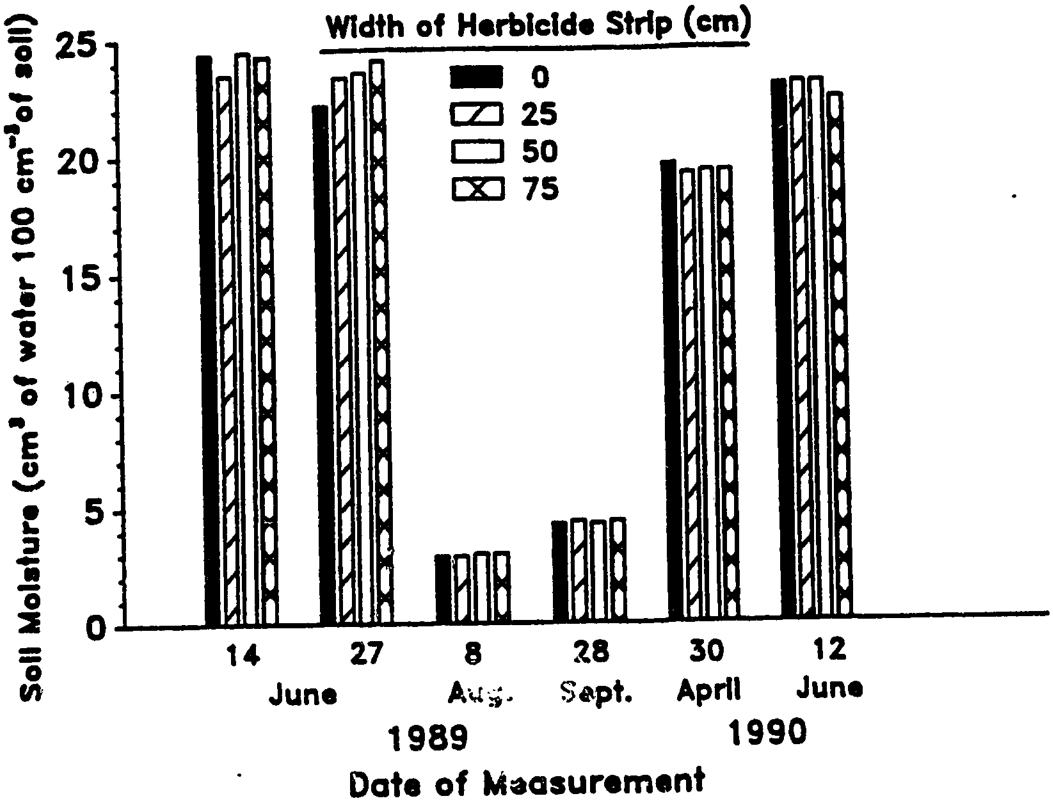


Figure 19: The effect of width of crested wheatgrass controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 2 seeded in 1989.

Table 27: Contrast results for the effect of width of crested wheatgrass controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 2 seeded in 1989 (Figure 19).

	Contrast			
		Trend in Width of Control		
Date	Glyphosate Application vs None	Linear	Quadratic	CV (%)
June 14 1989	NS	S	NS	6.0
June 27 1989	S	NS	NS	6.4
Aug 8 1989	S	NS	NS	8.4
Sept 28 1989	NS	NS	NS	6.2
Apr. 30 1990	NS	NS	NS	11.1
June 12 1990	NS	S	NS	5.6

S - significant for P<0.05, NS - not significant for P<0.05.

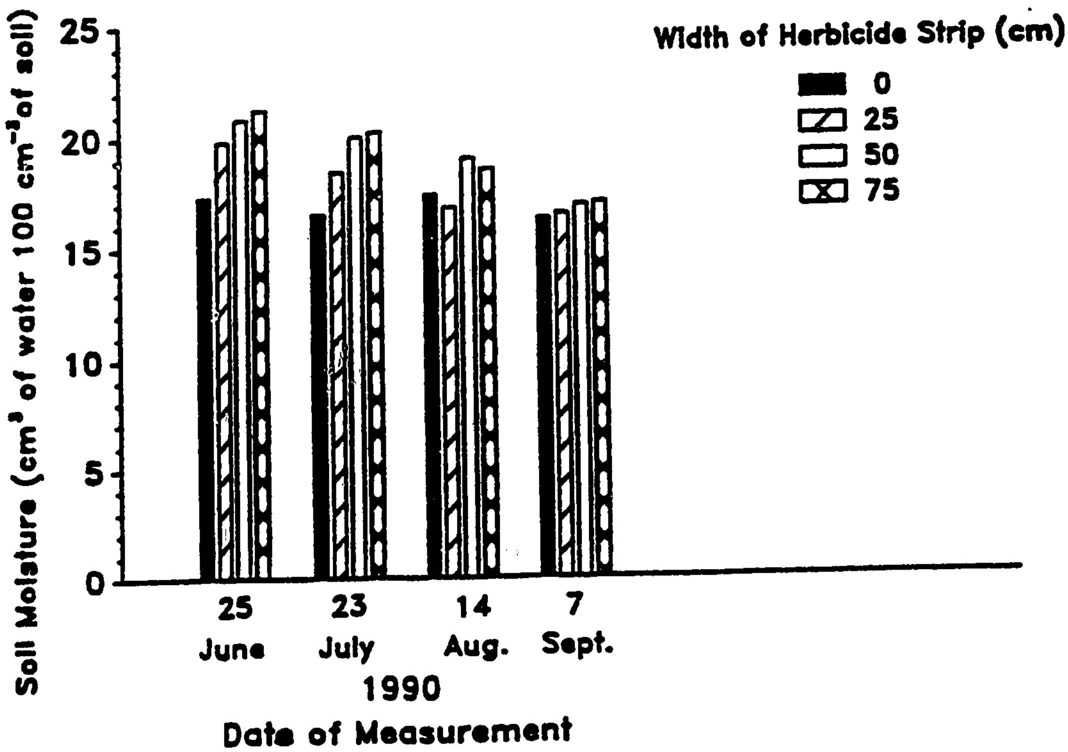


Figure 20: The effect of width of crested wheatgrass controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 1 seeded in 1990.

Table 28:Contrast results for the effect of width of crested wheatgrass controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 1 seeded in 1990 (Figure 20).

	Contrast			
		Trend in Width of Control		
Date	Glyphosate Application vs None	Linear	Quadratic	CV (%)
June 25 1990	S	S	NS	7.2
July 23 1990	S	S	NS	6.5
Aug 14 1990	S	S	S	5.9
Sept 7 1990	S	S	NS	5.6

S - significant for $P<0.05$, NS - not significant for $P<0.05$.

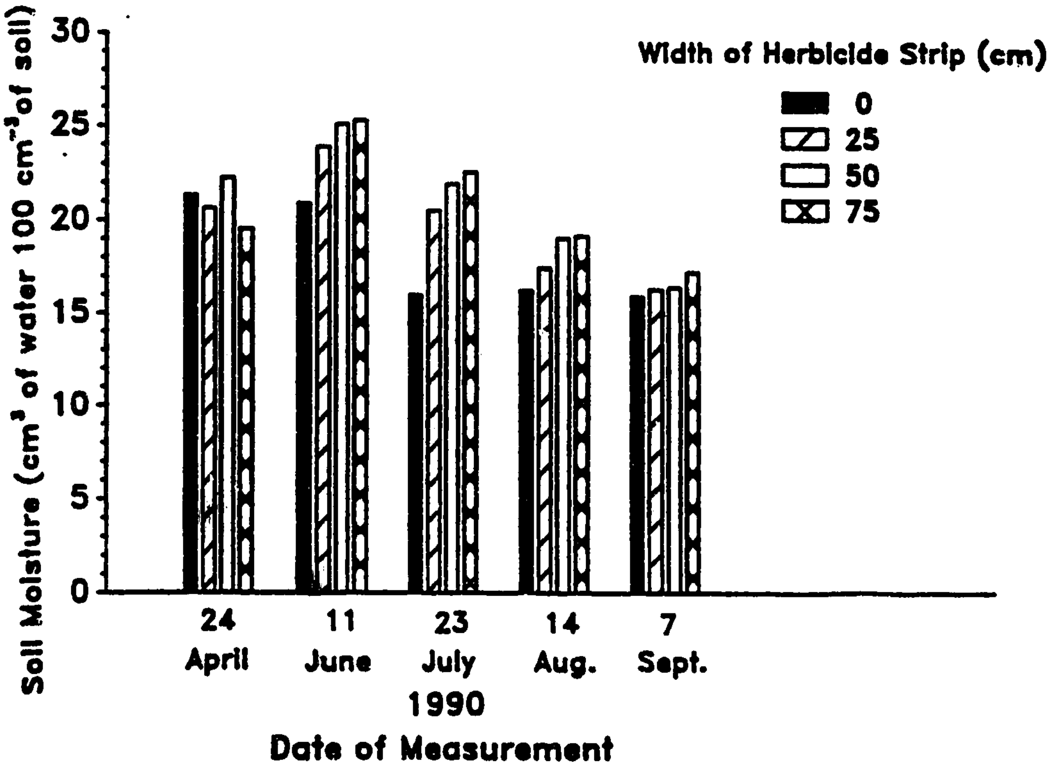


Figure 21: The effect of width of crested wheatgrass area controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 2 seeded in 1990.

Table 29: Contrast results for the effect of width of crested wheatgrass area controlled by glyphosate (0,25,50,75 cm) on surface soil moisture readings (cm^3 of water per 100 cm^3 of soil), taken with a neutron probe surface adapter, for site 2 seeded in 1990 (Figure 21).

	Contrast			
		Trend in Width of Control		
Date	Glyphosate Application vs None	Linear	Quadratic	CV (%)
Apr 24 1990	NS	NS	NS	15.2
June 11 1990	S	S	S	5.6
July 23 1990	S	S	NS	4.2
Aug 14 1990	S	S	S	8.2
Sept 7 1990	S	S	NS	5.7

S - significant for P<0.05, NS - not significant for P<0.05.

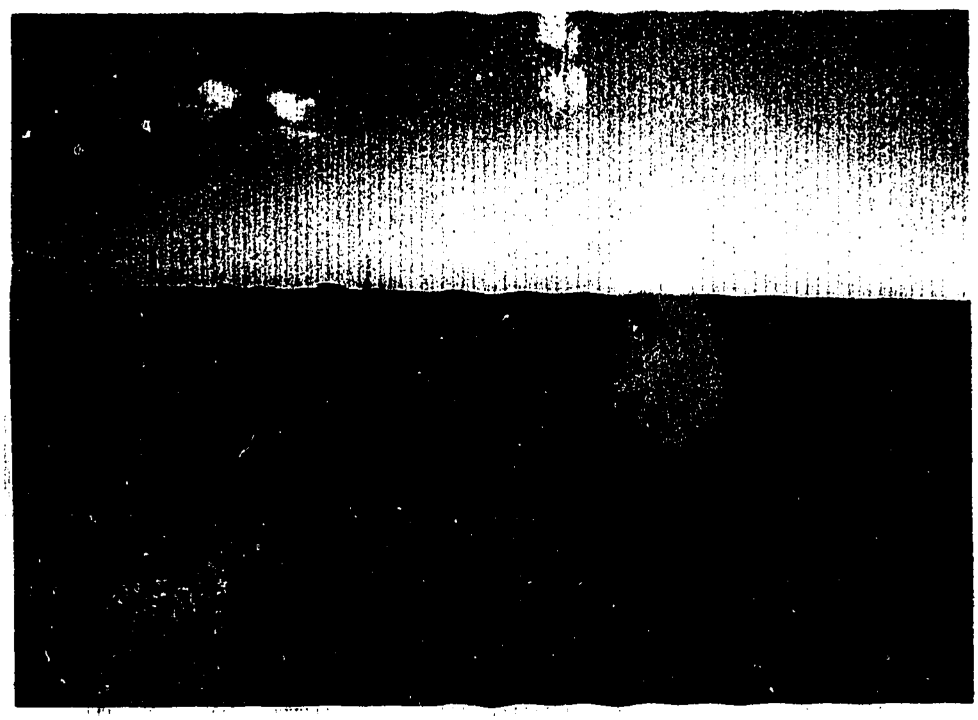


Figure 22: Non-dormant crested wheatgrass (arrows) growing adjacent to glyphosate treated strips in August 1989 at site 1 established in 1989.

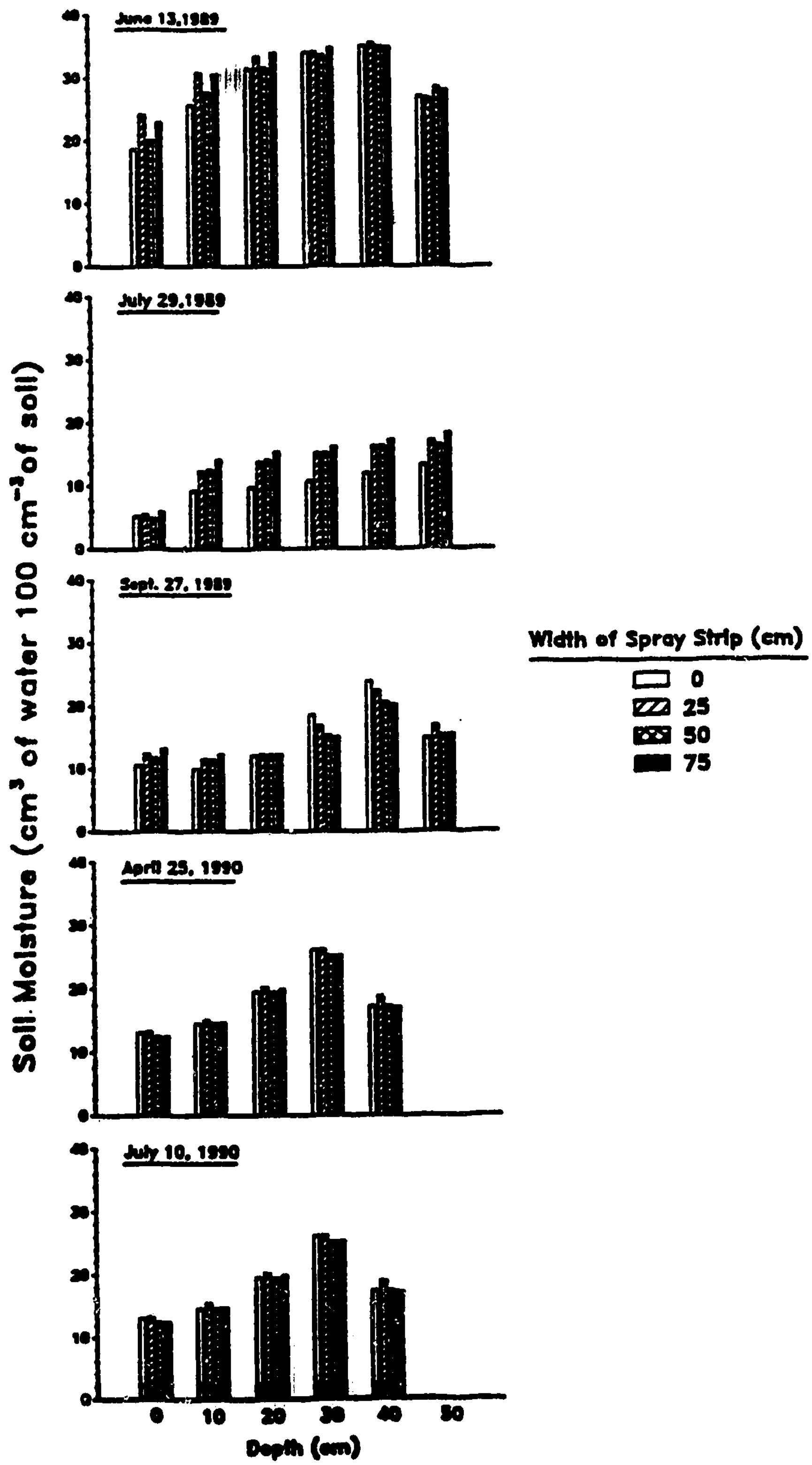


Figure 23: The effect of glyphosate application width (0, 25, 50, 75 cm) on soil moistures (cm^3 of water per 100 cm^3 of soil) obtained at various depths at 10 cm increments with a neutron probe for site 1 seeded in 1989.

Table 30: Orthogonal contrasts for the effect of width of crested wheatgrass area controlled by glyphosate (0, 25, 50, 75 cm) on soil moistures (cm^3 of water per 100 cm^3 of soils) obtained at various depths with a neutron probe for site 1 seeded in 1989 (Figure 23).

		Contrasts			
			Trend in Width of Control		
Date	Depth (cm)	Glyphosate Application vs None	Linear	Quadratic	CV (%)
June 13 1989	0	NS	NS	NS	30.0
	10	NS	NS	NS	15.9
	20	NS	NS	NS	7.6
	30	S	NS	S	4.9
	40	S	NS	S	4.7
	50	NS	NS	NS	16.6
July 29 1989	0	NS	NS	NS	56.1
	10	S	NS	NS	18.2
	20	S	NS	NS	23.5
	30	S	NS	NS	25.8
	40	S	NS	NS	23.8
	50	S	NS	NS	23.7
Sept 27 1989	0	NS	NS	NS	22.5
	10	S	S	NS	26.4
	20	S	NS	NS	26.6
	30	NS	NS	NS	19.7
	40	S	NS	NS	11.0
	50	S	NS	NS	26.6
Apr 25 1990	0	NS	NS	NS	8.5
	10	NS	NS	NS	9.0
	20	NS	NS	NS	18.5
	30	NS	NS	NS	30.7
	40	NS	NS	NS	37.5
July 10 1990	0	NS	NS	NS	23.1
	10	NS	NS	NS	27.9
	20	NS	NS	NS	25.4
	30	NS	NS	NS	16.7
	40	NS	NS	NS	31.5

S - significant, NS - not significant for $P<0.05$.

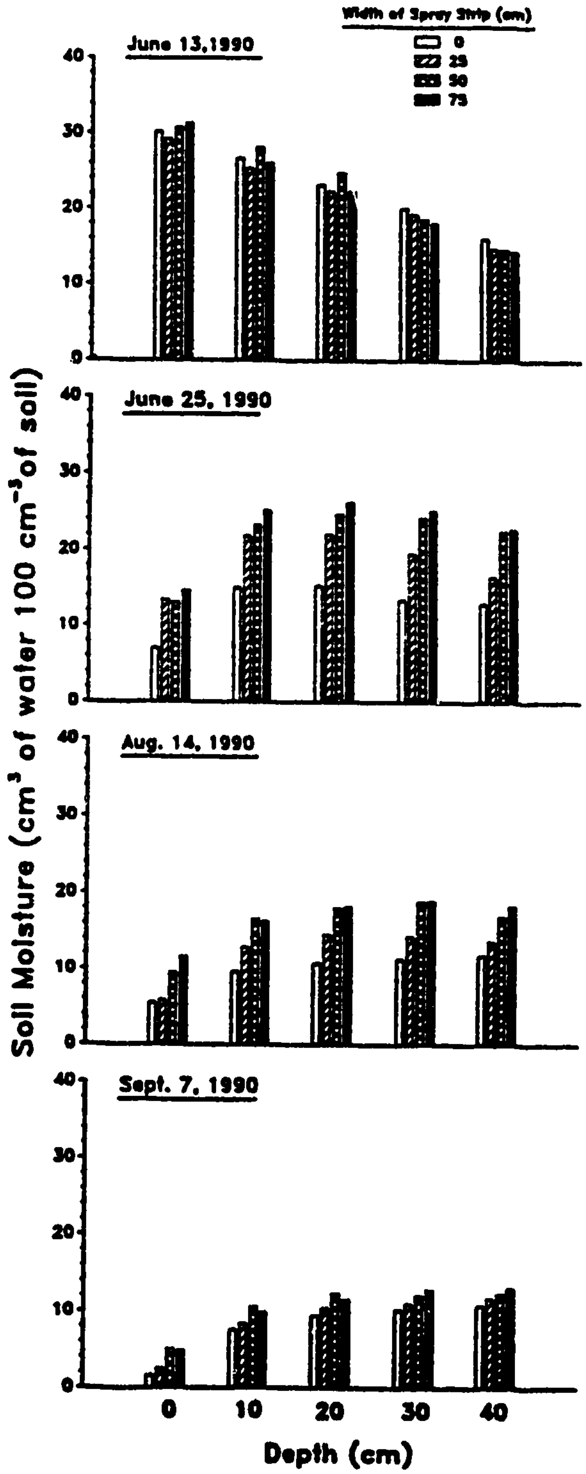


Figure 24: The effect of width of crested wheatgrass area controlled by glyphosate (0, 25, 50, 75 cm) on soil moistures (cm^3 of water per 100 cm^3 of soil) obtained at various depths with a neutron probe for site 1 seeded in 1990.

Table 31: Orthogonal contrasts results for the effect of width of crested wheatgrass area controlled by glyphosate (0, 25, 50, 75 cm) on soil moistures (cm^3 of water per 100 cm^3 of soils) obtained at various depths at 10 cm increments with a neutron probe for site 1 seeded in 1990 (Figure 24).

		Contrasts			
			Trend in Width Of Control		
Date	Depth (cm)	Glyphosate Application vs None	Linear	Quadratic	CV (%)
June 13 1990	0	NS	NS	NS	26.5
	10	NS	NS	NS	19.7
	20	NS	NS	NS	19.7
	30	NS	NS	NS	17.2
	40	NS	NS	NS	17.2
June 25 1990	0	S	S	S	19.8
	10	S	S	NS	15.7
	20	S	S	NS	15.0
	30	S	S	NS	16.3
	40	S	S	NS	46.1
Aug 14 1990	0	S	S	NS	21.5
	10	S	S	NS	20.9
	20	S	S	NS	21.6
	30	S	S	NS	21.1
	40	S	S	S	50.8
Sept 7 1990	0	NS	NS	NS	24.3
	10	NS	NS	NS	23.9
	20	S	NS	S	20.3
	30	S	S	S	20.1
	40	S	S	S	84.9

S - significant, NS - not significant for $P<0.05$.

B.3.70). One was on July 23 1990 at site 1 seeded in 1990 where plots with roots cut had volumetric surface soil moisture of 19.1% compared to a value of 18.5% where no roots were cut. The other was on June 12 1990 at site 2 seeded in 1989, where plots with roots cut had a volumetric surface soil measurement of 22.6%, significantly lower than the value of 23.2% where roots were not cut.

No significant ($P<0.05$) differences or trends were observed for surface soil moistures between plots with Mf3713 and Rangelander alfalfa germplasms (Appendix B, Table B.3.1 - B.3.46).

For site 1, seeded in 1989, the application of glyphosate resulted in higher soil moisture readings on July 29, 1989 at all depths and September 27, 1989 to a depth of 20 cm (Figure 23, Table 30). For the sites seeded in 1990 all soil moisture readings taken after June 13, 1990 were higher (Figure 24, Table 31) although not all results were significant ($P<0.05$).

Soil moisture tended to increase as width of the crested wheatgrass strips controlled by glyphosate increased (Figure 23 and 24, Table 30 and 31). For example, on June 25, 1990 the volumetric soil moistures for a 10 cm depth were 13.0% for no crested wheatgrass control, 22.0% for a crested wheatgrass control width of 25 cm, 22.5% for a crested wheatgrass control width of 50 cm and 24.7% for a crested wheatgrass control width of 75 cm. Not all readings resulted in significant differences between widths of crested wheatgrass control. The above noted trends were reversed for soil moisture measurements taken on September 27, 1989 at 30, and 40 cm depths. The volumetric soil moisture measurements for 30 cm were 18.5% for no crested wheatgrass control, 16.8% for a crested wheatgrass control width of 25 cm, 15.3% for a crested wheatgrass control width of 50 cm and 15.1% for crested wheatgrass control width of 75 cm. Similarly trends were present at the 40 cm depth and 50 cm depths.

The lowest volumetric soil moisture readings were obtained July 29, 1989 with an average reading of 5.5% for surface soil, well below the volumetric permanent wilting point of 11% (Figure 24, Table 30). Plots without a glyphosate application were below the wilting point to a depth of 40 cm whereas in plots treated with glyphosate only the surface reading was below the volumetric permanent wilting point. The spring snow melt failed to recharge the lower soil depths by April 25, 1990 (Figure 23).

Two significant ($P<0.05$) grass root cutting comparisons occurred, one for site 1 seeded in 1989 and the other for site 1 seeded in 1990. In both cases, plots where roots had been cut had more moisture at a depth of 10 cm than plots where roots had not been cut. On July 29, 1989, volumetric soil moisture was 12.7% where grass roots were cut as opposed to 11.5% where grass roots were not cut. Similarly in the experiment seeded at site 1 in 1990 volumetric readings of 22.5% where grass roots were cut and 20.3% for plots where grass roots were not cut were obtained on June 25.

Although other soil moisture readings at other depths and times were not significantly ($P<0.05$) different, when the readings were averaged for depth across dates, plots where grass roots were cut had more moisture than plots where roots were not cut (Table 32).

Table 32: Average volumetric soil moisture for 0 to 50 cm for site 1 seeded in 1989 and 1990. The average was derived from all readings for the particular site.

Site	Treatment	Depth (cm)					
		0	10	20	30	40	50
1989	Grass Roots Cut	15.9	18.5	20.2	21.0	21.6	20.1
	Grass Roots Not Cut	15.5	18.5	19.5	20.9	19.8	19.3
	N	5	5	5	5	5	3
1990	Grass Roots Cut	13.8	18.3	18.3	17.0	15.4	
	Grass Roots Not Cut	13.3	17.1	17.5	16.6	15.0	
	N	4	4	4	4	4	

3.3 The Effect of Reduced Root Competition on Alfalfa Establishment in a Russian Wildrye Stand

Only the main effects are reported; interactions were only occasionally significant (Appendix B).

3.3.1 1989 Experiment

Table 33: Effects of germplasm differences on seedling counts m^{-1} on July 15 and August 23, 1989, % emerged plants surviving to fall, and time required to reach the three leaf stage for alfalfa seeded in a Russian wildrye field in 1989.

Alfalfa Germplasm	Seedling Number m^{-1} July 15	Seedling Number m^{-1} Aug. 23	% Plants Surviving	Development Time (days)
Mf3713	66	39	63	33
Rangelander	46	31	70	28
Significance	*	ns	ns	*
CV (%)	29.5	27.4	19.5	13.2

* - significant, ns - not significant for P<0.05

In July, Mf3713 had a 30% higher plant population than Rangelander but by late August counts and per cent plants surviving were similar (Table 33). Rangelander alfalfa required a significantly shorter period of time to reach the three leaf stage (28 days) as opposed to Mf3713 (33 days).

Plots where grass roots were not cut had more seedlings present (67 m^{-1}) than plots where grass roots on one side of alfalfa row were cut (49 m^{-1}) or where grass roots on both sides of alfalfa row were cut (53 m^{-1}) (Table 34). Plant numbers in fall and per cent of emerged plants surviving to fall failed to demonstrate any differences for any of the grass root cutting treatments. The average number of fall plants was 35 m^{-1} with an average survival of 66%. The time that alfalfa plants required to reach the three leaf stage was similar for all treatments.

Table 34: Grass root cutting effect on July 15 and August 23, 1989 on seedling counts,% plants surviving to fall and time required to reach the three leaf stage of alfalfa seeded in a Russian wildrye field in 1989.

Roots Cut	Seedling Number m^{-1} July 15	Seedling Number m^{-1} Aug. 23	% Plant Surviving	Development Time (days)
None	67	40	61	30
One side of Alfalfa row	49	33	69	32
Both sides of Alfalfa row	53	33	68	31
Contrasts				
None vs root cutting	S	NS	NS	NS
Cut one side vs cut both sides	NS	NS	NS	NS
CV (%)	29.5	27.4	19.5	13.2

S = significant, NS = not significant for P<0.05

As of August 24, 1989, Rangelander plants were 27% taller (13 cm) than Mf3713 plants (9 cm)(Figure 25). On July 4, 1990, Rangelander (30 cm) had plants 11% taller than Mf3713 plants (27 cm).

Table 35: Alfalfa germplasm effects on dry matter yields (g m^{-2}) for Russian wildrye, alfalfa and weeds harvested September 21, 1989 and July 11, 1990 for the experiment established in 1989.

Year	Species	Alfalfa Germplasm Mf3713	Alfalfa Germplasm Rangelander	CV (%)
1989	Russian wildrye	46.9	49.9	25.6
	Alfalfa	3.5	3.7	80.6
	Total	48.9	53.6	24.4
1990	Russian wildrye	48.9*	32.0	36.4
	Alfalfa	91.1	104.2	31.0
	Total	140.0	140.0	23.6

* = significant for P<0.05

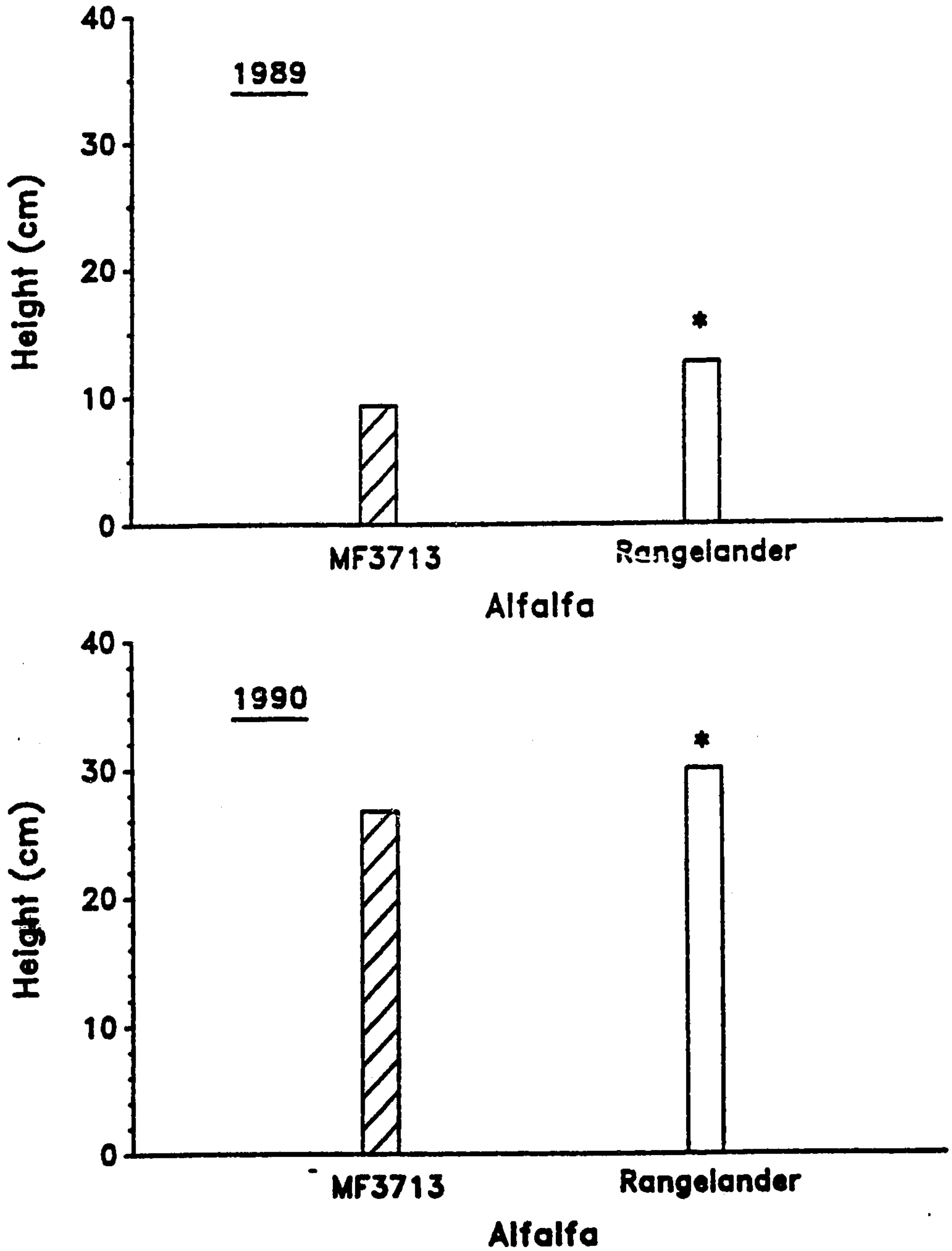


Figure 25: Heights of Rangelander and Mf3713 plants on August 24, 1989 and July 4, 1990, established in a Russian wildrye pasture in 1989. (* = significant for P<0.05)

Dry matter yields had only one statistically significant comparison: grass harvested July 11, 1990 from plots containing Rangelander alfalfa yielded 32.0 g m^{-2}, significantly less than the 48.9 g m^{-2} produced by plots containing Mf3713 alfalfa (Table 35). All plots had solid stands of alfalfa. Also, Russian wildrye plants adjoining the alfalfa rows produced seed heads, the only ones in the entire pasture.

Table 36: Effects of cutting grass roots on dry matter yields (g m^{-2}) of Russian wildrye, alfalfa and weeds harvested September 21, 1989 and July 11, 1990 for the site established in 1989.

		Russian wildrye roots cut adjacent to alfalfa			
Date of Harvest	Species	None	One Side	Two Sides	CV (%)
Sept. 1989	Grass	55.8	39.0	50.5	25.6
	Alfalfa	3.4	4.2	3.2	80.6
	Total	59.7	43.2	53.6	24.4
July 1990	Grass	40.3	35.3	45.8	36.4
	Alfalfa	95.1	94.4	103.4	31.0
	Total	135.4	129.7	149.2	23.6

No significant differences were detected for any of the grass, alfalfa or total dry matter yields for either the establishment year, 1989, or the following year. Total yields increased markedly from 1989 to 1990 as a consequence of the better alfalfa yields (Table 36).

Only in early spring 1989 did the soil moisture exceed the volumetric permanent wilting point of 11% (Table 37). Plots with Mf3713 alfalfa had more soil moisture than plots with Rangelander alfalfa, 12.2% vs 11.8% on June 14 and 11.4% vs 11.0% on September 25. Differences between moisture measurements at other dates were not significant.

No significant differences were found in soil moisture in plots with severed and unsevered Russian wildrye roots (Table 38), although plots with root cutting treatments tended to have slightly higher soil moisture values. On June 27 and July 6, 1989, plots with Russian wildrye roots cut on one side of the alfalfa had significantly more soil moisture than plots with Russian wildrye roots cut on both sides of the alfalfa row (Table 38).

Table 37: Effects of Rangelander and Mf3713 germplasm established in 1989 on surface soil moisture (cm^3 of water per 100 cm^3 of soil) in Russian wildrye.

Year	Date	Mf3713	Rangelander	CV (%)
1989	June 14	12.2*	11.8	3.7
	June 27	11.8	11.9	3.8
	July 6	11.4	11.2	3.4
	July 31	9.8	9.7	3.2
	August 9	7.7	7.7	3.4
	August 11	11.0	10.6	7.7
	August 22	10.5	10.5	3.4
	September 25	11.4*	11.0	3.7
1990	May 15[a]	14.0	14.1	6.5
	June 27	11.9	11.8	3.8

[a] - soil moisture determined gravimetrically
* = significant for $P<0.05$.

Table 38: The effect on surface soil moistures (cm^3 of water per 100 cm^3 soil) of cutting Russian wildrye roots.

Year	Date	Root Cutting none	one side	both sides	Contrasts cut vs none	one side vs both sides	CV(%)
1989	June 14	11.9	12.1	12.1	NS	NS	3.7
	June 27	11.7	12.1	11.8	NS	S	3.8
	July 6	11.2	11.5	11.2	NS	S	3.4
	July 31	9.6	9.9	9.8	NS	NS	3.2
	Aug. 9	7.7	7.8	7.7	NS	NS	3.4
	Aug. 11	10.4	10.8	11.1	NS	NS	7.7
	Aug. 22	10.4	10.6	10.5	NS	NS	3.4
	Sept. 25	11.1	11.1	11.3	NS	NS	3.7
1990	May 15[a]	13.6	13.8	14.7	NS	NS	6.5
	June 27	11.7	12.1	11.8	NS	NS	3.8

a - measurements obtained gravimetrically
Grass root cutting treatments: not at all = none; on one side of the alfalfa row = one side; on both sides of the alfalfa row = both sides.
S - significant, NS - not significant for P<0.05.

3.3.2 1990 Experiment

Due to heavy insect grazing in the spring of 1990, only a fall count of alfalfa seedlings was obtained and no plant measurements were taken.

Overall, Rangelander plots had 34% more seedlings m^{-1} than Mf3713 plots (20 vs 13) (Figure 26). Where Russian wildrye roots were cut, alfalfa seedling numbers were significantly higher than where they were not cut (Table 39). The grass root cutting treatments resulted in the alfalfa seedling numbers: no cutting (11) < two sides of one grass row cut (16) < two sides of alfalfa row (18) < one side of alfalfa row (19) = two sides of two grass rows (19).

Grass yields and total yields were not differentially affected by the two alfalfa germplasms (Figure 27). Grass dry matter yields averaged

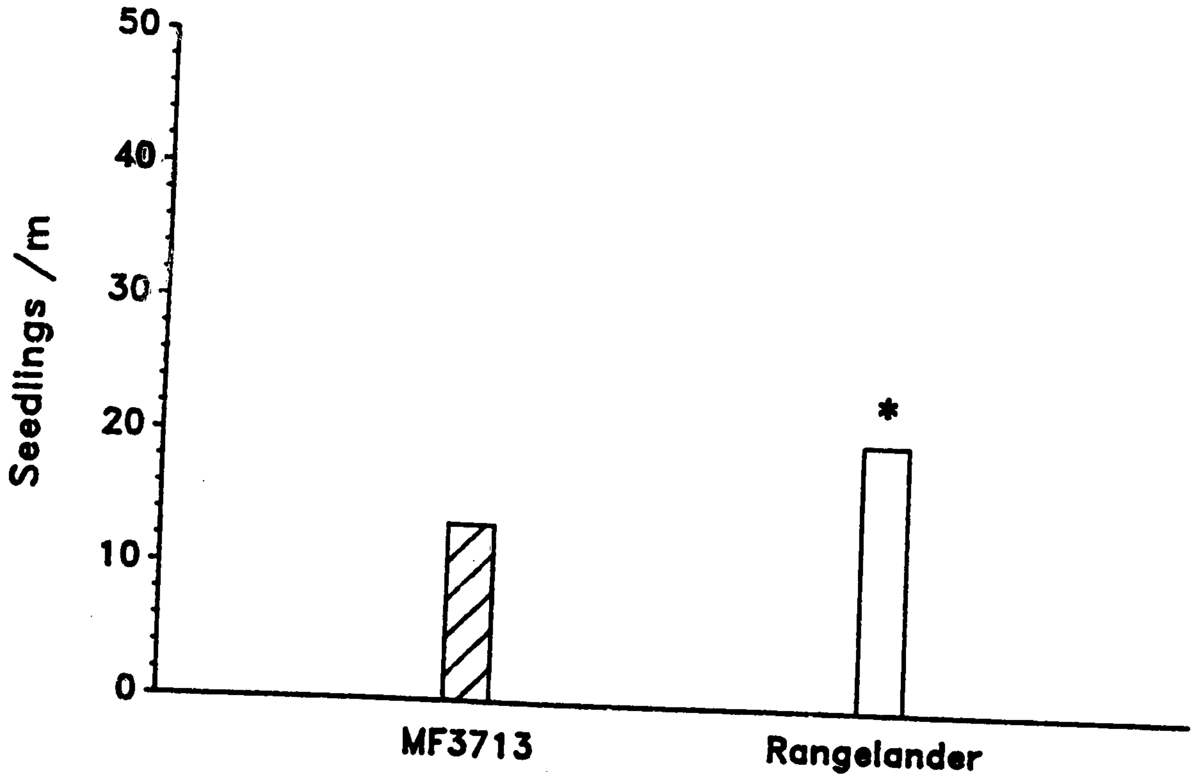


Figure 26:Effects of Mf3713 and Rangelander alfalfa germplasms, on September 5, 1990, on seedling counts on September 5, 1990 in Russian wildrye. (* = significant for $P<0.05$)

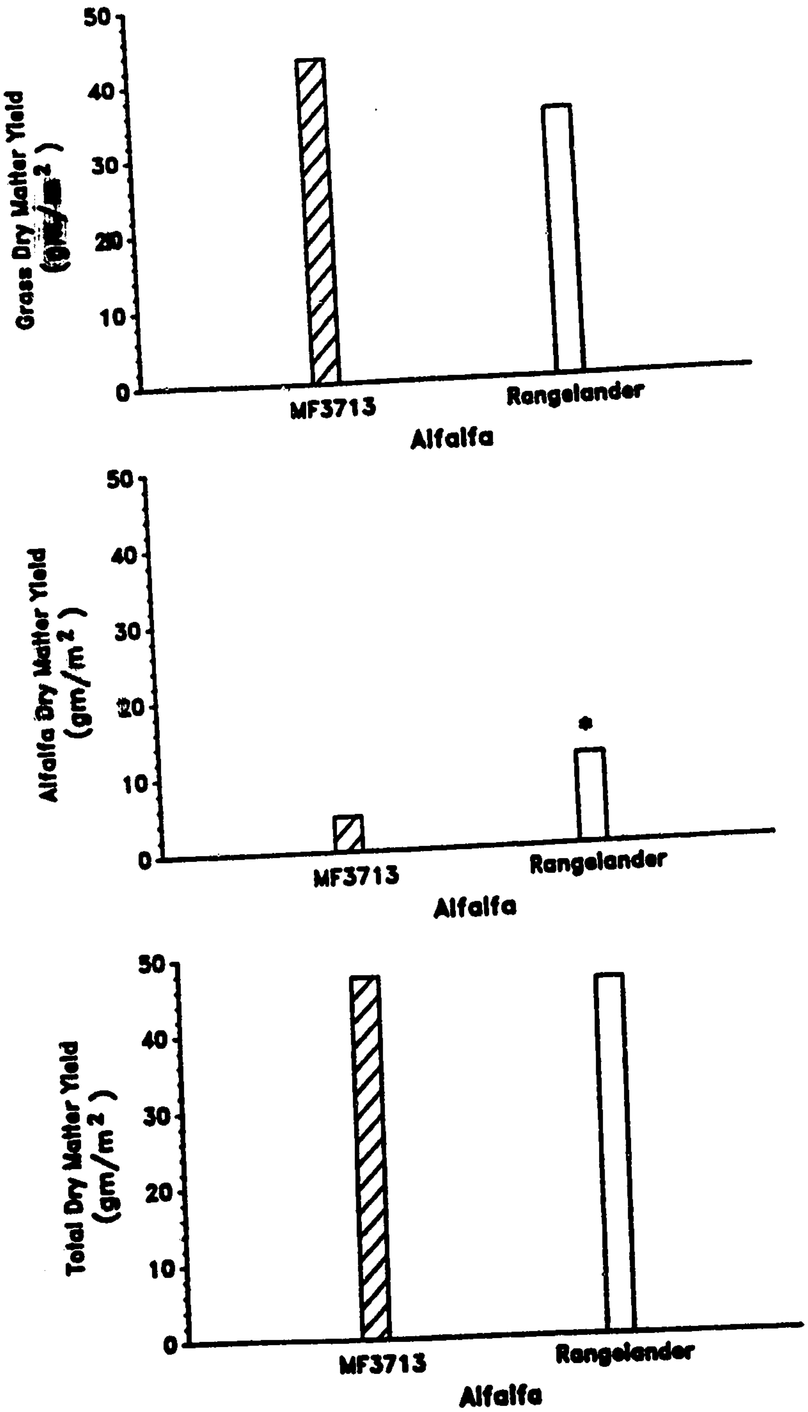


__Figure__ __27__: Effects of Rangelander and Mf3713 alfalfa germplasms on Russian wildrye, alfalfa and total dry matter yields on September 11, 1990 when direct-seeded into Russian wildrye in spring 1990. (* = significant for $P<0.05$)

Table 39: The effect of cutting Russian wildrye roots on alfalfa seedling numbers September 5, 1990 for alfalfa seeded in 1990.

Location of Cut Roots	Plant Count m-1
None (n)	11
One side of alfalfa row (oa)	19
Two sides of alfalfa row (ta)	18
Two sides of one grass row (og)	16
Two sides of two grass rows (tg)	19
CONTRASTS	
n vs oa,ta,og,tg	S
oa vs ta	NS
og vs tg	NS
oa,ta vs og,tg	NS
CV (%)	57.4

S - significant, NS - not significant for $P<0.05$.

39.08 g m^{-2} and the total dry matter yield averaged 47.16 g m^{-2} . Rangelander alfalfa significantly ($P<0.05$) outyielded Mf3713 alfalfa by 61% ($P<0.05$). No significant differences between the root cutting treatments were observed in any of the dry matter yields for the establishment year 1990 (Table 40).

On July 24, 1990, Mf3713 alfalfa plots had a volumetric surface soil moisture of 19.6% significantly higher than plots with Rangelander alfalfa (18.6%)(Table 41). Soil moisture measurements on all other sample dates were not significantly different. The surface soil moisture measurements reached a minimum on September 7,1990, with an average soil moisture of 10.7%.

The only significant difference between treatments was obtained on June 12, 1990. Plots where no Russian wildrye roots were cut had less moisture than plots given root cutting treatments (Table 42). When the surface soil moisture measurements were averaged across the four sampling

Table 40: The effects of cutting Russian wildrye roots on grass, alfalfa and total dry matter yields harvested on September 11, 1990 for the experiment started in 1990.

Root Cutting	Dry Matter Yields ($g\ m^{-2}$)		
	Grass	Alfalfa	Total
none (n)	45.2	4.1	49.3
one side one row (oa)	36.4	7.2	43.5
one side (ta) two row	34.3	8.6	42.8
two sides one row (og)	38.0	7.1	45.0
two sides two rows (tg)	42.5	13.8	56.3
CONTRASTS			
n vs oa,ta,og,tg	NS	NS	NS
oa vs ta	NS	NS	NS
og vs tg	NS	NS	NS
oa,ta vs og,tg	NS	NS	NS
CV (%)	36.6	100.8	34.1

Root cutting treatments: no roots cut = none, grass roots cut on one side of alfalfa row = one side one row, grass roots cut on both sides of alfalfa row = one side two rows, grass roots cut on both sides of grass row on one side of alfalfa row = two sides one row, and grass roots cut on both sides of grass row on both sides of alfalfa row = two sides 2 rows. S = significant, NS = not significant for $P<0.05$.

Table 41: Rangelander and Mf3713 germplasm effect on surface soil moisture (cm^3 of water per 100 cm^3 of soil) for Russian wildrye root competition reduction study established in 1990.

Year	Date	Mf3713	Rangelander	CV (%)
1990	June 12	18.7	18.7	6.4
	June 26	18.9	18.4	7.5
	July 24	19.6*	18.6	7.9
	September 7	10.4	10.9	3.1

(* = significant for $P<0.05$)

dates, the following ranking resulted: no roots cut (16.1%) < roots cut on one side of the grass rows on both sides of alfalfa row (16.7%) < roots cut on both sides of grass row on one side of the alfalfa row (16.8%) < roots cut on both sides of the grass row on both sides of alfalfa row (16.8%) < roots cut on one side of the grass row on one side of alfalfa row (17.1%). The September 7, 1990 surface soil moisture values were the only ones below the volumetric permanent wilting point of 11%.

There was more moisture in the surface soil in 1990 than in 1989 (Tables 37, 38, 41 and 42).

Table 42: The effect of cutting Russian wildrye roots on surface soil (0 -15 cm) moistures (cm^3 of water per 100 cm^3 soil) in the alfalfa establishment experiment started in 1990. (S - significant for P<0.05, NS - not significant for P<0.05)

	Measurement dates (1990)			
Root Cutting	June 12	June 26	July 27	September 7
None (n)	17.6	17.89	18.64	10.28
One side one row (oa)	19.5	19.0	19.6	10.4
One side two rows (ot)	18.9	18.5	19.0	10.3
Two sides one row (og)	18.7	19.0	19.0	10.4
Two sides two rows (bg)	18.7	18.8	19.2	10.4
CONTRASTS				
n vs oa,ot,og,bg	S	NS	NS	NS
oa vs ot	NS	NS	NS	NS
og vs bg	NS	NS	NS	NS
oa,ot vs og,bg	NS	NS	NS	NS
CV (%)	6.4	7.5	7.94	3.07

Root cutting treatments: no roots cut = none, grass roots cut on one side of alfalfa row = one side one row, grass roots cut on both sides of alfalfa row = one side two rows, grass roots cut on both sides of grass row on one side of alfalfa row = two sides one row, and grass roots cut on both sides of grass row on both sides of alfalfa row = two sides 2 rows. S - significant, NS - not significant for P<0.05.

3.4 Meteorological Conditions for Field Studies

3.4.1 Air Temperature for the Growing Season

The mean air temperature recorded at the Swift Current Research Station for the 1989 period, May 1 to September 30 inclusive was 14.9 degrees celsius with an average maximum of 21.3 degrees celsius and an average minimum of 9.0 degrees celsius (Figures 28, 29 and 30). The highest temperatures occurred in the period mid-July to mid-August.

In 1990 the mean temperature recorded at the Swift Current Research Station for the same period was 15.1 degrees celsius with an average maximum of 23.3 degrees celsius and an average minimum of 9.2 degrees celsius. The highest temperatures occurred during the same period as in 1989 but September 1990 was also hot while in 1989 a cooling trend was noted.

No statistical differences (Appendix C) were found for comparisons of the 30 year average (1958 to 1988), 1989 and 1990 average weekly temperature (Figure 28), maximum temperature (Figure 29) and minimum temperature (Figure 30).

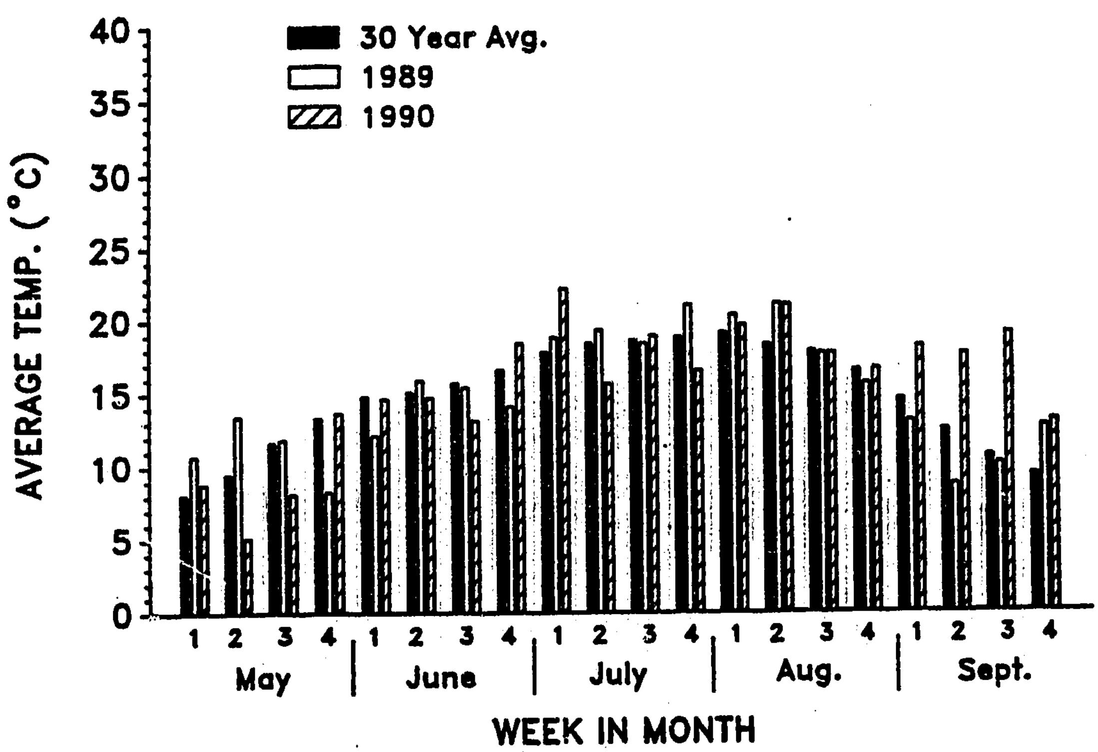


Figure 28: Average weekly temperatures ((maximum + minimum)/2) for the years 1989 and 1990 and the 30 year average (1958 to 1988).

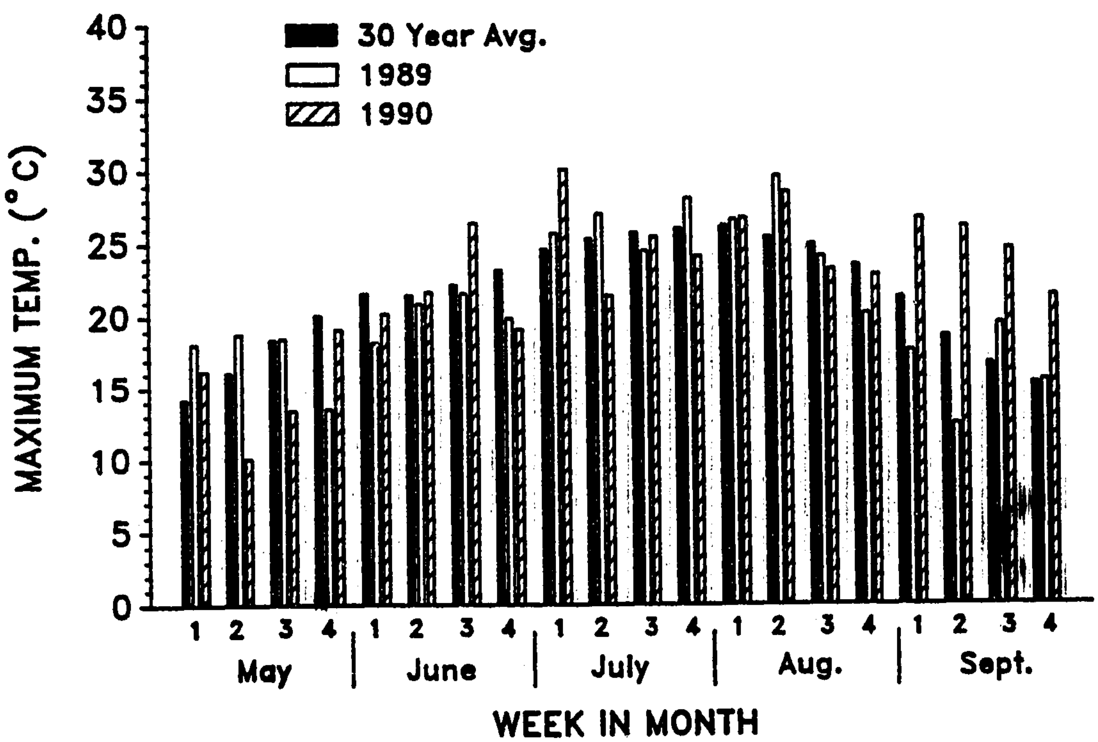


Figure 29: Maximum weekly temperatures for 1989, 1990 and the 30 year average (1958 to 1988).

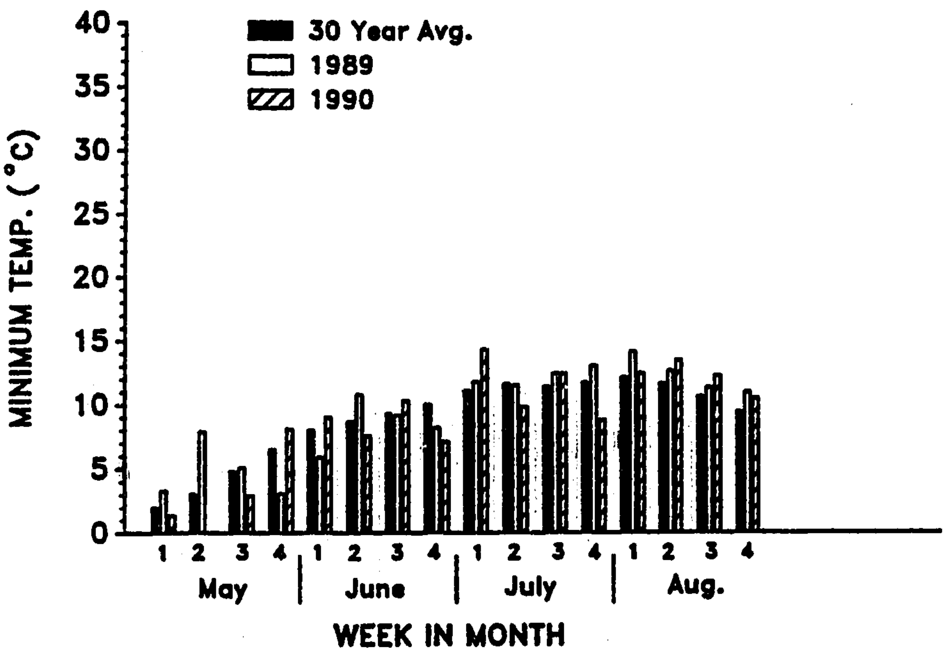


Figure 30: Minimum weekly temperatures for 1989, 1990 and the 30 year average (1958 to 1988).

3.4.2 Precipitation

In 1989 precipitation occurred regularly from May to September with major events in the second week of May, the second and fourth weeks of June and the third and fourth weeks of August.

Overall, less precipitation was received during the growing season of 1990 than in 1989. The major precipitation events occurred in the first week of May and from the first to the fourth week of July. Almost no precipitation fell in September 1990.

Comparisons of the 30 year average (1958 to 1988), 1989 and 1990 total weekly precipitations (Figure 31), using a square root transform to correct for non-normality, were not statistically different (Appendix C).

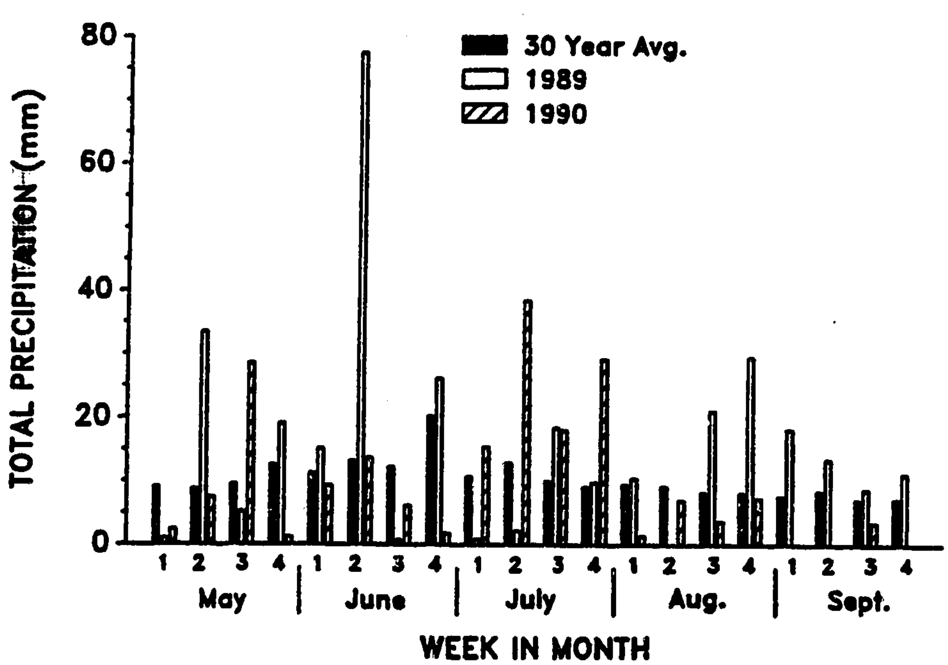


Figure 31: Total weekly precipitation values for May 1 to September 30 for 1989, 1990 and the 30 year average (1958 to 1988).

3.4.3 Potential Evaporation

The 30 year average (1958 to 1988) potential evaporation peaks in the fourth week of July (Figure 32). In 1989 and 1990 potential evaporation was greatest in July. Average weekly potential evaporation in 1990 tended to be greater (57.7 mm) than in 1989 (51.5 mm). In 1989, the maximum potential evaporation in a week was 128.7 mm while in 1990 maximum potential evaporation was 91.6mm. The minimum potential evaporation was in a week 1.6 mm for 1990 compared to 17.4 mm for 1989 (Figure 32). While 1989 had more precipitation than 1990 (Figure 31), 1989 also had a greater potential evaporation. Statistically the 30 year average, the 1989 and the 1990 potential evaporation were not different (Appendix C).

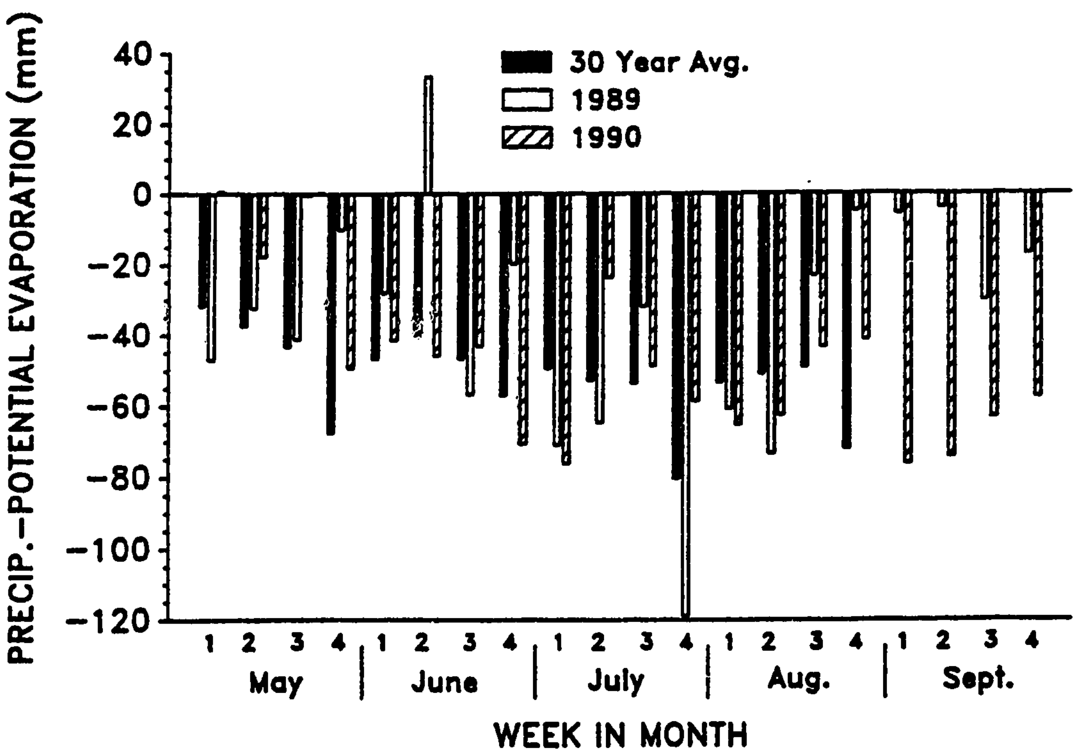


Figure 32: Potential evaporation for the period May 1 to September 30 for the years 1989 and 1990, May 1 to August 31 for the 30 year average.

3.4.4 Difference between Total Precipitation and Potential Evaporation

The 30 year average has a negative balance between May and September (Figure 33). However, for the second week of June 1989 and the first week of May 1990 precipitation exceeded the potential evaporation. Average water balances for 1989 were -30.54 mm, for 1990 -33.84 mm, and for the 30 year average -25.6 mm. The 1989 and 30 year average comparison was significantly different but the years 1989 and 1990 were not significantly different (Appendix C).

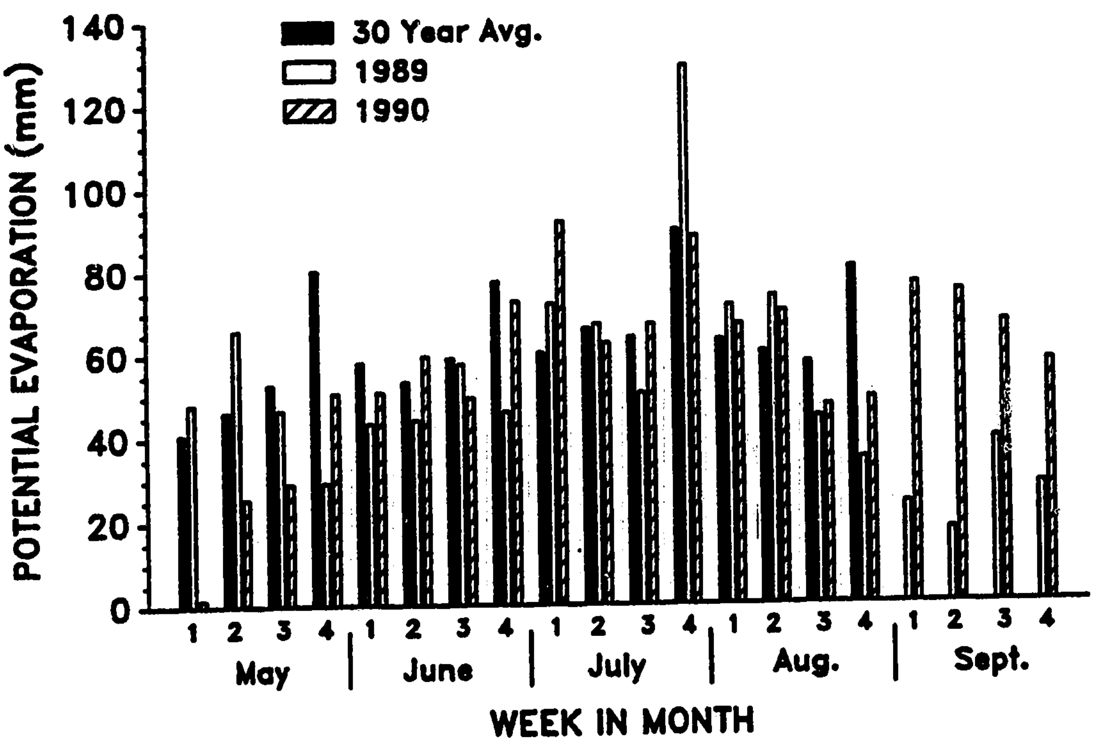


Figure 33: Difference between precipitation and potential evaporation for the period May 1 to September 30 for 1989 and 1990, May 1 to August 31 for the 30 year average (1958 to 1988).

5. Discussion

Alfalfa establishment by directly seeding into sod in southwest Saskatchewan is strongly dependant on moisture availability.The difference between precipitation and potential evaporation (Figure 33) indicates the plant's need to be as water efficient as possible. On average the greatest moisture deficit occurs during the last week of July although it occurred in September in 1990. The surface soil moisture values (Figure 23 to 24) followed the same trend as the evaporation defecit with a lag of one week. Because of its deep-rooting characteristic, established alfalfa plants obtain over half of their moisture requirement from soil below 60 cm (Bula and Massengale 1972). Until seedlings have developed a mature root system, they must extract all their moisture from the soil surface layers. As the surface soil dries, due to the precipitation to potential evaporation deficit, seedlings must endure less than ideal conditions.

Although air temperature, precipitation and evaporation did not differ statistically from the 30 year average or between 1989 or 1990, the precipitation pattern in 1990 was much more clumped, i.e. the greatest amount of precipitation fell in July (Figure 31) as compared to the more even precipitation pattern for 1989 or the 30 year average (artificial eveness due to averaging). The lack of precipitation in the fall of 1990 resulted in a sharp increase in potential evaporation (Figure 32). These different patterns of potential available moisture for plant growth resulted in different stresses being placed upon the seedlings in 1989 and 1990.

Maximum temperatures (Figure 28) sometimes exceeded the optimum temperature for alfalfa growth of 25 degrees celsius (Bula and Massengale 1972). The minimum (Figure 30) and average recorded temperatures (Figure 29) fell within optimum margins (Bula and Massengale 1972) for alfalfa growth.

Alfalfa establishment improved when competition from the existing sward was reduced. The combined effect of increased soil moisture (Figures 20 and 21, 23 and 24) and light intensity (Figure 17) provided an advantage or an 'ecological safe site' for alfalfa seedlings within the herbicide strips. A number of parameters, higher spring and fall seedling counts, percentage of survivors (Figure 10, Table 13), shorter development times (Figure 11, Table 14), taller plants (Figure 13, Table 19), increased dry matter yields, (Figure 14 and 15, Table 20 and 21) and greater vigor (Figure 16, Table 22) resulting from the effect of sprayed crested wheatgrass and root cutting provided evidence of reduced competition between the resident vegetation and alfalfa seedlings.

According to Vallentine (1980), the size of the 'gap' required for seedling establishment depends on the vigor of the resident vegetation. Russian wildrye has been observed to be more competitive than crested wheatgrass (Dubbs 1971, 1975). This was confirmed in the greenhouse competition study and it could therefore be postulated that a greater degree of suppression of Russian wildrye will be needed to establish seedlings.

A gap of 10 cm diameter noted by Goldberg (1987) as increasing the probability for establishment of perennials in multisuccessional fields would appear to be too small for the establishment of alfalfa in crested wheatgrass. A 'gap' area of 38.5 cm^2 for three seedlings resulted in poor alfalfa establishment in Russian wildrye and crested wheatgrass swards in the greenhouse. Some of the reduction in alfalfa establishment could be attributed to insufficient airflow, due to plastic cylinders around the alfalfa, which resulted in a micro-environment suitable for fungal disease organisms, but not all treatments had the tubes present. Hagood (1988) noted a linear relationship between suppression of <u>Festuca elatior</u> and alfalfa establishment and yield. The increased benefit of the wider-killed strips of crested wheatgrass would seem to support advocates of "the wider the better" school. Smoliak and Feldman (1978) found that for establishing Russian wildrye on native pasture under semi-arid conditions, the wider the tilled strip the better the establishment. Similarly, Byer and Templeton (1978) found that seeded alfalfa dry matter was greater when orchardgrass pastures were entirely killed compared to where 10.2 cm wide killed strips were killed. Kunelius and Campbell (1986) found in mesic Atlantic Canada, broadcast paraquat usually increased alfalfa dry matter yields the most. In the present experiments, a suppression width greater than 50 cm in the crested wheatgrass increased both alfalfa establishment and weed species. But does one wish to have a substantial increase in weeds? With annuals colonizing Illinois Poa pratensis fields, McConnaughay and Bazzaz (1990) noted a trend for survivorship, growth and reproduction to increase with increasing gap size. If an increase in weeds is not desired then the narrower width of 50 cm would be preferred, which supports Waddington's (1989) suggestion of "no need for anything wider than 40 cm". For the establishment of alfalfa in crested wheatgrass the present results suggest a gap size greater than 10 cm but not greater than 50 cm would be suitable. No weed problem arose when alfalfa established between Russian wildrye rows spaced 90 cm apart which lends further support to the contention of Dubbs (1971, 1975) that Russian wildrye is more competitive than crested wheatgrass. It is not known how much closer the rows of Russian wildrye could be, and still have satisfactory alfalfa establishment.

The positive relationships between soil moisture (Figures 18-24). alfalfa dry matter (Figure 14), alfalfa vigor (Figure 16), and the degree of suppression of the resident vegetation support previous findings. Fowler (1986) noted in her review of competition in arid and semiarid regions that competition for water does occur and is highly important. Barker et al. (1988) found Dactylis glomerata and Trifolium repens establishment in pasture, in which the resident vegetation was suppressed, was linearly related to rainfall in the first one to two weeks following seeding.

Also in the present experiments, seedlings in plots without sward suppression (no ecological safe site) were the first to experience drought conditions (July 25, 1989; Figure 23, June 25, 1990; Figure 24). Powell (1990) noted that drought was the major source of density-independent seedling mortality for Centaurea diffusa seedlings.

McGinnies (1984) found, after killing 30 cm wide strips of Bouteloua gracilis with glyphosate, that the grass had increased forage and seed yields. At Swift Current similar effects were observed for Russian wildrye seed production adjacent to the alfalfa rows, and increased crested wheatgrass dry matter yields were measured adjacent to spray strips in some experiments (Figures 14-16). This effect could be attributed to increased access to resources such as light and soil moisture. These beneficial effects were no longer evident by the spring of 1990 for crested wheatgrass sites seeded in 1989 because of reinvasion of the glyphosate-treated strips by the crested wheatgrass and utilization of the resources by the established alfalfa (Figure 15).

Within these limitations, soil moisture readings appear to demonstrate the benefit of suppressing the existing growth for the establishment of alfalfa seedlings, as present technology does not allow soil moisture measurements to be made exactly within the zone of influence of the seed and seedling it is not possible to say exactly when the seedlings were drought stressed.

One should note that measurements taken with a neutron probe at a depth of 0 cm. can include air moisture in the reading because of the increasing travel distance of neutrons as the soil dries (Gray et al. 1970). Consequently these readings should be utilized only to show a trend within the soil. Using a soil surface adapter shields the probe from the air moisture and results in a decrease in variability and a better measurement of the surface soil moisture (0 - 15 cm), where alfalfa seedlings were assumed to be actively competing for resources. Not surprisingly, the surface soil moisture readings obtained by the two methods showed the same trends (Figure 18 to 21, 23, and 24).

For site 1 seeded in crested wheatgrass in 1990 the 75 cm wide vegetation control strips had more plant available soil moisture than the 25 cm wide strips for all sample dates except the first (Figure 24). At several of the sample dates there was a significant ($P<0.05$) difference between the narrowest and widest strips. Not all soil moisture readings increase with increasing widths of vegetation control. The higher readings for the 50 cm width on September 7, 1990 may be the result of less water extracted by the alfalfa plants as a result of a slower growth rate (Figure 14, Table 19) than found in plots with a 75 cm wide glyphosate strip, and perhaps also a decrease in grass growth. On site 1 a measurement at 10 cm depth on September 27, 1989 demonstrated an advantage for the narrower strips (Figure 23). This higher reading could have resulted for several reasons: fewer alfalfa plants becoming established, a reduction in their growth rate, or decreased moisture utilization by the dormant crested wheatgrass.

The surface soil moisture readings taken from plots seeded in 1990 reflected imposed treatments more rapidly than in 1989. This may be attributed to the wetter spring conditions in 1989 (Figure 31) resulting in more rapid plant growth and thus a more rapid depletion of surface moisture.

The crested wheatgrass sites established in 1989 provide a somewhat confused picture in fall unless one also takes into consideration precipitation events, and evaporation rates with respect to development of alfalfa. Soil moisture measurements at dates which coincided with larger precipitation events, and reduced evaporation rates demonstrated no advantage for grass control. Control plots, in which alfalfa failed to establish or was poorly established, had higher moisture values than glyphosate-treated plots. This may have been due to the large, well-established alfalfa plants growing in strips where the crested wheatgrass had been killed withdrawing larger amounts of moisture by fall than the dormant grass in the control plots (Figure 23). Where a solid stand of alfalfa, seeded in 1989, was present in the spring of 1990, no apparent plant-available soil moisture advantage for increasing widths of crested wheatgrass suppression was evident, possibly due to replenishment of soil moisture from spring melt and precipitation. Evidence of the value of the treatments was provided by the presence of solid stands of alfalfa.

For sites established in the drier year of 1990, plots with herbicide application had higher soil moisture readings than the controls (Figure 18 to 21, 23 and 24). The one exception, the June 13, 1990 reading, showed no differences between control and glyphosate-treated plots. This can be attributed to larger spring soil moisture reserves (Figure 24), higher spring precipitation events up to June 13 (Figure 31) and the possibility that two weeks was insufficient time after application of glyphosate to curb moisture use by the crested wheatgrass.

Alfalfa seedlings within pots with no sward suppression in the greenhouse competition study, experienced lower light intensities than pots with sward suppression, as did alfalfa seedlings in the control and narrower suppression strips in the crested wheatgrass experiments. The seedlings were exposed to conditions of the neighboring grass "overtopping", a condition usually conferring a competitive advantage to the grass (Rhodes and Stern 1978). The lower light intensities at the alfalfa seedling canopy level would result in poorer production and decreased vigor in agreement with the results of Caldwell (1987), Casal et al. (1987), Salisbury and Ross (1985) and Smith (1982).

The application of glyphosate "opened up" the resident plant canopy as demonstrated by light intensity measurements (Figure 17) for all sites in their establishment year. The wider the herbicide application strip the more intense the light thus reducing competition for light as herbicide width increased. The alfalfa capitalized on advantages during the establishment year, filling in the canopy area left vacant by suppression of the previously existing plant community. As a result light intensity measurements taken the spring following seeding did not differ between treatments (Table 24).

Santhirasegaram and Black (1968) noted that growth of clover undersown to wheat was linearly related to availability of light. Most growth measurements showed a linear relationship with width of the strip of crested wheatgrass controlled by glyphosate. Seedlings which experienced lower light intensities had reduced vigor as demonstrated by a longer development time (Table 14, Figure 11), shorter plants (Table 19), lower dry matter yields for all harvests (Tables 20 and 21, Figures 14 and 15) and decreased regrowth capacity (etiolated growth) (Table 22, Figure 16). This proves that the larger the portion of a canopy removed, the greater the amounts of light able to reach seedlings at ground level. With increased access to light, competition for this resource is reduced allowing for an increase in the net photosynthesis (Ludlow 1978). One should note there is a limit to the positive benefit of reduced competition for light, at some point growth will exceed the limits of another resource, i.e. soil moisture and growth will stop.

Seedlings which experienced lower light intensities had reduced vigor as demonstrated by etiolated growth the following fall (Figure 16). This agrees with a possibility suggested by Rhodes and Stern (1978) that reduced light intensity or increased competition for light may reduce root growth and root:shoot ratio which may in turn affect the competitive ability of the plant's roots. Bula and Massengale (1972) reported that alfalfa seedlings did not tolerate low light intensities and that root development was greatly reduced by low light intensities.

Seedlings in the herbicide-treated plots also had shorter development times, which indicated more rapid growth rates of individual plants which in turn can be related to greater available space (Powell 1990). The time required to reach the "three true leaf" stage for the alfalfa seedlings exhibited a linear relationship with width of crested wheatgrass control for both sites seeded in 1989, and site 1 seeded in 1990, with seedlings in 25 cm wide strips taking longer (Figure 11). The alfalfa seedlings in the wider killed strips had greater access to light and moisture and thus had a faster growth rate. Shorter development times, taller plants and greater alfalfa dry matter yields for all harvests, and increased vigor (etiolated growth) with 75 cm wide strip herbicide applications compared to 25 cm widths demonstrate a distinct advantage for the wider treatment strips. However, weeds were also able to benefit from the wider-killed areas, which could create a management problem. The weeds increased at site 2 on crested wheatgrass seeded in 1989, as a result of the almost solid mats of Antennaria ssp., both outside and within the glyphosate-treated strips. In comparison, the weeds present at site 1 were only found within the glyphosate-treated strips. The decrease in weed dry matter yield in the spring of 1990, for site 1 on crested wheatgrass seeded in 1989, can be attributed to the solid stand of alfalfa outcompeting the volunteer weeds.

Excess residue has been noted as preventing seedling establishment for Carduus nutans (Hamrick and Lee 1987), Aristida longiseta, Bouteloua rigidiseta (Fowler 1988a) and Solidago ssp. (Goldberg and Werner 1987). Similarly, excess residue in 1990 may have been responsible for considerably fewer alfalfa and weed seedlings establishing in 1990 than in 1989 (Figure 10, 15, 14). Higher grass yields were obtained on sites seeded in 1990 than on those seeded in 1989. This may have been due to the moist fall of 1989 providing better spring soil moisture reserves in 1990. Also in 1990, there was a large amount of dead grass remaining from the growth in the excellent moisture conditions of the preceding year. One may assume that light available for seedlings in 1990 was reduced compared to 1989. Also a much larger amount of decaying vegetative material was present in plots treated with glyphosate in 1990 which may have resulted in a release of allelopathic compounds, and certainly resulted in poorer seed placement. Vallentine (1980) stated that such problems could prevent successful establishment.

The differences in total dry matter yield for the crested wheatgrass sites for the establishment years for all plots were due to the decrease in productive area due to herbicide treatment (Figure 14). The harvest in 1990, for sites seeded in 1989, demonstrated a reversal of the trend observed in the establishment year, with an increase in alfalfa and grass production (Figure 15). The increase in grass yields may have been due to nitrogen transfer from the alfalfa. Similar increases for grass (Agropyron pectineforme, A. intermedium, Psathyrostachys juncea) grown with alfalfa (Medicago sativa cv 'Rambler') were noted by Campbell (1963) in pastures at Swift Current, Saskatchewan.

Environmental conditions, specifically precipitation events, number and size, and evaporation rates appear to play an important role in determining the beneficial or deleterious effects of root cutting. Cutting the competing grass roots appears to provide greater benefits in a dry year as opposed to a moist one. But the year must provide some moisture in the form of precipitation in order for any benefit to be realized. Precipitation fell throughout the growing season in 1989, but 1990 had its greatest precipitation in the month of July with very little in August or September (Figure 31). Potential evaporation had an opposite trend for both years (Figure 32). With precipitation occurring in the clumped pattern of 1990 (Figure 31) grass root cutting appeared to aid the infiltration of moisture into the soil; creating a larger moisture reserve in the plots with grass roots cut which could be drawn upon at a later date. A precipitation pattern of regular rainfall, as found in 1989 (Figure 31) obviated the need for a moisture reserve. Root cutting may possibly have a negative effect by allowing increased evaporation due to exposure and breaking of the soil crust. The soil moisture data for 1989 indicated that plots with no roots cut had a higher soil moisture content than plots with roots cut. In 1990 soil moisture exhibited the opposite trend.

The question then arises, does this added moisture have a significant ($P<0.05$) benefit for plant growth? The answer for both the Russian wildrye plots and the crested wheatgrass plots appears to be no. For the Russian wildrye study seeded in 1989, plots with roots cut had the lower seedling numbers (Table 34) but in 1990 plots without roots cut had the lower seedling numbers (Table 35). Dry matter yields failed to demonstrate a positive effect for increased seedling numbers in either year (Table 37). Crested wheatgrass showed a similar trend (Table 15) which also applied to alfalfa plant height (Table 23).

Cutting roots of Russian wildrye increased alfalfa yields and decreased grass yields in both years (Tables 37, 38) but not to a significant extent ($P<0.05$). Crested wheatgrass showed no yield effects of root cutting.

The reduction in Russian wildrye yield, although not statistically significant, suggested root cutting had a deleterious effect on the grass as intended (Table 36, 37). However, the effect was not sufficient to increase alfalfa establishment and growth. The effect that was obtained, showed signs of diminishing by the spring of 1990 on plots seeded in 1989 (Table 37) with increased grass dry matter yields in plots where roots had been cut.

The cutting of grass roots adjacent to the alfalfa seedlings may have been ineffective because: 1) the depth to which they were cut was not sufficient possibly allowing uncut grass roots to continue to access resources; and/or 2) the grass roots may have rapidly regrown or uncut roots may have continued to grow and access resources.

Under the mesic conditions of the greenhouse, individual Rangelander alfalfa seedlings produced more than Mf3713 individual seedlings and had less grass per alfalfa plant (Table 3). A possible reason for Rangelander's greater vigor and suppression of grass growth is provided by the soil moisture data collected for the Russian wildrye root cutting experiment. Plots containing Rangelander alfalfa often had less water, not statistically significant (Table 39, 41), possibly due to greater water up take than by Mf3713. Greater water uptake may result in greater growth. This ability for rapid growth would also result in withdrawing the water resource prior to utilization by neighboring grass plants thus reducing their growth. Grass yields were less in Rangelander plots than Mf3713 plots for the Russian wildrye root cutting experiment (Table 36, Figure 27). This would agree with Harper's (1978) statement "a plant that takes up nutrients in excess of its ability to respond to them,... gains in fitness if the activity harms its neighbor", in this case the neighbor being the grass.

However, rapid growth can also result in a disadvantage, since as a plant grows rapidly its resources are depleted at a faster rate and if they are not renewed growth slows or stops. In 1990, precipitation occurred in a clumped pattern (Figure 31) and under those conditions Rangelander plants were shorter than Mf3713 for plots established the same year (Table 36), possibly because Rangelander's rapid withdrawal of soil moisture resulted in a deficit for later growth under more optimal conditions.

Rangelander's apparent ability to grow more rapidly than Mf3713 is further demonstrated by taller plants (Figure 26, Table 1, 16) for the green house study, and the 1989 establishment year for the field studies (Figure 31). Rhodes and Stern (1978) noted that even a small difference in height could confer considerable competitive advantage. In this case an advantage appears to be evident for Rangelander in 1989 in the field.

The shorter time required to achieve the third true-leaf stage (Table 33) would also provide a competitive advantage. Ross and Harper (1972) noted in experiment with Dactylis glomerata "earlier emergers continually increase their ability to capture resources at the expense of later emergers and in doing so increase their physical zone of influence".

Environmental conditions can also be used to help explain differences in yields and plant counts in the establishment years. Though there were more Mf3713 alfalfa plants than Rangelander in plots established in 1989 (Table 33, Figure 9) no significant (P<0.05) yield advantage was detected (Table 36, 17). In plots established in 1990, Rangelander had the higher plant count (Figure 25, 9) and the higher dry matter yields (Figure 27, Table 18). Mf3713 alfalfa's lower plant count for 1990 to some extent can be accounted for by drier spring conditions in 1990. Mf3713 has a large number of hard seeds (personal observation), which in the absence of scarification, require longer periods of contact with moisture in order to allow initialization of seed germination. The alfalfa seeds were not scarified for any of the experiments.

For the adjusted grass dry matter yields in the crested wheatgrass study (Table 17, 18) Rangelander alfalfa demonstrates some ability to suppress crested wheatgrass yields, when compared to plots with Mf3713. A more rapid withdrawal of soil moisture by Rangelander being the most likely cause. The possibility of allelopathy is not considered because the alfalfa seedlings would not have sufficient root or shoot mass to provide large enough amounts of allelopathic compounds to suppress the already established grass.

Vigor, as estimated by total etiolated growth, provided a clear contrast between the two alfalfas used in the study. Rangelander produced significantly (P<0.05) more dry matter in the first growth period, and Mf3713 produced more dry matter in the subsequent three growth periods (Figure 12), suggesting a possible advantage in grazing lands for Mf3713. Rangelander appeared to exhaust its root reserves with the burst of growth prior to the first cut. Rapid regrowth would lead to more frequent grazing, potentially resulting in the plant exhausting its reserves for further growth and winter survival. Mf3713, on the other hand produced smaller amounts of etiolated growth but continued to produce them over repeated harvests, thus demonstrating a possible adaptation allowing survival under conditions of repeated harvesting. Slow, decumbant regrowth and the ability to go dormant during midsummer drought were characteristics considered to give alfalfa with falcata parentage the advantage for rangeland interseeding in semiarid regions, Berdahl et al (1989). Bittman et al. (1991) found Mf3713 performed better in pastures over time than Medicago sativa ssp. sativa varieties.

Even though Mf3713 had apparent deficiencies, 1) shorter plants, 2) few seedlings, 3) slower development time, and 4) inability to inhibit grass growth compared to Rangelander, the plants continued to produce similar dry matter yields. This would suggest more efficient utilization of resources (light and water).

Harper (1978) noted that agronomic value rarely confers survival value. Looking at the repeated harvests of the vigor study Rangelander would seem to fall into this category. Rangelander's desirable characteristics of shorter development time, taller plants, an ability to compete successfully with grass for resources and large energy expenditure of resources for rapid regrowth may limit its survivabilty in situations when repeated harvests may occur.

When grown in pots inside a greenhouse with water non-limiting, Russian wildrye was more competitive than crested wheatgrass as evidenced by reduced alfalfa production for both harvests, and higher grass shoot production (Table 1 and 2, Figure 3). Other evidence supporting Russian wildrye as being more competitive includes reduced 1) alfalfa shoot dry matter yield per plant, 2) number of leaves and 3) leaf area, all for second cut (Figure 3). These observations of Russian wildrye's competitive ability agree with Dubbs (1975).

Russian wildrye pots were more acidic than pots of crested wheatgrass (Table 15). The range in pH which developed between the various treatment is not physiologically important for alfalfa establishment but may suggest a mechanism for Russian wildrye's competitive ability.

The cause of the difference in pH appeared to be associated with the presence of roots: pots with root competition present were more acidic than pots without (Figure 8). Roots are known to exude a variety of sugars, amino acids, enzymes, organic acids, etc. (Rovira 1969; Stanton 1988). The quantity and quality of exudates differs among plant species (Stanton 1988). Decreased amounts of both soluble and nonsoluble amino N have been noted by Bokhari et. al. (1979) for rhizosphere soil around Bouteloua gracilis (H.B.K.) Lag. ex Steud and Artemisia frigida Willd. This would suggest a possible nutrient capture advantage. Shamoot et al. (1968) noted increased deposition, in the rhizosphere zone of organic material from or associated with roots, during periods of active growth for a variety of grasses and legumes. The amount of organic deposition varied between plant species. One might postulate that the competitive advantage to Russian wildrye, of the lower soil pH, may be two fold: increased utilization of both soluble and nonsoluble amino N, and increased root growth.

In the greenhouse situation of water being non-limiting, shoot competition was more important than root competition. This contrasts strongly with statements made regarding root competition under field conditions for establishment of Macroptilium atropurpureum and Panicum maximum var. triglochum in an existing native grassland dominated by Heteropogon contortus (Cook and Ratcliff 1985) or with Martin and Field's (1984) observation of root competition being more important in earlier stages of growth for Trifolium repens.

In the pots where shoot competition was allowed, the grass could spread its leaves over a larger area, trap more light and develop shorter heavier shoots and possibly more of them (Figure 6, Table 6 and 8). Consequently shading of alfalfa shoots (Figure 8) would cause etiolation - fewer and sometimes smaller leaves (Figure 5, Table 13) and less dry matter (Figure 5, Table 13). In the pots where the grass shoots did not compete with the alfalfa, crowding would lead to etiolation of the grass but not for the alfalfa seedlings which were quite small (Figure 6, Table 6). These responses are consistent with observations made by Casal (1987), Casal et al. (1987), Salisbury and Ross (1985) for plants growing in far-red light rich environments. Grass yields were greater (Figure 6, Table 6) with reduced light (Figure 8, Table 11) to the alfalfa. The alfalfa in turn responded by increasing leaf area, but no yield increase was noted possibly due to thinner leaves (Figure 5, Table 5). The alfalfa seedling responses are documented responses for plants growing in low light conditions (Salisbury and Ross 1985).

The grass was able to access more light, in pots where shoot competition occurred, because of the inability of the alfalfa seedlings to compete (Figures 5 and 7, Tables 14 and 16). The grass had no need for greater stem elongation because of the ready supply of light and therefore produced shorter leaves (Table 6, Figure 6). Alfalfa was able to compete better where light was more easily accessed (Figure 8, Table 11) so yields, leaf area and number of leaves were increased (Figure 5, Table 5); this trend continued for alfalfa regrowth (Figure 7, Table 7) but not for the grass (Table 8). A possible reason for lack of response from the grass could be slower regrowth and a more rapid exhaustion of available nutrients.

From this study it appears that removal of top growth from the established sward to open up the canopy and limit shoot competition would be beneficial to establishment of introduced seedlings in mesic environments. However, a number of authors; Anonymous (1990), Taylor et. al. (1972), Anderson and Delaney (1979), Martin et al (1983) have shown that successful sod seeding can occur in the absence of sward suppression.

6. Conclusions

In the greenhouse alfalfa-grass competition experiment Russian wildrye cv. Swift, under water non-limiting conditions, was more competitive than crested wheatgrass cv. Nordan. The Russian wildrye outyielded the crested wheatgrass, and suppressed alfalfa growth more effectively. This experiment also demonstrated shoot competition suppressed alfalfa seedling growth more than root competition when soil moisture is not limiting.

Rangelander alfalfa was the more competitive variety in the greenhouse and Russian wildrye root cutting experiments. Rangelander was able to suppress grass growth relative to Mf3713's effect on grass yields. Rangelander also demonstrated its ability to grow taller, and faster than Mf3713 alfalfa in the Russian wildrye root cutting and crested wheatgrass root cutting and herbicide strip width experiments. This ability to grow taller and faster did not result in an ability to have significantly larger dry matter yields than Mf3713. The greater number of Rangelander alfalfa seedlings in 1990 also failed to result in a dry matter yield advantage.

These apparent agronomic advantages for Rangelander resulted only in a first cut increased etiolated growth yield, an ideal adaptation for hayland where rapid regrowth is desired, or an adaptation to take advantage of short periods of favorable environmental conditions. Mf3713 established its ability to sustain repeated harvests, an adaptation ideal for grazing land. Thus, which of these alfalfa varieties to chose for sodseeding into Russian wildrye or crested wheatgrass would depend upon future management of the pastures. Rangelander alfalfa would provide a stand but data indicated a susceptibility to vigor reduction under repeated harvests. The Mf3713 variety of alfalfa demonstrated some ability to withstand repeated harvests.

The beneficial effects of root cutting appear to be limited to a narrow set of environmental conditions. These environmental conditions appear to have occurred in the drier year of this study but only during the moister portions of those same years. Even then grass root cutting had almost no significant effect on alfalfa establishment. Site 1 seeded in 1990 was the only test to show significantly higher alfalfa production due to root cutting.

Soil moisture readings demonstrated a greater benefit for root cutting during the dry year 1990 but only for the periods when moisture was available, spring and early summer. Towards the end of the growing season root cutting appeared to have deleterious effects on soil moisture.

Herbicide application was beneficial for alfalfa establishment in crested wheatgrass pastures. Suppression of the pasture swards resulted in a more open canopy reducing light competition. Soil moisture also increased in the glyphosate application strips. The resulting additional moisture and available light resulted in higher alfalfa and grass yields. The grass yields equalled or exceeded yields in the control plots one year following treatment, for the 1989 study.

The width of the herbicide strips providing the best results were 75 and 50 cm wide strips. From a producer's point of view the 50 cm would probably provide the best results because of fewer management concerns; fewer weeds were found to occur with the narrower strips and less grass production area was suppressed.

Therefore establishment of alfalfa in crested wheatgrass stands would be facilitated by herbicide applied in 50 cm bands. Alfalfa establishment would be facilitated with root cutting of grass under appropriate environmental conditions but cumbersome equipment and economic considerations would make this a less attractive option.

Sodseeded alfalfa did establish in 1989 and 1990. As indicated environmental conditions and pest conditions will limit the applicability of sodseeding as a method of alfalfa establishment. The ability to predict environmental conditions would improve one's ability to determine sites best suited for establishment of alfalfa utilizing sodseeding. Also a better understanding of alfalfa stress tolerances would enable one to attempt management intervention when and if needed to ensure establishment. A better knowledge of seedling moisture requirements would allow for a better prediction of successful establishment prior to starting site renovation.

Sodseeding alfalfa in pasture and rangeland is an option that will result in establishment under appropriate environmental conditions and should be an option to replace conventional seeding methods for areas where ground cover is required to prevent degradation of the site.

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Appendix A: Tables of sources of variance, contrast hypotheses and contrasts for the greenhouse competition study: alfalfa established in Russian wildrye and crested wheatgrass swards, the effect of reduced root competition and alfalfa establishment in a Russian wildrye stand, and the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass experiments.

Table A.1: Sources of variance for alfalfa-grass competition study in greenhouse.

Source of Variation	Degrees of Freedom
Block	5
Grass Variety (G)	1
Alfalfa Variety(A)	1
Type of Competition (C)	3
G*A	1
G*C	3
A*C	3
G*A*C	3
Error	75
Total	95

Table A.2: Sources of variance with associated degrees of freedom for 1989 experimental design of the effect of reduced Russian wild-rye root competition on alfalfa establishment study.

Source of Variance	degrees of freedom
Blocks	3
Root cutting pattern (K)	2
Alfalfa varieties (A)	1
K*A	2
Error	15
Total	23

Table A.3: Sources of variance table with associated degrees of freedom for 1990 experimental design of the effect of reduced Russian wild-rye root competition on alfalfa establishment study.

Source of Variance	degrees of freedom
Blocks	3
Root Cutting pattern (K)	4
Alfalfa varieties (A)	1
K*A	4
Error	27
Total	39

Table A.4: Source of variance with associated degrees of freedom for the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass swards.

Source of Variance	degrees of freedom
Blocks	3
Width of killed strips (W)	3
Root cutting (K)	1
W*K	3
Alfalfa variety (A)	1
W*A	3
K*A	1
W*K*A	3
Error	45
Total	63

Table A.5: Greenhouse Competition Study: Alfalfa seedlings established in Russian Wildrye or Crested Wheatgrass swards contrast and hypotheses.

CONTRASTS	HYPOTHESES
Crested Wheatgrass vs Russian Wildrye	$\mu_1+\mu_2...+\mu_8=\mu_9+\mu_{10}...+\mu_{16}$
Rangelander vs MF3713	$\mu_1+...+\mu_4+\mu_9+...+\mu_{12}=\mu_5+...+\mu_8+\mu_{13}+...+\mu_{16}$
N vs R,S,B	$3(\mu_4+\mu_8+\mu_{12}+\mu_{16})=\mu_1+\mu_2+\mu_3+\mu_5+\mu_6+\mu_7+\mu_9+\mu_{10}+\mu_{11}+\mu_{13}+\mu_{14}+\mu_{15}$
B vs R,S	$\mu_1+\mu_2+\mu_5+\mu_6+\mu_9+\mu_{10}+\mu_{13}+\mu_{14}=2(\mu_3+\mu_7+\mu_{11}+\mu_{15})$
R vs S	$\mu_1+\mu_5+\mu_9+\mu_{13}=\mu_2+\mu_6+\mu_{10}+\mu_{14}$

Note: R= root competition present
S= shoot competition present
B= both root and shoot competition present
N= All competition absent

Table A.6: Effect of Reduced Root Competition on Alfalfa Establishment in Russian Wildrye Stands 1989 study contrasts and hypotheses.

Contrasts	Hypotheses
Rangelander vs MF3713	$\mu_1+\mu_2+\mu_3=\mu_4+\mu_5+\mu_6$
Check vs Cuts	$2(\mu_1+\mu_4)=\mu_2+\mu_3+\mu_5+\mu_6$
1 Side cut vs 2 Sides cut	$\mu_2+\mu_5=\mu_3+\mu_6$

Table A.7: Effect of Reduced Root Competition on Alfalfa Establishment in Russian Wildrye Stands 1990 study contrasts and hypotheses.

Contrasts	Hypotheses
Rangelander vs MF3713	$\mu_1+...+\mu_5=\mu_6+...+\mu_{10}$
Check vs Root Cutting	$4(\mu_1+\mu_6)=\mu_2+\mu_3+\mu_4+\mu_5+\mu_7+\mu_8+\mu_9+\mu_{10}$
Single Side Cut vs Two Sides Cut	$\mu_2+\mu_3+\mu_7+\mu_8=\mu_4+\mu_5+\mu_9+\mu_{10}$
1 Single Side Cut vs 2 Single Sides Cut	$\mu_2+\mu_7=\mu_3+\mu_8$
1 Row Both Sides vs 2 Rows Both Sides Cut	$\mu_4+\mu_9=\mu_5+\mu_{10}$

Table A.8: Effect of Spray Width and Reduced Root Competition on Alfalfa Establishment in Crested Wheatgrass Stands study contrasts and hypotheses.

Contrasts	Hypotheses
Rangelander vs MF3713	$\mu_1+...+\mu_8=\mu_9+...+\mu_{16}$
Herbicide vs No Herbicide	$3(\mu_1+\mu_5+\mu_9+\mu_{13})=\mu_2+...\mu_4+\mu_6+\mu_7+\mu_8+\mu_{10}+\mu_{11}+\mu_{12}+\mu_{14}+\mu_{15}+\mu_{16}$
Roots Cut vs No Cutting	$\mu_1+...\mu_4+\mu_9...+\mu_{12}=\mu_5+...\mu_8+\mu_{13}+...\mu_{16}$
Linear	$\mu_2+\mu_6+\mu_{10}+\mu_{14}=\mu_4+\mu_8+\mu_{12}+\mu_{16}$
Quadratic	$2(\mu_3+\mu_7+\mu_{11}+\mu_{15})=\mu_2+\mu_4+\mu_6+\mu_8+\mu_{10}+\mu_{12}+\mu_{14}+\mu_{16}$

Table A.9: Greenhouse competition study: Alfalfa seedlings established in Russian wildrye or crested wheatgrass swards factors and orthogonal contrasts.

	Crested Wheatgrass								Russian Wildrye							
	Rangelander				MF3713				Rangelander				MF3713			
Contrast\Factor	R	S	B	N	R	S	B	N	R	S	B	N	R	S	B	N
Crested Wheatgrass vs Russian Wildrye	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1
Rangelander vs MF3713	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1
N vs R,S,B	1	1	1	-3	1	1	1	-3	1	1	1	-3	1	1	1	-3
B vs R,S	1	1	-2	0	1	1	-2	0	1	1	-2	0	1	1	-2	0
R vs S	1	-1	0	0	1	-1	0	0	1	-1	0	0	1	-1	0	0

Note: R=Root competition present
S=Shoot competition present
B=Both root and shoot competition present
N=All competition absent

Table A.10: The Effect of Reduced Root Competition on Alfalfa Establishment in Russian Wildrye Stands 1989 study factors and orthogonal contrasts.

	Alfalfa					
	Rangelander			Mf3713		
Contrast\Factors	Check	1 Side Cut	2 Sides Cut	Check	1 Side Cut	2 Sides Cut
Rangelander vs MF3713	1	1	1	-1	-1	-1
Check vs cuts	2	-1	-1	2	-1	-1
1 Side cut vs 2 Sides cut	0	1	-1	0	1	-1

Table A.11: The Effect of Reduced Root Competition on Alfalfa Establishment in Russian Wildrye Stands 1990 study factors and orthogonal contrasts.

	Alfalfa									
	Rangelander					MF3713				
Contrast\Factors	C	1S	2S	1SB	2SB	C	1S	2S	1SB	2SB
Rangelander vs Mf3713	1	1	1	1	1	-1	-1	-1	-1	-1
Check vs Root Cutting	4	-1	-1	-1	-1	4	-1	-1	-1	-1
Single Side Cut vs 2 Sides Cut	0	1	1	-1	-1	0	1	1	-1	-1
1 single side vs 2 single side cuts	0	1	-1	0	0	0	1	-1	0	0
1 row both sides vs 2 rows both sides cut	0	0	0	1	-1	0	0	0	1	-1

Note: C=Check, 1S=1 row 1 side cut, 2S=2 rows 1 side cut
1SB=1 row 2 sides cut, 2SB=2 rows 2 sides cut.

Table A.12: The Effect of Spray Width and Reduced Root Competition on Alfalfa Establishment in Crested Wheatgrass Stands study factors, orthogonal and polynomial orthogonal contrasts.

Factors	Contrasts: Range-lander vs Mf3713	Herbicide vs None	Roots Cut vs None Cut	Linear	Qua-dratic
Rangelander					
Roots Cut					
Spray Width (cm)					
0	1	3	1	0	0
25	1	-1	1	-1	1
50	1	-1	1	0	-2
75	1	-1	1	1	1
No Roots Cut					
Spray Width (cm)					
0	1	3	-1	0	0
25	1	-1	-1	-1	1
50	1	-1	-1	0	-2
75	1	-1	-1	1	1
Mf3713					
Roots Cut					
Spray Width (cm)					
0	-1	3	1	0	0
25	-1	-1	1	-1	1
50	-1	-1	1	0	-2
75	-1	-1	1	1	1
No Roots Cut					
Spray Width (cm)					
0	-1	3	-1	0	0
25	-1	-1	-1	-1	1
50	-1	-1	-1	0	-2
75	-1	-1	-1	1	1

APPENDIX B. Analysis of variance tables, providing source, degrees of freedom (df), probability of a greater F value by chance (P>F), for all experiments.

Table B.1.1. Analysis of variance of alfalfa-grass competition in the greenhouse: first cut grass dry matter yields.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	148.65	0.10
Grass (G)	1	1.54	0.75
Alfalfa (A)	1	27.34	0.19
G * A	1	2.15	0.71
Competition (C)	3	338.01	0.00
G * C	3	124.85	0.05
A * C	3	8.97	0.90
G * A * C	3	33.92	0.53
Error	75	1145.63	

Table B.1.2. Analysis of variance of alfalfa-grass competition in the greenhouse: first cut average grass height.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	911.55	0.07
Grass (G)	1	263.34	0.08
Alfalfa (A)	1	23.01	0.61
G * A	1	319.01	0.06
Competition (C)	3	1746.95	0.00
G * C	3	443.53	0.17
A * C	3	119.36	0.71
G * A * C	3	211.37	0.49
Error	75	6418.62	

Table B.1.3. Analysis of variance of alfalfa-grass competition in the greenhouse: at the first harvest of alfalfa dry matter yield.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	0.06	0.65
Grass (G)	1	0.05	0.11
Alfalfa (A)	1	0.05	0.10
G * A	1	0.02	0.28
Competition (C)	3	0.14	0.07
G * C	3	0.05	0.42
A * C	3	0.02	0.79
G * A * C	3	0.02	0.76
Error	75	1.34	

Table B.1.4. Analysis of variance of alfalfa-grass competition in the greenhouse: alfalfa leaf area per alfalfa plant at the first harvest.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	711.69	0.53
Grass (G)	1	471.49	0.11
Alfalfa (A)	1	544.43	0.08
G * A	1	198.33	0.29
Competition (C)	3	1976.50	0.01
G * C	3	573.46	0.35
A * C	3	153.88	0.83
G * A * C	3	177.44	0.79
Error	75	17613.14	

Table B.1.5. Analysis of variance of alfalfa-grass competition in the greenhouse: number of alfalfa leaves per alfalfa plant at the first harvest.

Source	df	Sums of Squares	P > F
Replicates	5	489.86	0.71
Grass (G)	1	465.23	0.10
Alfalfa (A)	1	567.13	0.07
G * A	1	203.20	0.27
Competition (C)	3	1799.36	0.02
G * C	3	507.08	0.39
A * C	3	256.81	0.68
G * A * C	3	268.62	0.66
Error	75	12513.76	

Table B.1.6. Analysis of variance of alfalfa-grass competition in the greenhouse: alfalfa shoot dry matter yields per alfalfa plant at the second cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	0.79	0.07
Grass (G)	1	0.40	0.02
Alfalfa (A)	1	0.47	0.01
G * A	1	0.28	0.06
Competition (C)	3	0.83	0.01
G * C	3	0.15	0.57
A * C	3	0.07	0.82
G * A * C	3	0.22	0.39
Error	75	5.49	

Table B.1.7. Analysis of variance of alfalfa-grass competition in the greenhouse: alfalfa root dry matter yields per plant at the second cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	0.14	0.09
Grass (G)	1	0.01	0.40
Alfalfa (A)	1	0.08	0.02
G * A	1	0.[illegible]	0.23
Competition (C)	3	0.02	0.68
G * C	3	0.05	0.34
A * C	3	0.05	0.29
G * A * C	3	0.04	0.42
Error	75	1.04	

Table B.1.8. Analysis of variance of alfalfa-grass competition in the greenhouse: number of alfalfa leaves per alfalfa plant at second cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	6620.21	0.03
Grass (G)	1	3408.17	0.01
Alfalfa (A)	1	6208.17	0.00
G * A	1	2889.35	0.02
Competition (C)	3	6464.75	0.01
G * C	3	1280.13	0.48
A * C	3	768.36	0.68
G * A * C	3	1197.25	0.51
Error	75	38521.00	

Table B.1.9. Analysis of variance of alfalfa-grass competition in the greenhouse: alfalfa leaf area per plant at the second cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	16337.81	0.06
Grass (G)	1	10918.01	0.01
Alfalfa (A)	1	12704.47	0.00
G * A	1	8796.14	0.02
Competition (C)	3	18461.91	0.01
G * C	3	3456.43	0.50
A * C	3	1291.68	0.83
G * A * C	3	5108.15	0.33
Error	75	10915.86	

Table B.1.10. Analysis of variance of alfalfa-grass competition in the greenhouse: grass dry matter yields per pot at the second cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	5.94	0.84
Grass (G)	1	14.62	0.03
Alfalfa (A)	1	1.12	0.53
G * A	1	0.61	0.65
Competition (C)	3	8.90	0.38
G * C	3	15.88	0.15
A * C	3	4.43	0.67
G * A * C	3	3.66	0.74
Error	75	211.91	

Table B.1.11. Analysis of varinace of alfalfa-grass competition in the greenhouse: pH of soil taken from the centre of the pot.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	5	3.33	0.00
Grass (G)	1	0.41	0.04
Alfalfa (A)	1	0.16	0.19
G * A	1	0.06	0.43
Competition (C)	3	1.58	0.00
G * C	3	0.50	0.16
A * C	3	0.12	0.75
G * A * C	3	0.26	0.43
Error	75	12.78	

Table B.1.12. Analysis of variance of alfalfa-grass competition in the greenhouse: light intensity measurements taken from the centre of the pot at ground level just prior to the first cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	9	268.75	0.00
Grass (G)	1	12.94	0.10
Alfalfa (A)	1	12.16	0.10
G * A	1	15.69	0.07
Competition (C)	3	258.79	0.00
G * C	3	9.95	0.54
A * C	3	2.80	0.89
G * A * C	3	5.93	0.73
Error	135	613.74	

Table B.1.13. Analysis of variance of alfalfa-grass competition in the greenhouse: light intensity measurements taken from the centre of the pot at top of alfalfa canopy just prior to the first cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	9	885.95	0.00
Grass (G)	1	0.81	0.81
Alfalfa (A)	1	25.38	0.18
G * A	1	0.32	0.88
Competition (C)	3	424.21	0.00
G * C	3	38.68	0.44
A * C	3	7.82	0.91
G * A * C	3	55.71	0.27
Error	135	1886.30	

Table B.1.14. Analysis of variance of alfalfa-grass competition in the greenhouse: light intensity measurements differences, top of the alfalfa canopy minus the ground level reading, taken from the centre of the pot just prior to the first cut.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	9	484.04	0.00
Grass (G)	1	20.20	0.22
Alfalfa (A)	1	2.41	0.67
G * A	1	20.49	0.22
Competition (C)	3	645.54	0.00
G * C	3	12.49	0.82
A * C	3	1.43	0.99
G * A * C	3	38.15	0.42
Error	135	1815.22	

<u>Table B.2.1</u>. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on June 14, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.26	0.00
Root Cutting (K)	2	0.31	0.47
Alfalfa (A)	1	2.21	0.00
K * A	2	1.68	0.02
Error	39	7.88	

<u>Table B.2.2</u>. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on June 27, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	5.88	0.00
Root Cutting (K)	2	1.41	0.04
Alfalfa (A)	1	0.03	0.74
K * A	2	0.23	0.57
Error	39	7.70	

<u>Table B.2.3</u>. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on July 6, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	0.45	0.39
Root Cutting (K)	2	1.28	0.02
Alfalfa (A)	1	0.32	0.15
K * A	2	0.91	0.06
Error	39	5.70	

Table B.2.4. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on July 31, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.70	0.00
Root Cutting (K)	2	0.40	0.14
Alfalfa (A)	1	0.07	0.42
K * A	2	0.20	0.38
Error	39	6.19	

Table B.2.5. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on August 8, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	0.63	0.04
Root Cutting (K)	2	0.11	0.43
Alfalfa (A)	1	0.08	0.29
K * A	2	0.11	0.45
Error	39	2.46	

Table B.2.6. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on August 11, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	2.33	0.35
Root Cutting (K)	2	4.38	0.05
Alfalfa (A)	1	1.80	0.11
K * A	2	1.15	0.44
Error	39	26.11	

Table B.2.7. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on August 22, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	0.58	0.25
Root Cutting (K)	2	0.17	0.53
Alfalfa (A)	1	0.01	0.75
K * A	2	0.08	0.74
Error	39	1.90	

Table B.2.8. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on September 25, 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.36	0.06
Root Cutting (K)	2	0.30	0.41
Alfalfa (A)	1	1.37	0.01
K * A	2	0.22	0.51
Error	39	6.45	

Table B.2.9. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on May 15, 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	11.06	0.02
Root Cutting (K)	2	4.92	0.08
Alfalfa (A)	1	0.13	0.70
K * A	2	4.21	0.11
Error	15	32.84	

Table B.2.10. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on June 27, 1990 for experiment seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	5.88	0.00
Root Cutting (K)	2	1.40	0.04
Alfalfa (A)	1	0.03	0.68
K * A	2	0.23	0.57
Error	39	7.70	

Table B.2.11. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture (0-15 cm) on September 25, 1990 ($x10^{-2}$) for experiement seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.52	0.90
Root Cutting (K)	2	16.87	0.26
Alfalfa (A)	1	6.85	0.30
K * A	2	4.20	0.71
Error	39	236.91	

Table B.2.12. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: light intensity at ground surface for spring of 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	46334.84	0.00
Root Cutting (K)	2	8035.73	0.13
Alfalfa (A)	1	1259.76	0.40
K * A	2	787.07	0.79
Error	15	81527.11	

Table B.2.13. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: first spring count of seedlings for spring of 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1876.68	0.12
Root Cutting (K)	2	1535.29	0.09
Alfalfa (A)	1	2353.56	0.01
K * A	2	222.90	0.67
Error	15	4103.79	

Table B.2.14. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: first fall count of seedlings for fall of 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	74.82	0.85
Root Cutting (K)	2	280.44	0.25
Alfalfa (A)	1	384.00	0.06
K * A	2	51.44	0.76
Error	15	1377.74	

Table B.2.15. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: per cent of seedlings surviving from spring count of seedlings in fall of 1989 ($x10^{-2}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	12.82	0.09
Root Cutting (K)	2	3.12	0.41
Alfalfa (A)	1	3.91	0.14
K * A	2	0.97	0.75
Error	15	24.47	

Table B.2.16. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: height of alfalfa plants.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.89	0.97
Root Cutting (K)	2	5.44	0.69
Alfalfa (A)	1	71.19	0.01
K * A	2	20.26	0.27
Error	15	106.11	

Table B.2.17. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: grass dry matter yields for fall 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	334.91	0.55
Root Cutting (K)	2	1179.23	0.05
Alfalfa (A)	1	53.52	0.56
K * A	2	610.55	0.56
Error	15	2299.13	

Table B.2.18. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: alfalfa dry matter yields for fall 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	16.07	0.61
Root Cutting (K)	2	4.43	0.77
Alfalfa (A)	1	0.31	0.85
K * A	2	16.11	0.41
Error	13	109.85	

Table B.2.19. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: total dry matter yields for fall 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	319.74	0.58
Root Cutting (K)	2	983.50	0.08
Alfalfa (A)	1	57.30	0.56
K * A	2	737.36	0.14
Error	13	2053.03	

Table B.2.20. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: grass dry matter yields for spring 1990 for 1989 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1352.85	0.15
Root Cutting (K)	2	448.83	0.38
Alfalfa (A)	1	1724.66	0.01
K * A	2	279.94	0.54
Error	15	3246.51	

Table B.2.21. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: alfalfa dry matter yields for spring 1990 for 1989 experiment

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	592.80	0.88
Root Cutting (K)	2	396.72	0.81
Alfalfa (A)	1	1023.12	0.31
K * A	2	1908.29	0.38
Error	15	13699.49	

Table B.2.22. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: total dry matter yields for spring 1990 for 1989 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	2778.43	0.48
Root Cutting (K)	2	1615.26	0.49
Alfalfa (A)	1	91.07	0.77
K * A	2	3026.98	0.27
Error	15	15961.02	

Table B.2.23. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: soil surface moisture on June 12, 1990 for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	26.00	0.00
Root Cutting (K)	4	29.00	0.00
Alfalfa (A)	1	0.09	0.80
K * A	4	3.47	0.65
Error	67	94.32	

Table B.2.24. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture on June 26, 1990 for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	7.25	0.31
Root Cutting (K)	4	7.07	0.47
Alfalfa (A)	1	2.93	0.23
K * A	4	12.94	0.19
Error	27	52.48	

Table B.2.25. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surface soil moisture on July 23, 1990 for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	2	16.24	0.00
Root Cutting (K)	4	1.61	0.79
Alfalfa (A)	1	2.44	0.11
K * A	4	12.26	0.02
Error	68	64.41	

Table B.2.26. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: surfeace soil moisture on September 7, 1990 in 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	2.70	0.00
Root Cutting (K)	4	0.38	0.44
Alfalfa (A)	1	0.22	0.15
K * A	4	1.37	0.01
Error	67	6.78	

Table B.2.27. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: fall plant count results for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	381.90	0.25
Root Cutting (K)	4	1158.03	0.02
Alfalfa (A)	1	1346.70	0.00
K * A	4	255.97	0.59
Error	107	9725.77	

Table B.2.28. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: fall grass dry matter yields for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	796.14	0.30
Root Cutting (K)	4	597.81	0.58
Alfalfa (A)	1	623.36	0.09
K * A	4	706.24	0.50
Error	26	5346.08	

Table B.2.29. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: fall alfalfa dry matter yields for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	463.38	0.10
Root Cutting (K)	4	335.84	0.30
Alfalfa (A)	1	506.84	0.01
K * A	4	218.44	0.51
Error	26	1688.79	

Table B.2.30. Analysis of variance of the effect of reduced Russian wildrye root competition on alfalfa establishment: fall total dry matter yields for 1990 experiment.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1125.14	0.25
Root Cutting (K)	4	759.28	0.58
Alfalfa (A)	1	6.02	0.88
K * A	4	855.02	0.52
Error	26	6724.67	

Table B.3.1. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube reading on June 13, 1989 at depth 0 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	349.54	0.00
Width (W)	3	49.61	0.49
Root Cutting (K)	1	18.52	0.34
W * K	3	107.35	0.17
Alfalfa (A)	1	8.27	0.53
W * A	3	105.96	0.17
K * A	1	23.17	0.29
W * K * A	3	61.06	0.40
Error	45	911.07	

Table B.3.2. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube reading on June 13, 1989 at depth 10 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	18.33	0.10
Width (W)	3	3.76	0.71
Root Cutting (K)	1	0.04	0.90
W * K	3	17.85	0.11
Alfalfa (A)	1	0.12	0.83
W * A	3	1.47	0.91
K * A	1	0.02	0.93
W * K * A	3	3.70	0.72
Error	44	120.52	

Table B.3.3. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube reading on June 13, 1989 at depth 20 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.21	0.76
Width (W)	3	9.88	0.32
Root Cutting (K)	1	3.77	0.25
W * K	3	8.99	0.37
Alfalfa (A)	1	0.07	0.87
W * A	3	7.13	0.47
K * A	1	2.48	0.35
W * K * A	3	1.68	0.89
Error	45	124.18	

Table B.3.4. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube reading on June 13, 1989 at depth 30 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	2.84	0.93
Width (W)	3	75.03	0.01
Root Cutting (K)	1	0.59	0.76
W * K	3	7.70	0.75
Alfalfa (A)	1	3.02	0.49
W * A	3	11.82	0.60
K * A	1	6.33	0.32
W * K * A	3	8.10	0.73
Error	44	273.54	

Table B.3.5. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube reading on June 13, 1989 at depth 40 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	39.75	0.59
Width (W)	3	279.57	0.01
Root Cutting (K)	1	17.88	0.36
W * K	3	34.23	0.65
Alfalfa (A)	1	6.20	0.59
W * A	3	56.06	0.45
K * A	1	5.40	0.61
W * K * A	3	56.45	0.44
Error	43	886.82	

Table B.3.6. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube reading on June 13, 1989 at depth 50 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	129.50	0.39
Width (W)	3	299.42	0.08
Root Cutting (K)	1	51.81	0.27
W * K	3	122.21	0.41
Alfalfa (A)	1	3.03	0.79
W * A	3	166.55	0.28
K * A	1	9.78	0.63
W * K * A	3	149.01	0.32
Error	43	1791.60	

Table B.3.7. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 29, 1989 at depth 0 cm (s189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	59.25	0.12
Width (W)	3	9.47	0.80
Root Cutting (K)	1	0.22	0.88
W * K	3	48.31	0.18
Alfalfa (A)	1	5.31	0.46
W * A	3	34.81	0.31
K * A	1	12.74	0.25
W * K * A	3	11.49	0.75
Error	45	427.15	

Table B.3.8. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 29, 1989 at depth 10 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	47.55	0.03
Width (W)	3	182.15	0.00
Root Cutting (K)	1	23.65	0.03
W * K	3	1.21	0.97
Alfalfa (A)	1	2.80	0.45
W * A	3	5.56	0.77
K * A	1	0.30	0.80
W * K * A	3	7.68	0.67
Error	44	214.37	

Table B.3.9. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 29, 1989 at depth 20 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	40.53	0.26
Width (W)	3	278.00	0.00
Root Cutting (K)	1	13.94	0.24
W * K	3	9.12	0.82
Alfalfa (A)	1	0.80	0.78
W * A	3	30.53	0.38
K * A	1	9.05	0.34
W * K * A	3	10.91	0.77
Error	45	440.54	

Table B.3.10. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings for July 29, 1989 at depth 30 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	53.06	0.29
Width (W)	3	283.70	0.00
Root Cutting (K)	1	2.23	0.69
W * K	3	23.17	0.64
Alfalfa (A)	1	4.75	0.56
W * A	3	58.50	0.25
K * A	1	21.06	0.22
W * K * A	3	4.98	0.95
Error	44	604.57	

Table B.3.11. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings for July 29, 1989 at depth 40 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	33.92	0.48
Width (W)	3	269.52	0.00
Root Cutting (K)	1	0.87	0.80
W * K	3	48.31	0.33
Alfalfa (A)	1	0.00	0.99
W * A	3	47.60	0.33
K * A	1	9.71	0.40
W * K * A	3	3.76	0.96
Error	43	582.90	

Table B.3.12. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 29, 1989 at depth 50 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	38.91	0.46
Width (W)	3	213.12	0.01
Root Cutting (K)	1	0.58	0.85
W * K	3	33.35	0.53
Alfalfa (A)	1	0.49	0.86
W * A	3	44.47	0.40
K * A	1	1.23	0.77
W * K * A	3	8.32	0.91
Error	42	622.22	

Table B.3.13. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 27, 1989 at depth 0 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	119.59	0.09
Width (W)	3	32.44	0.60
Root Cutting (K)	1	13.19	0.39
W * K	3	112.68	0.10
Alfalfa (A)	1	1.41	0.78
W * A	3	151.91	0.04
K * A	1	23.95	0.25
W * K * A	3	158.62	0.04
Error	45	775.78	

Table B.3.14. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings for September 27, 1989 at depth 10 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	12.08	0.56
Width (W)	3	145.54	0.00
Root Cutting (K)	1	7.30	0.26
W * K	3	23.51	0.26
Alfalfa (A)	1	9.95	0.19
W * A	3	28.66	0.19
K * A	1	2.92	0.48
W * K * A	3	7.62	0.72
Error	45	257.37	

Table B.3.15. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 27, 1989 at depth 20 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	100.40	0.03
Width (W)	3	120.45	0.02
Root Cutting (K)	1	4.68	0.51
W * K	3	16.37	0.67
Alfalfa (A)	1	33.84	0.08
W * A	3	91.15	0.05
K * A	1	0.02	0.97
W * K * A	3	21.27	0.57
Error	45	472.49	

Table B.3.16. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 27, 1989 at depth 30 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	95.39	0.04
Width (W)	3	0.35	1.00
Root Cutting (K)	1	4.92	0.50
W * K	3	7.01	0.88
Alfalfa (A)	1	18.81	0.19
W * A	3	88.71	0.05
K * A	1	9.48	0.35
W * K * A	3	27.98	0.45
Error	44	461.48	

Table B.3.17. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 27, 1989 at depth 40 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	59.06	0.10
Width (W)	3	45.74	0.18
Root Cutting (K)	1	0.72	0.78
W * K	3	21.64	0.49
Alfalfa (A)	1	5.32	0.44
W * A	3	70.63	0.06
K * A	1	9.04	0.32
W * K * A	3	9.20	0.79
Error	43	381.56	

Table B.3.18. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 27, 1989 at depth 50 cm.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	42.48	0.14
Width (W)	3	57.37	0.06
Root Cutting (K)	1	0.70	0.76
W * K	3	34.03	0.22
Alfalfa (A)	1	1.37	0.67
W * A	3	45.25	0.12
K * A	1	0.29	0.84
W * K * A	3	2.30	0.96
Error	43	314.18	

Table B.3.19. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on April 25, 1990 at depth 0 cm for site 1 seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.62	0.73
Width (W)	3	5.17	0.80
Root Cutting (K)	1	0.21	0.84
W * K	3	8.89	0.63
Alfalfa (A)	1	16.45	0.08
W * A	3	11.40	0.53
K * A	1	0.20	0.84
W * K * A	3	82.87	0.00
Error	45	230.46	

Table B.3.20. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on April 25, 1990 at depth 10 cm for site 1 seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.78	0.87
Width (W)	3	21.05	0.28
Root Cutting (K)	1	0.78	0.70
W * K	3	31.83	0.13
Alfalfa (A)	1	0.25	0.83
W * A	3	30.50	0.14
K * A	1	14.81	0.10
W * K * A	3	33.95	0.11
Error	45	238.25	

Table B.3.20. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on April 25, 1990 at depth 20 cm for site 1 seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	63.58	0.21
Width (W)	3	41.09	0.40
Root Cutting (K)	1	21.08	0.22
W * K	3	21.28	0.67
Alfalfa (A)	1	15.24	0.30
W * A	3	121.47	0.04
K * A	1	19.98	0.23
W * K * A	3	82.47	0.13
Error	45	613.17	

Table B.3.21. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on April 25, 1990 at depth 30 cm for site 1 seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	17.42	0.81
Width (W)	3	24.74	0.71
Root Cutting (K)	1	1.69	0.76
W * K	3	110.51	0.12
Alfalfa (A)	1	0.52	0.87
W * A	3	46.79	0.46
K * A	1	16.89	0.33
W * K * A	3	103.21	0.14
Error	45	798.20	

Table B.3.21. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on April 25, 1990 at depth 40 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	10.95	0.85
Width (W)	3	26.43	0.59
Root Cutting (K)	1	3.54	0.61
W * K	3	110.25	0.06
Alfalfa (A)	1	1.66	0.73
W * A	3	37.57	0.44
K * A	1	34.93	0.12
W * K * A	3	47.32	0.34
Error	45	613.92	

Table B.3.22. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 10, 1990 at depth 0 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.73	0.76
Width (W)	3	4.76	0.84
Root Cutting (K)	1	7.37	0.26
W * K	3	4.63	0.85
Alfalfa (A)	1	11.34	0.17
W * A	3	62.09	0.02
K * A	1	40.99	0.01
W * K * A	3	15.52	0.44
Error	43	243.90	

Table B.3.23. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 10, 1990 at depth 10 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	32.54	0.03
Width (W)	3	2.97	0.82
Root Cutting (K)	1	0.04	0.91
W * K	3	13.01	0.37
Alfalfa (A)	1	4.27	0.25
W * A	3	17.11	0.16
K * A	1	0.36	0.74
W * K * A	3	2.23	0.87
Error	43	136.22	

Table B.3.24. Analysis of variance of the effect of spray width and reduced competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 10, 1990 at depth 20 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	34.22	0.11
Width (W)	3	1.14	0.98
Root Cutting (K)	1	0.42	0.78
W * K	3	4.50	0.84
Alfalfa (A)	1	1.08	0.66
W * A	3	17.75	0.36
K * A	1	2.32	0.52
W * K * A	3	10.12	0.60
Error	43	23.11	

Table B.3.25. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 10, 1990 at depth 30 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	18.80	0.20
Width (W)	3	1.25	0.96
Root Cutting (K)	1	0.09	0.88
W * K	3	6.86	0.63
Alfalfa (A)	1	1.15	0.59
W * A	3	7.17	0.61
K * A	1	5.36	0.25
W * K * A	3	6.09	0.67
Error	41	166.70	

Table B.3.26. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on July 10, 1990 at depth 40 cm (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	9.38	0.22
Width (W)	3	1.97	0.81
Root Cutting (K)	1	0.16	0.78
W * K	3	12.11	0.13
Alfalfa (A)	1	0.22	0.74
W * A	3	6.13	0.40
K * A	1	2.30	0.29
W * K * A	3	3.85	0.60
Error	42	85.47	

Table B.3.27. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 13, 1990 at depth 0 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	4.79	0.63
Width (W)	3	4.04	0.69
Root Cutting (K)	1	0.05	0.89
W * K	3	20.49	0.07
Alfalfa (A)	1	0.26	0.76
W * A	3	1.78	0.89
K * A	1	1.87	0.41
W * K * A	3	12.25	0.23
Error	45	123.68	

Table B.3.28. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 13, 1990 at depth 10 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	10.77	0.18
Width (W)	3	6.40	0.40
Root Cutting (K)	1	0.29	0.71
W * K	3	18.55	0.04
Alfalfa (A)	1	1.50	0.40
W * A	3	0.66	0.96
K * A	1	0.01	0.95
W * K * A	3	6.50	0.39
Error	45	94.49	

Table B.3.29. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 13, 1990 at depth 20 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	8.20	0.29
Width (W)	3	5.41	0.47
Root Cutting (K)	1	0.08	0.84
W * K	3	1.74	0.84
Alfalfa (A)	1	0.17	0.78
W * A	3	11.10	0.17
K * A	1	0.30	0.71
W * K * A	3	3.81	0.62
Error	45	94.97	

Table B.3.30. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 13, 1990 at depth 30 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	10.31	0.08
Width (W)	3	3.61	0.48
Root Cutting (K)	1	0.15	0.75
W * K	3	1.50	0.79
Alfalfa (A)	1	0.06	0.85
W * A	3	3.07	0.55
K * A	1	1.76	0.27
W * K * A	3	9.69	0.10
Error	45	64.33	

Table B.3.31. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 13, 1990 at depth 40 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	13.25	0.05
Width (W)	3	2.81	0.63
Root Cutting (K)	1	0.08	0.82
W * K	3	5.60	0.33
Alfalfa (A)	1	0.14	0.77
W * A	3	4.08	0.47
K * A	1	2.17	0.25
W * K * A	3	13.03	0.06
Error	45	71.64	

Table B.3.32. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 25, 1990 at depth 0 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.25	0.80
Width (W)	3	57.70	0.00
Root Cutting (K)	1	1.28	0.53
W * K	3	13.11	0.26
Alfalfa (A)	1	0.87	0.60
W * A	3	15.09	0.20
K * A	1	0.00	0.99
W * K * A	3	3.26	0.79
Error	45	142.26	

Table B.3.33. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 25, 1990 at depth 10 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	7.52	0.12
Width (W)	3	92.63	0.00
Root Cutting (K)	1	9.11	0.01
W * K	3	17.86	0.01
Alfalfa (A)	1	1.52	0.27
W * A	3	4.93	0.27
K * A	1	2.23	0.18
W * K * A	3	3.31	0.44
Error	45	54.22	

Table B.3.34. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 25, 1990 at depth 20 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.39	0.13
Width (W)	3	109.99	0.00
Root Cutting (K)	1	4.91	0.04
W * K	3	20.71	0.00
Alfalfa (A)	1	0.21	0.66
W * A	3	2.14	0.58
K * A	1	1.73	0.22
W * K * A	3	3.03	0.44
Error	45	49.01	

Table B.3.35. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 25, 1990 at depth 30 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	0.92	0.83
Width (W)	3	135.64	0.00
Root Cutting (K)	1	1.62	0.22
W * K	3	15.27	0.01
Alfalfa (A)	1	0.00	0.99
W * A	3	1.06	0.80
K * A	1	1.24	0.28
W * K * A	3	6.64	0.11
Error	44	46.18	

Table B.3.36. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on June 25, 1990 at depth 40 cm (S190)($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	0.22	0.98
Width (W)	3	108.00	0.00
Root Cutting (K)	1	3.66	0.11
W * K	3	10.47	0.07
Alfalfa (A)	1	1.62	0.28
W * A	3	0.19	0.99
K * A	1	0.41	0.59
W * K * A	3	12.75	0.04
Error	43	59.05	

Table B.3.37. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on August 14, 1990 at depth 0 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	11.29	0.05
Width (W)	3	30.60	0.00
Root Cutting (K)	1	0.04	0.89
W * K	3	3.16	0.61
Alfalfa (A)	1	2.70	0.22
W * A	3	4.50	0.46
K * A	1	0.89	0.48
W * K * A	3	0.27	0.98
Error	30		

Table B.3.38. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on August 14, 1990 at depth 10 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	11.96	0.00
Width (W)	3	37.82	0.00
Root Cutting (K)	1	1.97	0.14
W * K	3	6.43	0.08
Alfalfa (A)	1	1.61	0.18
W * A	3	5.40	0.12
K * A	1	0.02	0.89
W * K * A	3	0.90	0.79
Error	30	25.67	

Table B.3.39. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on August 14, 1990 at depth 20 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	15.87	0.00
Width (W)	3	43.55	0.00
Root Cutting (K)	1	0.85	0.39
W * K	3	5.64	0.19
Alfalfa (A)	1	0.92	0.37
W * A	3	6.47	0.14
K * A	1	0.00	0.97
W * K * A	3	1.77	0.66
Error	30	32.93	

Table B.3.40. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on August 14, 1990 at depth 30 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	11.72	0.01
Width (W)	3	48.92	0.00
Root Cutting (K)	1	0.06	0.81
W * K	3	1.98	0.62
Alfalfa (A)	1	0.84	0.39
W * A	3	5.25	0.22
K * A	1	0.53	0.50
W * K * A	3	2.52	0.53
Error	29	32.09	

Table B.3.41. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on August 14, 1990 at depth 40 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.22	0.57
Width (W)	3	28.80	0.00
Root Cutting (K)	1	0.67	0.43
W * K	3	1.31	0.74
Alfalfa (A)	1	0.25	0.63
W * A	3	6.63	0.13
K * A	1	0.15	0.71
W * K * A	3	6.41	0.14
Error	30	24.26	

Table B.3.42. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 6, 1990 at depth 0 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	5.10	0.13
Width (W)	3	13.65	0.00
Root Cutting (K)	1	2.11	0.12
W * K	3	1.45	0.64
Alfalfa (A)	1	2.60	0.09
W * A	3	1.66	0.59
K * A	1	2.34	0.11
W * K * A	3	2.99	0.34
Error	45	38.72	

<u>Table B.3.43</u>. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 6, 1990 at depth 10 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.57	0.02
Width (W)	3	8.72	0.00
Root Cutting (K)	1	0.99	0.09
W * K	3	0.89	0.45
Alfalfa (A)	1	0.25	0.39
W * A	3	0.78	0.51
K * A	1	0.27	0.37
W * K * A	3	1.19	0.32
Error	45	14.91	

<u>Table B.3.44</u>. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 6, 1990 at depth 20 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.45	0.01
Width (W)	3	7.73	0.00
Root Cutting (K)	1	0.59	0.28
W * K	3	1.70	0.34
Alfalfa (A)	1	1.09	0.14
W * A	3	0.76	0.67
K * A	1	0.05	0.75
W * K * A	3	0.97	0.58
Error	45	22.12	

Table B.3.45. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 6, 1990 at depth 30 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	5.80	0.07
Width (W)	3	6.38	0.05
Root Cutting (K)	1	0.01	0.96
W * K	3	1.21	0.66
Alfalfa (A)	1	0.98	0.26
W * A	3	0.98	0.73
K * A	1	0.27	0.56
W * K * A	3	1.58	0.56
Error	43	32.52	

Table B.3.46. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: neutron access tube readings on September 6, 1990 at depth 40 cm (S190) ($x10^{-3}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	5.96	0.09
Width (W)	3	4.48	0.17
Root Cutting (K)	1	0.55	0.42
W * K	3	1.63	0.59
Alfalfa (A)	1	0.23	0.61
W * A	3	1.65	0.59
K * A	1	0.54	0.43
W * K * A	3	13.58	0.66
Error	38	32.05	

Table B.3.47. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 13, 1989 (S189) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	11.36	0.96
Width (W)	3	85.78	0.55
Root Cutting (K)	1	8.00	0.66
W * K	3	139.69	0.34
Alfalfa (A)	1	15.96	0.53
W * A	3	199.43	0.19
K * A	1	0.21	0.94
W * K * A	3	192.67	0.20
Error	45	18035.70	

Table B.3.48. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 20, 1989 (S189) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	53.22	0.47
Width (W)	3	1453.68	0.00
Root Cutting (K)	1	3.94	0.67
W * K	3	145.11	0.08
Alfalfa (A)	1	91.44	0.04
W * A	3	62.62	0.40
K * A	1	35.74	0.19
W * K * A	3	263.52	0.01
Error	109	2278.70	

Table B.3.49. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 27, 1989 (S189) ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	19.40	0.17
Width (W)	3	50.70	0.01
Root Cutting (K)	1	0.01	0.96
W * K	3	19.86	0.16
Alfalfa (A)	1	16.75	0.04
W * A	3	39.58	0.02
K * A	1	6.22	0.20
W * K * A	3	7.02	0.60
Error	109	411.28	

Table B.3.50. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on July 4, 1989 (S189) ($x10^{-2}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	62.95	0.76
Width (W)	3	7303.30	0.00
Root Cutting (K)	1	5.05	0.84
W * K	3	4088.77	0.00
Alfalfa (A)	1	12.62	0.74
W * A	3	2226.52	0.00
K * A	1	462.68	0.05
W * K * A	3	1224.64	0.02
Error	78	8976.36	

Table B.3.51. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on July 29, 1989 (S189) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	88.82	0.22
Width (W)	3	136.24	0.09
Root Cutting (K)	1	32.48	0.20
W * K	3	16.19	0.84
Alfalfa (A)	1	3.53	0.67
W * A	3	76.42	0.28
K * A	1	0.33	0.89
W * K * A	3	14.38	0.86
Error	45	872.29	

Table B.3.52. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on August 8, 1989 (S189) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	50.68	0.04
Width (W)	3	162.49	0.00
Root Cutting (K)	1	0.75	0.72
W * K	3	94.30	0.00
Alfalfa (A)	1	5.52	0.33
W * A	3	78.14	0.01
K * A	1	18.28	0.08
W * K * A	3	29.69	0.18
Error	105	616.72	

Table B.3.53. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on August 23, 1989 (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.10	0.54
Width (W)	3	4.53	0.18
Root Cutting (K)	1	1.33	0.22
W * K	3	1.53	0.63
Alfalfa (A)	1	0.56	0.43
W * A	3	1.39	0.66
K * A	1	0.11	0.73
W * K * A	3	6.16	0.09
Error	30	25.89	

Table B.3.54. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on September 27, 1989 (S190) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	58.74	0.42
Width (W)	3	122.54	0.12
Root Cutting (K)	1	1.48	0.79
W * K	3	9.53	0.93
Alfalfa (A)	1	0.64	0.86
W * A	3	298.68	0.00
K * A	1	100.66	0.03
W * K * A	3	78.96	0.28
Error	109	2228.54	

Table B.3.55. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 10, 1990 (S189) (x10^{-5}).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	21.63	0.56
Width (W)	3	29.65	0.42
Root Cutting (K)	1	24.96	0.13
W * K	3	76.74	0.08
Alfalfa (A)	1	15.50	0.23
W * A	3	88.27	0.05
K * A	1	0.19	0.89
W * K * A	3	1.81	0.98
Error	45	468.07	

Table B.3.56. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on September 25, 1989 (S189) (x10^{-5}).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	5.86	0.84
Width (W)	3	97.35	0.01
Root Cutting (K)	1	0.04	0.94
W * K	3	53.20	0.06
Alfalfa (A)	1	0.11	0.90
W * A	3	66.15	0.03
K * A	1	0.70	0.76
W * K * A	3	52.71	0.07
Error	107	7587.36	

Table B.3.57. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 25, 1990 (S190) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	140.31	0.09
Width (W)	3	1363.60	0.00
Root Cutting (K)	1	105.60	0.03
W * K	3	37.98	0.61
Alfalfa (A)	1	57.24	0.10
W * A	3	17.32	0.84
K * A	1	0.13	0.94
W * K * A	3	108.34	0.17
Error	44	896.66	

Table B.3.58. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on July 23, 1990 (S190) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	47.64	0.37
Width (W)	3	1402.42	0.00
Root Cutting (K)	1	86.04	0.02
W * K	3	114.90	0.06
Alfalfa (A)	1	10.20	0.41
W * A	3	22.96	0.67
K * A	1	6.26	0.52
W * K * A	3	27.54	0.60
Error	45	6619.26	

Table B.3.59. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on August 14, 1990 (S190) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.19	0.91
Width (W)	3	498.20	0.00
Root Cutting (K)	1	0.08	0.93
W * K	3	96.36	0.05
Alfalfa (A)	1	1.04	0.76
W * A	3	112.99	0.03
K * A	1	5.69	0.48
W * K * A	3	110.83	0.03
Error	45	505.95	

Table B.3.60. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on September 7, 1990 (S190) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	43.94	0.18
Width (W)	3	107.04	0.01
Root Cutting (K)	1	0.00	0.99
W * K	3	46.50	0.16
Alfalfa (A)	1	1.82	0.65
W * A	3	12.71	0.69
K * A	1	12.26	0.24
W * K * A	3	29.46	0.34
Error	109	949.85	

Table B.3.61. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 14, 1989 (S289).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	18.19	0.04
Width (W)	3	18.92	0.04
Root Cutting (K)	1	3.40	0.21
W * K	3	0.87	0.94
Alfalfa (A)	1	5.45	0.11
W * A	3	10.11	0.20
K * A	1	0.20	0.76
W * K * A	3	8.29	0.28
Error	109	232.34	

Table B.3.62. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 27, 1989 (S289).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	15.80	0.09
Width (W)	3	32.37	0.01
Root Cutting (K)	1	2.00	0.35
W * K	3	1.75	0.85
Alfalfa (A)	1	0.53	0.63
W * A	3	2.23	0.80
K * A	1	2.83	0.27
W * K * A	3	0.27	0.99
Error	45	100.80	

Table B.3.63. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on August 8, 1989 (S289).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.19	0.02
Width (W)	3	6.91	0.01
Root Cutting (K)	1	0.11	0.65
W * K	3	1.72	0.38
Alfalfa (A)	1	0.99	0.18
W * A	3	1.88	0.33
K * A	1	1.00	0.18
W * K * A	3	0.59	0.78
Error	44	23.69	

Table B.3.64. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on September 28, 1989 (S289).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	8.90	0.10
Width (W)	3	5.54	0.27
Root Cutting (K)	1	1.42	0.31
W * K	3	3.14	0.52
Alfalfa (A)	1	3.06	0.14
W * A	3	8.61	0.11
K * A	1	1.55	0.29
W * K * A	3	6.21	0.22
Error	109	150.02	

Table B.3.65. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements obtained from gravimetric sampling on April 30, 1990 (S289) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	197.79	0.25
Width (W)	3	15.99	0.95
Root Cutting (K)	1	5.91	0.72
W * K	3	131.71	0.42
Alfalfa (A)	1	0.46	0.92
W * A	3	117.46	0.47
K * A	1	66.84	0.23
W * K * A	3	285.90	0.12
Error	45	2067.05	

Table B.3.66. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 12, 1990 (S289).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	6.85	0.25
Width (W)	3	10.81	0.09
Root Cutting (K)	1	9.25	0.02
W * K	3	8.18	0.18
Alfalfa (A)	1	0.13	0.78
W * A	3	0.45	0.95
K * A	1	1.49	0.34
W * K * A	3	1.55	0.81
Error	108	176.74	

Table B.3.67. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on June 11, 1990 (S290) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	120.72	0.09
Width (W)	3	3635.81	0.00
Root Cutting (K)	1	20.16	0.29
W * K	3	29.97	0.64
Alfalfa (A)	1	25.82	0.23
W * A	3	212.86	0.01
K * A	1	3.01	0.68
W * K * A	3	67.56	0.29
Error	108	1928.81	

Table B.3.68. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on July 23, 1990 (S290) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	421.97	0.01
Width (W)	3	7993.74	0.00
Root Cutting (K)	1	64.43	0.15
W * K	3	68.45	0.54
Alfalfa (A)	1	2.81	0.77
W * A	3	91.00	0.41
K * A	1	87.21	0.10
W * K * A	3	239.49	0.06
Error	107	3337.71	

Table B.3.69. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on August 14, 1990 (S290) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	134.76	0.12
Width (W)	3	934.03	0.00
Root Cutting (K)	1	18.04	0.37
W * K	3	104.49	0.20
Alfalfa (A)	1	2.66	0.73
W * A	3	28.57	0.73
K * A	1	9.77	0.51
W * K * A	3	2.71	0.99
Error	45	975.99	

Table B.3.70. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: surface soil moisture measurements made with surface adapter for neutron probe on September 7, 1990 (S290) ($x10^{-5}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	309.76	0.00
Width (W)	3	264.90	0.00
Root Cutting (K)	1	10.82	0.27
W * K	3	104.01	0.01
Alfalfa (A)	1	2.34	0.61
W * A	3	16.36	0.60
K * A	1	28.02	0.08
W * K * A	3	19.47	0.53
Error	107	929.37	

Table B.3.71. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: quantum readings taken in the establishment year (S189).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	303986.82	0.00
Width (W)	3	298068.51	0.00
Root Cutting (K)	1	9086.38	0.17
W * K	3	4278.31	0.82
Alfalfa (A)	1	51.37	0.92
W * A	3	13306.75	0.42
K * A	1	27149.15	0.02
W * K * A	3	24927.84	0.16
Error	45	205114.51	

Table B.3.72. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: quantum readings taken in the establishment year (S190).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	7710971.81	0.00
Width (W)	3	1952886.05	0.00
Root Cutting (K)	1	1933.55	0.88
W * K	3	134778.95	0.67
Alfalfa (A)	1	217790.93	0.12
W * A	3	505268.39	0.13
K * A	1	316341.03	0.06
W * K * A	3	67868.70	0.85
Error	45	3876901.39	

Table B.3.73. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: quantum readings taken in the establishment year (S289).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	2652690.62	0.00
Width (W)	3	186085.67	0.05
Root Cutting (K)	1	5050.02	0.63
W * K	3	130066.43	0.13
Alfalfa (A)	1	5474.89	0.62
W * A	3	13189.12	0.89
K * A	1	10072.58	0.50
W * K * A	3	10044.85	0.93
Error	45	975539.77	

Table B.3.74. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: quantum readings taken in the establishment year (S290).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	23900.29	0.90
Width (W)	3	1817304.53	0.00
Root Cutting (K)	1	32370.97	0.38
W * K	3	36803.66	0.83
Alfalfa (A)	1	818.46	0.89
W * A	3	190676.13	0.22
K * A	1	24878.21	0.44
W * K * A	3	138656.35	0.36
Error	45	1861711.42	

Table B.3.75. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: spring count for experiment one seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1015.84	0.07
Width (W)	3	293.02	0.53
Root Cutting (K)	1	312.11	0.13
W * K	3	552.81	0.26
Alfalfa (A)	1	1013.36	0.01
W * A	3	189.72	0.70
K * A	1	18.06	0.71
W * K * A	3	634.47	0.20
Error	45	5921.83	

Table B.3.76. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: 1989 count for experiment 1 seeded in 1989.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	489.67	0.59
Width (W)	3	13577.14	0.00
Root Cutting (K)	1	902.50	0.06
W * K	3	41.35	0.98
Alfalfa (A)	1	1153.17	0.04
W * A	3	84.91	0.95
K * A	1	64.67	0.61
W * K * A	3	969.16	0.29
Error	45	11291.02	

Table B.3.77. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) per cent of seedlings surviving 1989 ($x10^{-2}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	11.46	0.78
Width (W)	3	707.92	0.00
Root Cutting (K)	1	14.88	0.24
W * K	3	14.59	0.71
Alfalfa (A)	1	4.03	0.54
W * A	3	25.91	0.49
K * A	1	6.01	0.45
W * K * A	3	18.38	0.63
Error	45	47.45	

Table B.3.78. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) spring 1989 seedling count.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	674.40	0.17
Width (W)	3	344.38	0.45
Root Cutting (K)	1	65.88	0.48
W * K	3	87.09	0.88
Alfalfa (A)	1	334.69	0.11
W * A	3	676.17	0.17
K * A	1	92.50	0.40
W * K * A	3	1037.80	0.06
Error	45	5711.53	

Table B.3.79. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) fall 1989 seedling count.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	779.45	0.10
Width (W)	3	8440.45	0.00
Root Cutting (K)	1	2.07	0.90
W * K	3	151.04	0.74
Alfalfa (A)	1	104.20	0.35
W * A	3	342.80	0.42
K * A	1	0.04	0.99
W * K * A	3	452.10	0.30
Error	45	5332.91	

Table B.3.80. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) 1989 per cent seedling survival ($x10^{-2}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	20.50	0.21
Width (W)	3	505.93	0.00
Root Cutting (K)	1	1.82	0.52
W * K	3	12.12	0.43
Alfalfa (A)	1	1.98	0.50
W * A	3	6.79	0.67
K * A	1	0.91	0.65
W * K * A	3	16.39	0.30
Error	45	193.92	

Table B.3.81. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) spring 1990 seedling count.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	266.09	0.11
Width (W)	3	1144.74	0.00
Root Cutting (K)	1	101.93	0.12
W * K	3	60.45	0.70
Alfalfa (A)	1	308.49	0.01
W * A	3	269.58	0.11
K * A	1	14.82	0.55
W * K * A	3	238.47	0.14
Error	44	1818.32	

Table B.3.82. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) fall 1990 seedling count.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	97.46	0.35
Width (W)	3	2295.81	0.00
Root Cutting (K)	1	262.89	0.00
W * K	3	141.43	0.20
Alfalfa (A)	1	677.09	0.00
W * A	3	263.51	0.04
K * A	1	0.04	0.97
W * K * A	3	220.54	0.07
Error	43	1246.48	

Table B.3.83. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) 1990 per cent seedling survival ($x10^{-2}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	41.79	0.02
Width (W)	3	785.81	0.00
Root Cutting (K)	1	386.62	0.00
W * K	3	46.60	0.01
Alfalfa (A)	1	66.07	0.00
W * A	3	23.49	0.13
K * A	1	21.61	0.02
W * K * A	3	17.44	0.23
Error	41	160.26	

Table B.3.84. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) spring 1990 seedling count.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	232.72	0.12
Width (W)	3	701.76	0.00
Root Cutting (K)	1	10.20	0.61
W * K	3	7.01	0.98
Alfalfa (A)	1	36.13	0.34
W * A	3	314.73	0.06
K * A	1	71.73	0.18
W * K * A	3	95.94	0.48
Error	43	1683.66	

Table B.3.85. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) fall 1990 seedling count.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	83.85	0.14
Width (W)	3	542.87	0.00
Root Cutting (K)	1	111.02	0.01
W * K	3	72.70	0.19
Alfalfa (A)	1	51.45	0.07
W * A	3	104.00	0.08
K * A	1	11.23	0.39
W * K * A	3	28.29	0.59
Error	43	642.34	

Table B.3.86. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) 1990 per cent seedling survival.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	12.28	0.18
Width (W)	3	6.87	0.43
Root Cutting (K)	1	5.67	0.13
W * K	3	8.48	0.33
Alfalfa (A)	1	1.36	0.46
W * A	3	5.82	0.50
K * A	1	0.23	0.76
W * K * A	3	10.73	0.23
Error	43	106.34	

Table B.3.87. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) number of days to reach true three leaf stage.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3.51	0.93
Width (W)	3	360.70	0.00
Root Cutting (K)	1	4.72	0.45
W * K	3	21.35	0.46
Alfalfa (A)	1	15.77	0.17
W * A	3	15.67	0.59
K * A	1	3.02	0.54
W * K * A	3	8.83	0.78
Error	44	355.85	

Table B.3.88. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) number of days to reach true three leaf stage.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	20.80	0.62
Width (W)	3	1677.80	0.00
Root Cutting (K)	1	10.71	0.34
W * K	3	20.67	0.62
Alfalfa (A)	1	0.52	0.83
W * A	3	37.18	0.38
K * A	1	18.81	0.21
W * K * A	3	50.46	0.24
Error	45	525.04	

Table B.3.89. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) number of days to reach true three leaf stage.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	129.69	0.08
Width (W)	3	517.19	0.00
Root Cutting (K)	1	8.19	0.51
W * K	3	17.32	0.81
Alfalfa (A)	1	27.75	0.22
W * A	3	12.86	0.87
K * A	1	10.48	0.45
W * K * A	3	46.96	0.47
Error	45	815.50	

Table B.3.90. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) number of days to reach true three leaf stage.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	446.39	0.46
Width (W)	3	5959.57	0.00
Root Cutting (K)	1	2.02	0.91
W * K	3	705.50	0.26
Alfalfa (A)	1	0.05	0.99
W * A	3	634.51	0.31
K * A	1	20.19	0.73
W * K * A	3	155.36	0.82
Error	44	7510.00	

Table B.3.91. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant height for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	306.03	0.05
Width (W)	3	4505.53	0.00
Root Cutting (K)	1	28.53	0.39
W * K	3	515.40	0.01
Alfalfa (A)	1	27.67	0.39
W * A	3	243.17	0.10
K * A	1	24.83	0.42
W * K * A	3	385.96	0.02
Error	107	4038.60	

Table B.3.92. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) plant height for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	362.20	0.02
Width (W)	3	19436.33	0.00
Root Cutting (K)	1	2123.39	0.00
W * K	3	1100.78	0.00
Alfalfa (A)	1	1660.50	0.00
W * A	3	624.10	0.00
K * A	1	504.61	0.00
W * K * A	3	384.22	0.01
Error	168	5663.23	

Table B.3.91. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant height for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	306.03	0.05
Width (W)	3	4505.53	0.00
Root Cutting (K)	1	28.53	0.39
W * K	3	515.40	0.01
Alfalfa (A)	1	27.67	0.39
W * A	3	243.17	0.10
K * A	1	24.83	0.42
W * K * A	3	385.96	0.02
Error	107	4038.60	

Table B.3.92. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) plant height for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	362.20	0.02
Width (W)	3	19436.33	0.00
Root Cutting (K)	1	2123.39	0.00
W * K	3	1100.78	0.00
Alfalfa (A)	1	1660.50	0.00
W * A	3	624.10	0.00
K * A	1	504.61	0.00
W * K * A	3	384.22	0.01
Error	168	5663.23	

Table B.3.93. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) plant height for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	133.35	0.10
Width (W)	3	1562.06	0.00
Root Cutting (K)	1	4.20	0.65
W * K	3	104.40	0.18
Alfalfa (A)	1	9.36	0.50
W * A	3	33.49	0.65
K * A	1	0.17	0.93
W * K * A	3	66.78	0.36
Error	45	915.06	

Table B.3.94. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) grass dry matter yields adjusted for area differences for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1045.20	0.84
Width (W)	3	14429.93	0.01
Root Cutting (K)	1	1273.66	0.31
W * K	3	6110.41	0.19
Alfalfa (A)	1	5240.31	0.04
W * A	3	5230.82	0.25
K * A	1	1044.91	0.36
W * K * A	3	380.20	0.96
Error	45	55105.05	

Table B.3.95. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) grass dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	898.41	0.47
Width (W)	3	23928.18	0.00
Root Cutting (K)	1	562.28	0.21
W * K	3	1574.93	0.22
Alfalfa (A)	1	836.80	0.13
W * A	3	222.53	0.89
K * A	1	264.14	0.39
W * K * A	3	67.19	0.98
Error	45	15593.47	

Table B.3.96. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) alfalfa dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	215.33	0.10
Width (W)	3	1996.76	0.00
Root Cutting (K)	1	0.69	0.89
W * K	3	294.75	0.04
Alfalfa (A)	1	6.31	0.66
W * A	3	140.04	0.25
K * A	1	74.79	0.14
W * K * A	3	16.49	0.92
Error	37	1195.87	

Table B.3.97. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) weed dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1598.75	0.72
Width (W)	3	17205.67	0.01
Root Cutting (K)	1	1129.13	0.33
W * K	3	4231.73	0.33
Alfalfa (A)	1	2411.55	0.16
W * A	3	3702.11	0.38
K * A	1	1686.95	0.24
W * K * A	3	5023.64	0.25
Error	45	53395.22	

Table B.3.98. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) total dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	458.22	0.83
Width (W)	3	1282.68	0.50
Root Cutting (K)	1	193.40	0.55
W * K	3	2185.20	0.26
Alfalfa (A)	1	33.012	0.80
W * A	3	1946.89	0.31
K * A	1	28.01	0.82
W * K * A	3	802.84	0.68
Error	37	19441.06	

Table B.3.99. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) grass dry matter yields adjusted for area differences for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1789.83	0.25
Width (W)	3	185.66	0.93
Root Cutting (K)	1	1012.85	0.13
W * K	3	352.49	0.84
Alfalfa (A)	1	837.52	0.17
W * A	3	618.55	0.69
K * A	1	282.89	0.42
W * K * A	3	480.26	0.77
Error	45	19046.55	

Table B.3.100. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) grass dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	773.84	0.14
Width (W)	3	4126.39	0.00
Root Cutting (K)	1	484.92	0.06
W * K	3	233.85	0.63
Alfalfa (A)	1	175.20	0.26
W * A	3	137.30	0.79
K * A	1	35.08	0.61
W * K * A	3	45.61	0.95
Error	45	5967.91	

Table B.3.101. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) alfalfa dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	32.45	0.57
Width (W)	3	454.71	0.00
Root Cutting (K)	1	32.68	0.16
W * K	3	66.03	0.26
Alfalfa (A)	1	6.40	0.53
W * A	3	6.68	0.94
K * A	1	0.20	0.91
W * K * A	3	1.98	0.99
Error	37	585.66	

Table B.3.102. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) weed dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	42.28	0.95
Width (W)	3	1228.30	0.03
Root Cutting (K)	1	136.53	0.30
W * K	3	204.00	0.65
Alfalfa (A)	1	129.35	0.31
W * A	3	205.77	0.65
K * A	1	16.43	0.72
W * K * A	3	1130.31	0.04
Error	45	5536.20	

Table B.3.103. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) total dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	444.71	0.42
Width (W)	3	1018.60	0.10
Root Cutting (K)	1	73.71	0.49
W * K	3	286.31	0.61
Alfalfa (A)	1	0.49	0.96
W * A	3	630.63	0.27
K * A	1	174.96	0.29
W * K * A	3	1113.77	0.08
Error	37	5691.44	

Table B.3.104. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) grass dry matter yields adjusted for area differences for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	12431.41	0.26
Width (W)	3	682012.51	0.00
Root Cutting (K)	1	38.50	0.91
W * K	3	145.45	1.00
Alfalfa (A)	1	1628.34	0.47
W * A	3	892.93	0.96
K * A	1	203.27	0.80
W * K * A	3	5559.57	0.61
Error	44	132665.43	

Table B.3.105. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) grass dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1499.96	0.57
Width (W)	3	5395.74	0.05
Root Cutting (K)	1	15.59	0.89
W * K	3	23.51	1.00
Alfalfa (A)	1	407.42	0.46
W * A	3	253.43	0.95
K * A	1	53.01	0.79
W * K * A	3	638.16	0.83
Error	44	32139.36	

Table B.3.106. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) alfalfa dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	80.71	0.27
Width (W)	3	1123.21	0.00
Root Cutting (K)	1	150.49	0.01
W * K	3	166.48	0.05
Alfalfa (A)	1	31.60	0.22
W * A	3	22.95	0.77
K * A	1	15.00	0.39
W * K * A	3	25.85	0.73
Error	45	901.53	

Table B.3.107. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) weed dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	119.59	0.31
Width (W)	3	509.96	0.00
Root Cutting (K)	1	0.87	0.87
W * K	3	6.17	0.98
Alfalfa (A)	1	104.18	0.[illegible]
W * A	3	129.46	0.28
K * A	1	41.64	0.27
W * K * A	3	47.74	0.69
Error	45	1473.68	

Table B.3.108. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S190) total dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	3092.55	0.30
Width (W)	3	1623.09	0.58
Root Cutting (K)	1	102.15	0.73
W * K	3	227.88	0.97
Alfalfa (A)	1	5.96	0.93
W * A	3	464.92	0.90
K * A	1	420.62	0.48
W * K * A	3	385.57	0.93
Error	44	36072.39	

Table B.3.109. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) grass dry matter yields adjusted for differences in area for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	139539.47	0.05
Width (W)	3	2471024.42	0.00
Root Cutting (K)	1	10969.05	0.42
W * K	3	45991.65	0.44
Alfalfa (A)	1	30508.41	0.18
W * A	3	122110.33	0.08
K * A	1	870.60	0.82
W * K * A	3	15481.72	0.82
Error	44	730880.72	

Table B.3.110. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) grass dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	26893.66	0.00
Width (W)	3	22232.12	0.01
Root Cutting (K)	1	10.55	0.93
W * K	3	15242.58	0.03
Alfalfa (A)	1	6480.40	0.05
W * A	3	30893.83	0.00
K * A	1	44.80	0.87
W * K * A	3	3889.96	0.47
Error	44	66855.72	

Table B.3.111. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) alfalfa dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	131.66	0.02
Width (W)	3	124.63	0.03
Root Cutting (K)	1	51.81	0.05
W * K	3	15.07	0.75
Alfalfa (A)	1	40.50	0.08
W * A	3	32.60	0.46
K * A	1	5.65	0.50
W * K * A	3	5.06	0.94
Error	43	526.35	

Table B.3.112. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) weed dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	927.90	0.16
Width (W)	3	2561.09	0.00
Root Cutting (K)	1	729.47	0.04
W * K	3	1150.65	0.09
Alfalfa (A)	1	40.44	0.63
W * A	3	104.74	0.89
K * A	1	4.18	0.88
W * K * A	3	2.06	1.00
Error	44	7436.36	

Table B.3.113. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S290) total dry matter yields for the establishment year.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	32342.86	0.00
Width (W)	3	21487.20	0.01
Root Cutting (K)	1	781.41	0.47
W * K	3	20698.58	0.01
Alfalfa (A)	1	6588.57	0.04
W * A	3	33521.21	0.00
K * A	1	9.71	0.94
W * K * A	3	4169.83	0.43
Error	43	63067.10	

Table B.3.114. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) grass dry matter yields adjusted for area differences for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	14425.47	0.00
Width (W)	3	13375.94	0.00
Root Cutting (K)	1	328.61	0.46
W * K	3	1351.92	0.53
Alfalfa (A)	1	274.69	0.50
W * A	3	3918.10	0.10
K * A	1	141.83	0.63
W * K * A	3	1015.72	0.64
Error	45	27056.25	

Table B.3.115. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) grass dry matter yields for spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	10351.34	0.00
Width (W)	3	1936.90	0.27
Root Cutting (K)	1	227.95	0.49
W * K	3	1008.56	0.55
Alfalfa (A)	1	343.25	0.40
W * A	3	2564.28	0.16
K * A	1	111.82	0.63
W * K * A	3	668.62	0.70
Error	45	21277.97	

Table B.3.116. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) alfalfa dry matter yields for spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	420.30	0.37
Width (W)	3	15922.09	0.00
Root Cutting (K)	1	6.21	0.83
W * K	3	1731.87	0.00
Alfalfa (A)	1	46.95	0.55
W * A	3	194.27	0.69
K * A	1	68.56	0.47
W * K * A	3	249.62	0.60
Error	44	5762.76	

Table B.3.117. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) weed dry matter yields for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	0.61	0.55
Width (W)	3	1.52	0.17
Root Cutting (K)	1	0.05	0.67
W * K	3	0.16	0.91
Alfalfa (A)	1	0.51	0.19
W * A	3	1.52	0.17
K * A	1	0.05	0.67
W * K * A	3	0.16	0.91
Error	45	12.81	

Table B.3.118. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) total dry matter yields for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	14447.81	0.00
Width (W)	3	7314.10	0.01
Root Cutting (K)	1	222.08	0.52
W * K	3	1054.66	0.58
Alfalfa (A)	1	794.05	0.27
W * A	3	1631.33	0.39
K * A	1	230.49	0.51
W * K * A	3	419.77	0.85
Error	44	23223.99	

Table B.3.119. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) grass dry matter yields adjusted for differences in area for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	19002.27	0.14
Width (W)	3	7673854.79	0.00
Root Cutting (K)	1	674.44	0.66
W * K	3	2256.54	0.88
Alfalfa (A)	1	5.85	0.97
W * A	3	12218.26	0.31
K * A	1	765.38	0.63
W * K * A	3	23365.60	0.09
Error	45	150011.42	

Table B.3.120. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) grass dry matter yields for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	4845.84	0.07
Width (W)	3	1931.80	0.40
Root Cutting (K)	1	115.54	0.67
W * K	3	822.80	0.73
Alfalfa (A)	1	0.77	0.97
W * A	3	2561.28	0.28
K * A	1	643.56	0.32
W * K * A	3	6093.07	0.03
Error	45	28785.59	

Table B.3.121. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) alfalfa dry matter yields for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	2989.87	0.20
Width (W)	3	10317.41	0.00
Root Cutting (K)	1	67.18	0.74
W * K	3	2214.81	0.33
Alfalfa (A)	1	21.14	0.86
W * A	3	2248.55	0.32
K * A	1	194.00	0.58
W * K * A	3	1601.53	0.47
Error	45	28020.93	

Table B.3.122. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) weed dry matter yields for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1826.24	0.00
Width (W)	3	45.64	0.94
Root Cutting (K)	1	2.69	0.88
W * K	3	52.88	0.92
Alfalfa (A)	1	13.88	0.73
W * A	3	259.13	0.51
K * A	1	76.63	0.41
W * K * A	3	679.95	0.12
Error	45	4983.63	

Table B.3.123. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S289) total dry matter yields for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	8197.20	0.05
Width (W)	3	5487.87	0.14
Root Cutting (K)	1	17.57	0.89
W * K	3	3245.52	0.35
Alfalfa (A)	1	55.46	0.81
W * A	3	9679.20	0.03
K * A	1	932.82	0.33
W * K * A	3	671.37	0.87
Error	45	42855.71	

Table B.3.124. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) spring 1990 quantum readings below alfalfa canopy at ground level.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1179117.37	0.04
Width (W)	3	1300311.74	0.07
Root Cutting (K)	1	1991.76	0.91
W * K	3	100675.79	0.89
Alfalfa (A)	1	88580.08	0.47
W * A	3	161372.67	0.87
K * A	1	37207.60	0.64
W * K * A	3	45456.87	0.96
Error	30	4966219.31	

Table B.3.125. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) spring 1990 quantum readings from the top of the alfalfa canopy.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	187950.21	0.34
Width (W)	3	303873.23	0.33
Root Cutting (K)	1	50271.91	0.45
W * K	3	571656.74	0.10
Alfalfa (A)	1	0.01	1.00
W * A	3	128924.72	0.68
K * A	1	3748.87	0.84
W * K * A	3	328542.65	0.30
Error	30	2545463.11	

Table B.3.126. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) spring 1990 difference between quantum readings above and below the alfalfa canopy.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	546962.59	0.11
Width (W)	3	13485852.99	0.02
Root Cutting (K)	1	32250.70	0.60
W * K	3	335713.11	0.42
Alfalfa (A)	1	88631.64	0.39
W * A	3	543244.77	0.21
K * A	1	17335.60	0.70
W * K * A	3	245029.45	0.55
Error	30	3435267.62	

Table B.3.127. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant height for the spring of 1990.

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	306.03	0.05
Width (W)	3	4505.53	0.00
Root Cutting (K)	1	28.52	0.39
W * K	3	515.40	0.01
Alfalfa (A)	1	27.67	0.39
W * A	3	243.17	0.10
K * A	1	24.83	0.42
W * K * A	3	385.96	0.02
Error	107	4038.60	

Table B.3.128. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant vigor for first harvest ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	204.83	0.37
Width (W)	3	700.89	0.02
Root Cutting (K)	1	64.62	0.32
W * K	3	67.65	0.79
Alfalfa (A)	1	531.75	0.01
W * A	3	222.08	0.33
K * A	1	211.57	0.08
W * K * A	3	247.98	0.29
Error	62	5046.51	

Table B.3.129. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant vigor for second harvest ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	58.03	0.29
Width (W)	3	450.21	0.00
Root Cutting (K)	1	1.04	0.80
W * K	3	55.80	0.30
Alfalfa (A)	1	2.00	0.72
W * A	3	25.52	0.64
K * A	1	33.37	0.14
W * K * A	3	5.78	0.94
Error	62	1288.05	

Table B.3.130. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant vigor for third harvest ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	22.25	0.38
Width (W)	3	120.46	0.00
Root Cutting (K)	1	0.01	0.98
W * K	3	24.14	0.34
Alfalfa (A)	1	33.17	0.03
W * A	3	8.63	0.75
K * A	1	0.97	0.71
W * K * A	3	5.74	0.85
Error	62	309.44	

Table B.3.131. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant vigor for fourth harvest ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.13	0.99
Width (W)	3	212.75	0.00
Root Cutting (K)	1	0.22	0.88
W * K	3	1.77	0.98
Alfalfa (A)	1	148.27	0.00
W * A	3	39.79	0.27
K * A	1	4.43	0.50
W * K * A	3	2.55	0.97
Error	62	429.95	

Table B.3.132. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant vigor for fifth harvest ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	1.95	0.98
Width (W)	3	141.52	0.00
Root Cutting (K)	1	0.01	0.98
W * K	3	36.15	0.28
Alfalfa (A)	1	124.49	0.00
W * A	3	50.22	0.15
K * A	1	16.08	0.19
W * K * A	3	11.62	0.73
Error	62	397.38	

Table B.3.133. Analysis of variance of the effect of spray width and reduced root competition on alfalfa establishment in crested wheatgrass stands: (S189) plant vigor for total harvest ($x10^{-4}$).

Source of Variance	degrees of freedom	Sums of Squares	P > F
Replicates	3	210.35	0.83
Width (W)	3	6949.35	0.00
Root Cutting (K)	1	90.87	0.54
W * K	3	488.89	0.57
Alfalfa (A)	1	21.32	0.77
W * A	3	171.72	0.87
K * A	1	751.89	0.08
W * K * A	3	437.30	0.61
Error	62	10485.07	

Appendix C.1: Results of tests of equality assuming unequal variances for average weekly temperature, weekly maximum and minimum temperature, weekly total precipitation.

			Comparison t values		
Meteor-logical data		Degrees of freedom	30 year av vs 1989	30 year av. vs 1990	1989 vs 1990
Average Weekly Total Temp.	38	-0.1	-0.6	-0.5	
Weekly Maximum Temp.	38	0.4	-0.6	-0.9	
Weekly Minimum Temp.	38	-0.6	-0.6	-0.1	
Square Root Total Weekly Precip.		38	-1.5	0.2	1.4

Appendix C.2: Results of tests of equality assuming unequal variances for weekly potential evaporation, difference between weekly total precipitation and weekly potential evaporation. Values are t values.

Comparison	Estimated Degrees of Freedom	Weekly Potential Evaporation	Total Weekly Precipitation - Weekly Potential Evaporation
30 year average vs 1989	30	1.8	
30 year average vs 1990	32	0.9	
1989 vs 1990	37	-0.9	
30 year average vs 1989	25		-2.1
30 year average vs 1990	30		-0.7
1989 vs 1990	33		1.4

Appendix D: Swinton soil association morphological description (Ayres et al. 1985).

	Horizons			
	Ap	Bm1	Bm2	Ck
Depth (cm)	0-8	8-24	24-48	48-79
Particle size and Distribution				
Coarse & Medium Sand	1.9	1.4	0.7	1.2
Fine Sand	3.4	2.4	0.7	1.6
Very Fine Sand	11.7	11.2	9.1	7.9
Total Sand	17.0	15.0	10.5	10.7
Total Silt	61.0	61.0	65.6	71.1
Total Clay	22.0	24.0	23.9	18.2
Fine Clay	13.1	16.9	18.5	9.2