ALFALFA TERMINATION STRATEGIES TO CONSERVE SOIL MOISTURE FOR NO-TILL CROP ESTABLISHMENT

BY

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A Thesis
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Forward

This thesis is written in manuscript style, containing three manuscripts. The manuscripts are preceded by a literature review. Two manuscripts are held within the main body of the thesis, each of which contains an independent abstract, introduction, materials and methods, results and discussion, and summary and conclusions. The third manuscript is contained within the appendix with an abstract, introduction, materials and methods, results and discussion, and summary and conclusions. The first two manuscripts are in preparation for submission to Agronomy Journal. The third manuscript has been published as a Manitoba Agriculture recommendation fact sheet. All manuscripts are preceded by a general abstract and literature review. The first two manuscripts are followed by a general summary, recommendations, and future research section describing the practical value of the projects.

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General Abstract

Alfalfa Termination Strategies to Conserve Soil Moisture for No-Till Crop Establishment. William John Bullied. Department of Plant Science, University of Manitoba. Major Professor, Dr. Martin Entz.

Perennial alfalfa (*Meticago sativa* L.) termination and soil moisture conservation are concerns of producers who include alfalfa in their crop rotations on the Canadian Prairies. Termination of an alfalfa stand by conventional tillage often results in considerable alfalfa regrowth, unacceptable soil moisture losses, and inadequate establishment of the crop following alfalfa. Alternate methods for terminating alfalfa need to be made available to crop managers experiencing unacceptable results from alfalfa termination with tillage.

The ability of herbicides to terminate alfalfa in the fall or spring, and the feasibility of establishing wheat (cv. Roblin) and barley (cv. Bedford) was investigated at Portage la Prairie, MB., in 1992, and at Glenlea, MB., in 1993. Parameters measured included soil moisture content (0-10cm), crop emergence, crop aerial biomass, alfalfa aerial biomass, and weed aerial biomass, spike density population, grain yield, and alfalfa regrowth. An additional fall alfalfa termination experiment was performed to evaluate herbicides and combinations of herbicides at Glenlea in 1993 by measuring alfalfa regrowth in late May and late June of the following year.

In the alfalfa termination trials, termination (alfalfa termination with herbicides or tillage) x post-emergence herbicide application (dicamba 0.11 kg a.i. ha^{-1} + MCPAK 0.42 kg a.i. ha^{-1}) interactions occurred for post-harvest alfalfa regrowth measurements in all 4 site-years, indicating that the post-emergence herbicide application was relatively more effective for the less effective initial termination treatments. Post-emergence herbicide treatment within all herbicide treatments was significant for fall alfalfa termination, however significance of post-emergence herbicide existed only with the sublethal herbicide treatments for spring alfalfa termination. Glyphosate at 1.78 kg a.i. ha^{-1} terminated alfalfa as well as tillage for both fall and spring dates at both sites. The 1.78 kg a.i. ha^{-1}

glyphosate treatment also produced higher grain yields than the tillage treatment for fall alfalfa termination, however, the opposite occurred for spring alfalfa termination. In the herbicide evaluation trial, herbicides were evaluated for their ability to terminate alfalfa. Combinations of glyphosate and dicamba, and glyphosate and 2,4-D were found to suppress alfalfa to a greater extent than glyphosate applied alone. As well, 2,4-D was found to enhance the ability of clopyralid to suppress alfalfa.

Soil moisture conservation and successive crop establishment of wheat (cv. Katepwa) was compared under different management dates and methods of terminating alfalfa stands at Glenlea, Carman, and Holland, in 1992-1993, and Carman and Winnipeg in 1993-1994. Alfalfa was removed using herbicides, tillage, and a combination of herbicides and delayed tillage, after the first cut (date 1 termination), after the second cut (date 2), and at spring (date 3 - herbicide only). Parameters measured included soil moisture content (0-190cm), residue cover, crop emergence, spike density population, grain and biomass yield, and water use efficiency of grain and biomass.

The moisture conservation experiments indicated that greater soil moisture levels were conserved in the upper soil profile by fall of the year of alfalfa removal, due to both the date and method of alfalfa termination. Greater soil moisture levels were evident at seeding in the following spring due to the method of alfalfa removal only, with the herbicide treatments having higher soil moisture levels (0-30 cm soil increment) than the tillage treatments. Results indicate that the potential exists to conserve soil moisture in the upper 30 cm soil profile, and also obtain a second cutting of alfalfa by utilizing herbicide to terminate alfalfa at date 2 rather than using tillage or herbicide plus delayed tillage at date 1. Grain yield was 15.3 % and 14.4 % higher by terminating alfalfa with herbicides at date 1 or date 2 respectively, compared to using tillage at date 1.

It is concluded from these studies that termination of alfalfa with herbicides is feasible, providing potential for improved alfalfa suppression, as well as increased soil moisture conservation, which can enable producers to rotate out of alfalfa more readily.

1.0 Introduction

The greatest limitations to dryland crop rotations on the Canadian Prairies involving perennial alfalfa are inadequate suppression of the alfalfa stand, and insufficient soil moisture reserves for the successive grain crop. The transition from alfalfa to successive crops in a rotation presents difficulty regarding alfalfa suppression, soil and moisture conservation, and successive crop establishment. Therefore, many producers prolong the duration of the alfalfa stand, and rotation to annual crops. This results in extending the alfalfa stand beyond the time of its optimum productivity, as well as a loss of potential benefits to the crop rotation (Entz et al., 1995).

Currently, the majority of alfalfa stands in the eastern Prairies are removed by means of tillage (Entz et al., 1995). Adequate suppression of alfalfa requires a large amount of tillage, which often contributes to soil erosion and soil moisture loss (Benoit and Lindstrom, 1987). Unfortunately, few studies have investigated alternative approaches to lessen the adverse effects of removing alfalfa stands when rotating to the following crop. While producers have shown interest in removing alfalfa stands with herbicides (Entz et al., 1995), glyphosate has only recently become registered for alfalfa suppression, and there are no tank mixes of herbicides currently registered specifically for alfalfa suppression.

The present study was conducted to compare management strategies for removing alfalfa stands in a rotational cropping system, in hope of developing a more reliable method of easing the transition from alfalfa, to the following crop in the rotation. Objectives were to 1) evaluate the ability of different herbicides (and combinations of herbicides) to terminate alfalfa, 2) obtain information as to the best time of year to terminate alfalfa, 3) compare soil moisture conservation under different alfalfa termination management systems, and 4) assess the performance of wheat (cv. Katepwa; cv. Roblin), and barley (cv. Bedford) seeded into chemically suppressed alfalfa residue.

Hypotheses included 1) an anticipated increase in alfalfa suppression with the use of herbicides over that of tillage, and 2) an increase in soil moisture conservation by means of alfalfa removal with herbicides, over that of alfalfa termination with tillage.

2.0 Literature Review

2.1 Alfalfa Termination

2.1.1 Alfalfa Termination with Tillage

Tillage has been the traditional method of terminating forage stands in the Canadian Prairie region, and is currently the most frequently employed method (Entz et al., 1995). Moldboard plows, chisel plows, and discers are commonly used to break up alfalfa (*Meticago sativa* L.) sod (Entz et al., 1995; Moomaw, 1990).

Sprague (1952) conducted experiments with Kentucky bluegrass (*Poa pratensis*) and white clover (*Trifolium repens*) sod with different amounts of tillage. He concluded that a large number of tillage treatments were required to sufficiently kill a well established sod, and that complete kill of existing sod was not accomplished by any tillage practice, including plowing. Sprague (1952) further concluded that two to three discings of a sodium trichloracetate and sodium arsenite treated (dead) Kentucky bluegrass and white clover sod produced essentially the same degree of successive crop establishment and yield as 10 to 12 discings of unsprayed sod. Termination of perennial grass sod with different types of tillage revealed that subsequent wheat (*Triticum aestivum* L.) yields were higher with moldboard plowing, than when discers, cultivators, or rotary tillers were used (Agriculture Canada, 1991). However, the moldboard plowing treatment retained the least amount of root fiber in the surface soil, indicating increased erosion potential.

Under conventional tillage, few differences have been observed in the subsequent crop yield, due to the time of plowing to remove perennial alfalfa/grass vegetation (Moomaw and Martin, 1976; Smith et al., 1992a). Foster (1990) suggested that during dry years, early incorporation of sweetclover to conserve soil moisture for succeeding crops would be beneficial. In his trials, wheat yield following sweetclover was 80 % greater when sweetclover was incorporated June 15 as compared to July 15. Sprague

(1952) suggested that breaking of perennial sod is best started in late July to take advantage of midsummer heat and dry weather to aid in sod suppression.

Adams et al. (1970), Carreker et al. (1972), Elkins et al. (1979), and Smith et al. (1992a) stressed a need for no-till cropping systems to replace conventional methods of removing perennial sod. The primary concern was that the large amount of tillage required to sufficiently suppress perennial sod resulted in unacceptable soil losses, especially from rolling topography.

2.1.2 Alfalfa Termination with Herbicide

There has been an increase in interest among producers in the Canadian Prairies in using herbicides instead of traditional tillage methods to suppress alfalfa stands (Entz et al., 1995). Incomplete kill of the alfalfa stand, loss of available soil moisture, and increased vulnerability of the field to erosion were notable concerns by alfalfa producers employing tillage to remove forage stands (Entz et al., 1995). Research with improved soil erosion control has resulted in the development of conservation systems, which reduce soil disturbance while retaining crop residue on the soil surface (Benoit and Lindstrom, 1987).

A number of trials have been conducted to support the concept that suppression of alfalfa by herbicides can reduce the number of tillage operations required to break up alfalfa stands (Button, 1991; Knake et al., 1986a; Koethe et al., 1988). Buhler and Mercurio (1988) suggested that in order to control deep-rooted perennial species such as alfalfa, a translocated systemic herbicide is required. Herbicides used to control alfalfa include glyphosate [N-(phosphonomethyl) glycine] (Davis, 1978), dicamba (3,6-dichloro-2-methoxybenzoic acid) (Knake et al., 1984c), 2,4-D [(2,4-dichlorophenoxy) acetic acid] (Moomaw and Martin, 1976), and clopyralid (3,6-dichloropicolinic acid) (Button, 1991).

2.1.2.1 Herbicide Mode of Action

Herbicide mode of action refers to the entire sequence of events from introduction of a herbicide into the environment to the death of the plant (Ashton and Crafts, 1981). This definition includes physiological and biochemical aspects of herbicide action including absorption, translocation, molecular fate, biochemical responses, and plant growth and structure.

Glyphosate is applied as a foliar post-emergence spray. Glyphosate is readily translocated to underground propagules of perennial species, preventing regrowth from these sites. Glyphosate is mobile in the plant phloem and will accumulate in meristematic areas of the treated plants according to source-sink relationships (Bromilow and Chamberlain, 1991). Uptake by plant roots is precluded by absorption of glyphosate to soil and inactivation of the herbicide (Humburg, 1989). Glyphosate translocation in plants occurs by cell to cell movement as well as transport by the symplasm. Apoplastic movement of glyphosate occurs between cells and in xylem tissue. The efficient transport of the phloem to the rhizomes and roots aid the effectiveness of glyphosate activity.

Glyphosate inhibits the aromatic amino acid biosynthetic pathway, via the inhibition of 5-enolpyruvylshikimic acid-3-phosphate (EPSP) synthase, an enzyme of the shikimic acid pathway. Inhibition of the shikimic acid pathway reduces the supply of aromatic amino acids for protein synthesis, including phenylalanine, tyrosine, and tryptophan. The absence of these major end products of the shikimic acid pathway thus inhibit protein synthesis, as well as a diverse array of phenolic end products (Cole, 1985). Plant death occurs slowly over days or weeks as a result of this biochemical inhibition. The characteristics of high mobility, slow degradation within the plant, and innate phytotoxicity enable glyphosate to be ideal for perennial plant control.

Glyphosate also inhibits chlorophyll synthesis, possibly by inhibiting synthesis of porphyrin containing compounds (Cole, 1985). Symptoms of glyphosate activity in plants include foliar chlorosis followed by necrosis. Perennial plant regrowth following glyphosate treatment often display foliar malformation. Bromilow and Chamberlain, (1991) showed that glyphosate rapidly inhibited allocation of carbon to starch during photosynthesis. The reduction of starch consequently inhibited sucrose export, and glyphosate movement, being dependent on bulk flow in the phloem, was also reduced (Bromilow and Chamberlain, 1991).

Dicamba is a trisubstituted benzoic acid herbicide, which is active from application to soil and foliage (Bromilow and Chamberlain, 1991). Dicamba is readily absorbed by plant leaves and roots, is translocated via the symplasm and apoplasm, although long distance transport may be slow. In some plants, dicamba accumulates in mature leaf tips indicating apoplastic translocation (Humburg, 1989). Dicamba possesses the properties of an auxin-like growth regulator and accumulates in areas of high metabolic activity resulting in phytotoxic symptoms of growth inhibition of developing buds and apices. Dicamba also is excreted or leaked from plant roots into the surrounding medium (Bromilow and Chamberlain, 1991), therefore care must be taken to avoid successive crops that are sensitive to dicamba.

The herbicide, 2,4-D is a phenoxy aryloxyalkanoic acid herbicide, which induces abnormalities in plant growth and structure including rapid epinastic bending, tumors and secondary roots. Plants treated with 2,4-D stimulate ethylene production, causing differential responses (stimulation vs inhibition) in cell division. The herbicide, 2,4-D is readily absorbed by plant leaves and translocated primarily by the symplastic system. Transport of 2,4-D, however, is considerably less than that of photosynthate, due to the formation of immobile complexes of the compound in the plant. The herbicide, 2,4-D is moved very efficiently in the phloem over short distances, but long distance symplastic movement is inhibited by ion trapping of the herbicide in tissue adjacent to the vascular system (Bromilow and Chamberlain, 1991). The herbicide, 2,4-D will, however, move from phloem to xylem in the stem and be carried back to transpiring leaves by the transpiration stream (Ashton and Crafts, 1981). The abnormal stimulation of biochemical and metabolic plant processes by low levels of 2,4-D lead to uncontrolled growth. High levels of 2,4-D inhibit these processes, thus inhibiting growth (Ashton and Crafts, 1981). The herbicide, 2,4-D causes abnormal growth response and affects respiration, food reserves, and cell division (Humburg, 1989). Greater accumulations of 2,4-D were measured in Hemp Dogbane roots under conditions of higher light intensities (Schultz and Burnside, 1980). They did not, however, find any increase in translocation of 2,4-D in Hemp Dogbane under conditions of higher temperatures (30°C vs 25°C).

Clopyralid is a readily phloem mobile herbicide which acts as an auxin mimic (Bromilow and Chamberlain, 1991). Clopyralid is active in the soil, therefore careful crop selection should follow clopyralid application. The absorption and translocation of ^{14}C labeled clopyralid in Canada thistle (*Cirsium arvense* L. Scop.) and perennial sowthistle (*Sonchus arvensis* L.) was studied by Devine and Vanden Born (1985). They observed significantly reduced shoot regrowth in both Canada thistle and perennial sowthistle from foliar applications of clopyralid. They also measured rapid exportation of ^{14}C clopyralid from the treated leaves of Canada thistle, and recovered 29 % of the applied ^{14}C clopyralid in the roots and developing buds 144 h after application. Turnbull and Stephenson (1985) indicated that the rate of absorption and export of ^{14}C clopyralid and ^{14}C 2,4-D were similar in Canada thistle, however the distribution of herbicide in the plant differed such that twice as much ^{14}C clopyralid was recovered from the plant roots. Zollinger et al. (1992) observed that ^{14}C clopyralid was absorbed slowly with 60 % absorption 216h after application with less than 28 % of ^{14}C clopyralid being exported from perennial sowthistle leaf.

2.1.2.2 Herbicides to Terminate Alfalfa

Several workers have investigated the performance of herbicides on alfalfa sods. Button (1991) observed that alfalfa terminated with glyphosate at a rate of 0.89 kg a.i. ha^{-1} provided poor control of alfalfa. He also observed that dicamba applied at a rate of 0.139

kg a.i. ha^{-1} resulted in some alfalfa regrowth. Current recommendations for alfalfa termination in Manitoba are with fall applied glyphosate at a rate of 1.34 kg a.i. ha^{-1} to 1.78 kg a.i. ha^{-1} (Manitoba Agriculture, 1997), which is primarily based on the work in this thesis.

Alfalfa has been shown to have partial tolerance to glyphosate (Davis et al., 1978; Dawson and Saghir, 1983; Dawson, 1989). Dawson (1989) found that alfalfa tolerated glyphosate sufficiently, and that rates of 0.075 to 0.150 kg ha^{-1} could be used to control attached dodder (*Cuscuta campestris* Yunck)in established alfalfa. The resultant alfalfa yield was reduced by only 6 % to 14 %. Davis (1976) concluded that although many individual alfalfa plants were killed at rates of 0.8 kg ha^{-1} and 1.0 kg ha^{-1} of glyphosate, surviving plants eventually resumed growth in a normal manner.

The effects of mixing glyphosate with broadleaf weed herbicides were found to give antagonistic and synergistic results in different studies. Generally, glyphosate has been shown to be compatible with salt formulations of 2,4-D or dicamba (Turner, 1985). Clayton (1982) observed that combinations, rather than individual applications of glyphosate, dicamba, and 2,4-D provide improved control of alfalfa. The highest degree of alfalfa suppression occurred with combinations of 2.25 kg a.i. ha^{-1} 2,4-D plus 0.42 kg a.i. ha^{-1} dicamba, and 1.75 kg a.i. ha^{-1} glyphosate plus 2.25 kg a.i. ha^{-1} 2,4-D, however, the level of alfalfa control was insufficient for crop production the following year. Knake et al. (1984c) concluded that herbicide combinations which included dicamba generally gave better control of alfalfa than treatments which included only 2,4-D or glyphosate. This was further substantiated by Buhler and Mercurio (1988) who suggested that dicamba or 2,4-D applied alone were not as effective in suppressing alfalfa as when applied together in a herbicide combination. Button (1991) also observed that combinations of herbicides had a greater suppressive effect on alfalfa than herbicides used alone. In his study, the most effective suppression was observed with the following herbicide treatments: 0.076 kg a.i. ha^{-1} clopyralid plus 0.588 kg a.i. ha^{-1} 2,4-D, 0.525 kg a.i. ha^{-1} dichlorprop plus

0.494 kg a.i. ha-1 2,4-D, 0.89 kg a.i. ha^{-1} glyphosate plus 0.825 kg a.i. ha^{-1} 2,4-D, and 0.139 kg a.i. ha^{-1} dicamba plus 0.588 kg a.i. ha^{-1} 2,4-D. Buhler and Mercurio (1988) observed that dicamba applied at 0.6 kg a.i. ha^{-1} controlled 66 % to 89 % of alfalfa across different years, whereas dicamba applied at 0.3 kg a.i. ha^{-1} plus 2,4-D at 0.6 kg a.i. ha^{-1} provided 88 % to 91 % control of alfalfa. Knake and Raines (1984a) also concluded that mixtures of dicamba and 2,4-D provided increased suppression of alfalfa over either herbicide used alone.

The feasibility of growing no-till corn after chemically suppressed alfalfa (Knake et al., 1986e) and meadow fescue (*Festuca elatior*) (Box et al., 1980) has been demonstrated. Krall et al. (1989) further substantiated the potential for no-till corn production into alfalfa sod, using herbicides to control weeds and alfalfa. Moomaw and Martin (1976) reported that control of alfalfa with 1.12 kg a.i. ha^{-1} 2,4-D and 0.28 a.i. kg ha^{-1} dicamba was equivalent to ploughing. However, they found a reduction in the yield of corn following alfalfa where alfalfa was not adequately controlled. These results point out the importance of complete control of the alfalfa stand. Mercurio and Buhler (1985) indicated that greater than 90 % alfalfa control during the first three weeks after corn planting is critical to corn development.

Consideration must also be given to perennial weeds that exist in the alfalfa stand. Buhler and Proost (1990) suggested that planting into untilled alfalfa infested with perennial weeds was an extreme form of no-till crop production. They found that sequential herbicide treatments, which included fall-applied glyphosate at 1.1 kg ha-1, provided the greatest control for alfalfa containing perennial weed species.

Knake et al. (1986d) cautioned that failure to plan ahead for fall herbicide treatments could result in herbicide residue injury to the following crop. In one study, he confirmed that dicamba residue from 2.24 kg ha^{-1} fall applied dicamba was sufficient to result in 20 % growth reduction of soybean.

2.1.2.3 Timing of Alfalfa Termination

The plant development stage and growth rate can influence the mode of action of herbicides. Davis et al (1979) conducted studies with glyphosate applied to alfalfa at various plant development stages, and concluded that plant mass had no significant effect on glyphosate uptake or translocation of ^{14}C labeled glyphosate. The exception was when alfalfa plants were subjected to temperatures of -4°C; in this case they found that there was a greater reduction in glyphosate translocation in the smaller alfalfa plants. Also, for herbicides such as 2,4-D, dicamba, and glyphosate to be effective in suppressing growth, the plant must have sufficient top growth to intercept the herbicide, and also be actively growing (Buhler and Mercurio, 1988).

Smith et al. (1992a) summarized that fall suppression of perennial alfalfa/grass produced grain yields of the subsequent corn crop comparable to conventional tillage, whereas spring suppression resulted in variable yields. In their experiments, spring suppression of alfalfa/grass resulted in a 10 to 50 percent lower grain yield compared to fall suppression. It was suggested that the reduced yield was due to delayed crop emergence and subsequent delayed development throughout the growing season. According to Buhler and Mercurio (1988), splitting herbicide applications into fall (glyphosate 1.7 kg ha^{-1}) and preemergence (atrazine 2.2 kg ha^{-1}) applications provided better control of alfalfa, perennial grass, and orchardgrass, and higher corn yields than preemergence treatments alone. Buhler and Proost (1990) indicated that sequential applications of early preplant atrazine (3.3 kg a.i. ha^{-1}), and preplant atrazine (3.3 kg a.i. ha^{-1}), in addition to fall applied glyphosate (1.1 kg a.e. ha^{-1}) produced the best control of alfalfa.

Knake et al. (1986a) found that 0.28 kg a.i. ha^{-1} dicamba plus a post-emergence treatment of 0.56 kg ha^{-1} dicamba controlled alfalfa completely, however the subsequent corn (*Zea mays* L.) population was lower than other herbicide treatments. Clayton (1982) observed unacceptable levels of alfalfa suppression from initial termination treatments of glyphosate, dicamba, 2,4-D, applied alone and in mixtures at mid-summer, and therefore undertook to apply post-emergent application of Dowco 290[6] (clopyralid) at 0.30 kg a.i. ha^{-1} the following spring. He observed no significant interaction between Dowco 290[6] at 0.3 kg a.i. ha^{-1}, and the initial alfalfa termination treatments applied the previous summer. Owen et. al. (1992) noted that initial applications of herbicides did not adequately control a mixture of alfalfa, bromegrass and orchardgrass, regardless of the time of application. He further reported that post-emergence application of atrazine or nicosulfuron was required to provide acceptable levels of alfalfa control. Knake et. al. (1992) reported that combinations of dicamba and 2,4-D gave good suppression of established alfalfa, however, post-emergence application of nicosulfuron and bromoxynil were necessary for control of annual grass and broadleaf weeds. In addition to initial alfalfa termination treatment of glyphosate 2.24. kg a.i ha^{-1}, Smith et al. (1992b) utilized post-emergence application of dicamba 0.56 kg a.e. ha^{-1} to control alfalfa and dandelion regrowth.

2.1.2.4 Environmental Influence

Environmental factors such as temperature, humidity, and soil moisture have been found to influence herbicide entry, movement, and activity within plants (Ashton and Crafts, 1981, Caseley and Coupland, 1985). The relationship between environmental factors and herbicide performance centers on the duration and timing of a particular environmental condition in relation to herbicide application and absorption by the plant. Environmental conditions, which influence absorption of a herbicide, will consequently also influence translocation of the herbicide. For example, since temperature affects the rate of metabolic activity in a plant, a rise in temperature increases both absorption and translocation of foliar applied herbicides (Cole, 1983). Also, Bula and Massengale (1972) suggest that low temperature inhibition of translocation may be an important environmental response in alfalfa. Schultz and Burnside (1980) reported increased translocation of glyphosate (39 % vs 18 %) in Hemp Dogbane (*Apocynum cannabinum*) with higher temperatures (30°C vs 25°C, respectively). They also noted greater accumulations of glyphosate into untreated areas of the treated leaf under conditions of higher light intensities.

Prolonged dry conditions or low temperatures at the time of herbicide application, or in the weeks following application, will decrease glyphosate movement within the plant, resulting in decreased effectiveness (Davis, 1976; Price, 1983). High relative humidity was found to enhance the uptake of water soluble applied herbicides such as glyphosate by maintaining a fully hydrated plant cuticle (Davis, 1976; Price, 1983). Price (1983) concluded that soil moisture influences a herbicide's activity only to the extent that it influences the water status of the plant. Prolonged periods of soil water deficit inhibited overall plant growth and metabolism, resulting in decreased movement of herbicide within the plant. Davis (1976) concluded that alfalfa was less sensitive to glyphosate injury when growing under high soil moisture stress, than under low soil moisture stress.

Davis et al. (1979) demonstrated that light fall frost of -2°C increased the phytotoxicity of glyphosate to alfalfa due to increased herbicide uptake. However, fall frost at -4°C injured the phloem tissue of alfalfa, thereby reducing glyphosate translocation and subsequent suppression of the plant. Davis et al. (1979) suggested delaying glyphosate treatments for alfalfa exposed to -4°C to allow for recovery of frost injured phloem, therefore enabling adequate glyphosate translocation to give optimum control.

2.1.3 Alfalfa Escapes and Crop Competition

Competition exists between a crop and weeds for available light, water, and nutrients (Dew, 1972; Spitters et al., 1983). The plant canopy as well as the root zone of each species strive for dominance. Taller species will intercept a greater portion of the incoming light than its share of the total leaf index (Spitters et al., 1983). In a competitive relationship, the weed's effect on the crop is the primary focus, however the crop's effect on the weed is important in minimizing effects from the weed (Aldrich, 1984).

An alfalfa crop can efficiently shade other plant species, and compete for soil moisture, which prevents weed germination, and weed growth (Bendixen and Lanini, 1993). These attributes also make alfalfa competitive against annual crops seeded into suppressed alfalfa residue. Regrowth from suppressed alfalfa will compete vigorously with spring seeded crops especially if the regrowth occurs prior to crop emergence. Sprague (1952) indicated that existing vegetation from perennial Kentucky bluegrass and white clover must be suppressed sufficiently to prevent serious competition with seeded crops. As an alfalfa stand naturally thins with age, it becomes more susceptible to weed invasion; weeds provide additional competition to the successive grain crop (Bendixen and Lanini, 1993).

The duration of crop - weed competition influences the crop such that the longer the weeds compete after crop emergence, the greater their effect on crop yield (Zimdahl, 1980). Smith et al. (1992) indicated that increased early season competition for water and light from delayed sod suppression in spring compared to fall sod suppression resulted in decreased corn grain yields in 3 of 4 years. Delayed germination and slower development of the subsequent crop may also be due to generally cooler soil temperatures in the alfalfa sod under no-till compared to conventional tillage (Buhler and Mercurio, 1988; Moomaw and Martin, 1990; Smith et al., 1992a). Knake et al. (1992) noted that corn plants following alfalfa were taller, and higher plant populations were maintained with conventional tillage compared to no-till under spring removal of alfalfa. The slow herbicide action to suppress alfalfa in the spring, in addition to potentially cooler soil temperatures, may have allowed for greater competition by the alfalfa to the emerging grain crop. However, Smith et al. (1992b) observed that increased residue cover in no-till treatments did not consistently influence soil temperature or moisture after planting compared to conventional tillage. Clayton (1982) attributed poor emergence of spring seeded wheat in no-till compared with tilled alfalfa, to inadequate seed-soil contact, and desiccation of the seeds.

Buhler and Mercurio (1988) noted that lack of total perennial sod control contributed to depression of corn yields, due to competition between emerging corn and the sod for water, light, and nutrients. Using regression analysis, Krall et al. (1995) recorded a barley yield reduction of 87.75 kg ha^{-1} for every end-of-season alfalfa plant 0.5 m^{-2}. Clayton (1982) observed that ineffective control of alfalfa and other weeds increased the difficulty of establishing spring wheat the year following alfalfa. Over the duration of the cropping season, Knake et al. (1985c) discovered improved control of alfalfa in no-till corn, which may have been due to shading of the alfalfa by the corn. In another study, Knake et al. (1992), indicated that alfalfa mulch possessed the ability to suppress emerging weeds in no-till corn. Buhler and Proost, (1990) conducted perennial sod termination studies near Arlington, WI., in a mixed population of alfalfa (12 crowns m^{-2}), dandelion (17 plants m^{-2}), and orchardgrass (12 plants m^{-2}). They reported that fall applied glyphosate at 1.1 kg ha^{-1} with no post-emergence herbicide treatment controlled 66 % alfalfa, 96 % dandelion, and 97 % orchardgrass, which resulted in corn yield of 1,570 kg ha^{-1}, whereas the addition of post-emergence atrazine at 1.7 kg ha^{-1} controlled 95 % alfalfa, 99 % dandelion, and 98 % orchardgrass, and resulted in corn yield of 9880 kg ha^{-1}.

Differences in rooting patterns among species enables advantages to exist for the uptake of available soil moisture (Spitters et al., 1983). The relative root volume of the crop or weed determine the degree of competition by each for water resources (Aldrich, 1984). Both lateral and vertical root distribution are factors in determining moisture extraction capacity. Alfalfa tends to be more competitive for moisture than cereal crops because of its deeper vertical root distribution. The shallower fibrous rooted cereals are more dependent on rain fed moisture than the deeper rooted alfalfa. In the absence of adequate precipitation, alfalfa will lower soil moisture in the profile beyond the depth of cereal roots. Moomaw and Martin (1990), suggested that alfalfa should be suppressed as early in the spring as growing conditions permit in order to conserve soil moisture for the subsequent crop. Adams et al. (1970) indicated that the success of a corn crop following

Coastal bermudagrass (*Cynodon dactylon L.*) and tall fescue (*Festuca arundinacea L.*) was primarily dependent on the degree of competition from the established perennial grasses for soil water availability.

No-till cropping has been observed to cause differential responses among different weeds (Baeumer and Bakermans, 1973) A general reduction in weed number has been found under no-till conditions with many annual species, possibly due to less favorable germination conditions. Perennial species, on the other hand have generally been found to increase in number under no-till. Baeumer and Bakermans (1973) observed that perennial weed species in well established sods and adapted grassland vegetation were able to resist most control measures in a no-tillage system.

The impact of competition from in-crop plant species to the crop following alfalfa is often reduced by the application of a post-emergence herbicide, in addition to initial pre-plant herbicide termination treatments. In addition to an initial alfalfa termination treatment of 0.28 kg a.i. ha^{-1} dicamba, Knake et al. (1986a) utilized a post-emergence treatment of 0.56 kg ha^{-1} dicamba to obtain complete control of alfalfa escapes. Owen et. al. (1992) reported that post-emergence application of 1.68 kg ha^{-1} atrazine was necessary to provide acceptable levels of alfalfa termination, whereas initial application of 2.24 kg ha^{-1} glyphosate applied alone did not provide adequate control. Smith et al. (1992b) controlled alfalfa and dandelion growth in corn by utilizing post-emergence application of 0.56 kg a.e. ha^{-1} dicamba in addition to initial alfalfa termination treatment of 2.24. kg a.i ha^{-1} glyphosate.

2.2 Soil and Water Conservation

Including alfalfa in a cropping system provides many agronomic benefits including improved soil tilth, reduced water and nutrient leaching, and reduced soil erosion (Hanson et al., 1988). However, the attribute of efficient moisture extraction by alfalfa from the soil profile often results in low moisture reserves for successive crops in the rotation

(Duley, 1929; Hobbs, 1953). Over the period of several years, perennial alfalfa often depletes soil moisture to a level below that which annual crops are able to extract moisture. Subsoil moisture depletion by alfalfa has been measured to a depth of 2.4 m from one year growth (Voorhees and Holt, 1969), to a depth of 4.5 m depth from a four year stand of alfalfa (Kiesselbach et al., 1934), and to a depth of 6 m in Kansas (Duley, 1929; Hobbs, 1953). Consequently, successive crops in rotation with alfalfa are often water stressed due to insufficient moisture reserves in their rooting zone, and are therefore dependent on current rainfall for growth.

Alfalfa will initially extract water from the upper soil layers where its root density is greatest, and the flow path is shortest (Hanson et al., 1988). The zone of active water extraction then moves downward in the soil profile, as the upper soil layers dry. Kohl and Kolar (1976) measured soil water uptake by alfalfa from July 8 to July 22 which showed that four-fifths of the water extracted from the top 2.3 m of soil came from the first meter. Hoyt and Leitch (1983) concluded that soil moisture to 120 cm depth was 1.1 to 3.7 cm lower during the spring following 2-3 years of alfalfa than after a fallow control. They also noted that the alfalfa caused no appreciable change in soil moisture used by the following barley crop. Grandfield and Metzger (1936) concluded that 2 years of fallow were necessary to restore subsoil moisture in an old alfalfa stand to a point where the roots of a newly seeded crop could penetrate through moist soil. These observations suggest that in order to optimize crop production in alfalfa containing crop rotations, moisture conservation must be a high priority. Because alfalfa plays such a beneficial role in crop rotations, it cannot be abandoned in agricultural practices, and therefore, the best strategy is to increase water conservation during alfalfa termination.

The limits of plant available water have been characterized by Ritchie (1981). The lower limit of available water has been termed the wilting point (-1.5 MPa), and the upper limit has been termed the field capacity (-0.03 MPa). However, plant growth may be inhibited before the lower limit is reached even though root water extraction may continue beyond the lower limit of available water (Denmead and Shaw, 1962; Ritchie, 1981). The available water capacity of a soil has been shown to be approximately linearly related to the percentages of sand, silt and organic carbon in soils, being correlated negatively to coarse sand, and correlated positively to silt and organic carbon (Salter et al., 1966). Medium textured soils have been found to have a higher available water content than coarser or finer textured soils (Salter and Williams, 1965a; Salter and Williams, 1965b). Bennett and Entz (1989) evaluated estimates of moisture retention parameters for coarse textured soils in Alberta in order to define the minimum acceptable limits of available moisture on the basis of particle size. Their assessment indicated that estimates for field capacity were significantly underestimated, although the wilting point moisture could be satisfactorily estimated.

2.2.1 Soil Moisture Recharge

Under continuous cropping in temperate areas, soil moisture recharge is primarily a result of post-harvest rainfall, snowfall accumulation, and spring rainfall (Aase and Tanaka, 1987; Greb, 1979; Johnson, 1977; Willis and Carlson, 1962). Since water availability is a limiting factor to crop yield in the northern Great Plains (Deibert et al., 1986), and the Canadian prairies (Grevers et al., 1986; Zentner et al., 1990), and because of the nature of the prairie climate (variable rainfall and intermittent drought), precipitation use efficiency by crops is very important. Bauer et al. (1965) reported that moisture reserves were required by crops during the growing season in North Dakota, in addition to rainfall typically received. Hence, there is a need to emphasize improved moisture conservation and direct it toward crop use in the prairies. Blevins et al. (1971) suggested that conservation of additional soil water under no-till production may be sufficient to carry a crop through short drought periods without severe moisture stress.

The replenishment of soil moisture reserves following alfalfa can be influenced by the way in which alfalfa is removed from the rotation. Hennig and Rice (1977) found that the later the forage stand was removed in the season, the lower the level of available water in the upper 120 cm of the soil at spring seeding. Hoyt and Leitch (1983) studied the effect of soil moisture reserves of legumes in cereal rotations in the Black soil zone. They concluded that alfalfa depleted the moisture reserves in the subsoil at depths of 60-135 cm for two succeeding crop years. However, the yield of the subsequent barley (*Hordeum vulgare* L.) crops was not affected by the moisture deficit. Entz et al. (1992) confirmed this result in a Portage la Prairie rotation study, in which alfalfa used significantly more water than annual crops below 120 cm. However, the risk for drought in wheat in the year following alfalfa was no greater than that following an annual crop. By the end of the second growing season, the small decrease in soil water level in the annual crop rooting zone (upper 100 cm soil profile) by alfalfa compared to an annual cropping rotation was reduced due to a recharging by fall rainfall and snowfall accumulation. In the drier environment of Colorado, Coburn (1906) concluded that terminating an alfalfa stand by tillage in September or October would render the soil extremely loose, and vulnerable to drying out rapidly, which would be problematic for the following wheat crop.

Soil moisture conservation is extremely important for crops following alfalfa. Previous research has shown soil moisture conservation benefits that may be utilized in an alfalfa rotation. Voorhees and Holt (1969) suggested that while fallowing prior to August in western Minnesota and eastern South Dakota was not an effective means of conserving rainfall because most rainfall was lost by evaporation, fallowing during late August when precipitation exceeded evapotranspiration, was found to be effective in conserving soil moisture. Aase and Tanaka (1987) indicated that there was little difference between chemical fallow and conventional fallow in terms of conserving summer rainfall. Smika and Wicks (1968) found soil moisture storage to be greater when herbicides were utilized to control weeds in fallow compared to conventional tillage. The higher moisture level under herbicide treatments occurred in the upper 60 cm of the soil profile, and was largely due to increased water storage during and after harvest.

Water recharge is dependent to an extent on the rate of water infiltration into the soil profile. According to Unger (1992), there was no close relationship between any soil condition and water infiltration, except with low residues, where infiltration was increased by tillage, which loosened the soil. Triplett et al. (1968) reported a significantly greater increase in water infiltration rate and total infiltration in treatments with 80 % residue cover, than with other treatments with less cover. Unger (1992), however, found groundcover percent of surface residue from dryland grain sorghum and winter wheat crops not to be closely related to water infiltration rates. He also noted that with limited crop residue, tillage increased water infiltration.

The rate of water infiltration into a soil influences the amount of runoff during periods of rain, as well as moisture evaporation from the upper soil layers. A large percentage of moisture from winter snowfall is usually lost in the form of water runoff during the spring thaw, and any means of holding the snowmelt in place until the moisture can infiltrate the soil would aid in retaining soil moisture (Willis and Carlson, 1962). Meek et al. (1990) observed an increase in the moisture infiltration rate over time in a sandy loam soil when alfalfa was grown. They also measured increased infiltration rates in no-till cotton following alfalfa, compared to conventional cotton culture, which they attributed to flow through macropores created by the alfalfa roots. Edwards et al. (1988) suggested that no-till cropping practices will preserve the macropore flow channels from one crop to the next, whereas tillage operations tend to destroy natural channels that conduct water to the root zone. Dao (1993) concluded that water infiltration into no-till soil was significantly higher than into plowed soil. He observed a continuous wetting depth of 0.4 m to 0.6 m under no-till compared to a layered pattern in plowed soil, and attributed the consistent recharge in the no-till soil profile to undisturbed macropores. Gantzer and Blake (1978) indicated that no-till treatments on a clay loam in south-central Minnesota resulted in a significantly higher volumetric water content (0.28 to 0.35 cm/cm) than conventional tillage (0.25 to 0.31 cm/cm) in the surface 30 cm. They also noted that at depths greater than 30 cm, the tillage treatments were not significantly different with regard to soil moisture. This evidence suggests that crops following no-till alfalfa stand removal may be less susceptible to drought due to increased soil water recharge because infiltration is generally higher under no-till.

Zentner et al. (1990) stressed the importance of stored soil moisture in the root zone because of the unpredictability of growing season precipitation. Crop rotations including alfalfa have been shown to have improved soil aggregate stability, implying greater water storage compared to that of continuous corn (Raimbault and Vyn, 1991). Sugiharto et al. (1994) concluded that reduced tillage combined with alfalfa, effectively lowered water runoff and sediment loss from fields compared to that from conventional tillage.

Snow management is an important aspect of water conservation in the prairie region, since snow can constitute a significant portion (approximately 30 %) of the total annual precipitation (de Jong and Steppuhn, 1983; Greb, 1975; Greb et al., 1970; Smika and Unger, 1986; Steppuhn, 1981;). Snow management has been estimated to add 3 cm of additional soil water to the next crop (de Jong and Cameron, 1980). Measurements taken in southwestern Saskatchewan by Willis and Carlson (1962) have shown that snow management can increase over winter soil water approximately 4.5 cm, which was comparable to the additional moisture added by summerfallowing.

The amount of water available from snowfall depends on the depth, distribution, and duration of snow cover, weather conditions during snowmelt, and the soil properties influencing infiltration and storage of the snowmelt (Steppuhn, 1981). Staple et al. (1960) reported that additional water from snowmelt appeared to be more beneficial in drier fields. Therefore, annual cropping systems should benefit to a greater extent from additional water from snow cover than systems with summerfallow (Steppuhn, 1981). It follows, therefore, that fields previously in alfalfa should benefit even more from additional snow cover since infiltration rate is higher in terminated alfalfa sod, and the soil is more receptive to water because it is usually drier.

Soil water storage can be increased by maintaining standing residues on the soil surface which enhances snow trapping, and subsequently allows snowmelt to enter the soil. de Jong and Steppuhn (1983) reported that crop stubble was effective in trapping windborne snow, compared to bare soil, which retained little or no windborne snow. Smika and Unger (1986), and Bond et al. (1971) concluded that crop residue was most effective for trapping snow when it was standing. The height of crop stubble has been shown to influence the amount of additional water added to the soil by snowfall (Smika and Whitfield, 1966; Steppuhn, 1981). Standing small grain stubble in Saskatchewan was found to trap 51 mm of stored soil water whereas bare fallow had only 11 mm (Staple et al., 1960).

2.2.2 Evaporation and Crop Residue

Sources of soil water loss after alfalfa termination include water loss by evaporation in the fall, and evaporation between snowmelt and crop emergence in spring. Crop residue has been found to generally increase water conservation by increasing infiltration, reducing runoff, and reducing the rate of evaporation (Bond and Willis, 1969; Duley and Russel, 1939; Frye et al., 1988; Russel, 1939; Smika and Unger, 1986). Peters (1960) reported that as much as 50 % of the total water loss in a season in the Midwest, USA occurs due to evaporation from the soil surface. This water loss is influenced by plant, soil, and atmospheric conditions.

The process of soil moisture loss can be differentiated into first and second stage evaporation. Adams et al. (1976), Bond and Willis (1969), Idso et al. (1974) and Lemon (1956) all characterized first stage evaporation as a high, and constant rate of moisture evaporation which is dependent on water flow through the soil as affected by soil surface wetness, wind speed, temperature, solar radiation, and relative humidity. Second stage evaporation, or falling rate evaporation, depends on the drying soil to regulate moisture flow to the surface, and is less dependent on atmospheric conditions. Idso et al. (1974) also characterized a third stage of evaporation, which was described as being a very low, and nearly constant rate of moisture loss from a very dry soil.

Residue cover on the field will slow first-stage drying (Bond and Willis, 1969; Bond and Willis, 1970; Unger et al., 1971; Unger et al., 1988), allowing water additional time to move deeper into the soil where it will be less susceptible to evaporative loss. Unger and Parker (1976) reported cumulative evaporation to be most strongly influenced (in order of importance) by residue thickness, surface coverage, residue application rate, and residue specific gravity. Crop residues tend to decrease the soil surface temperature (Smika, 1983; Gauer et al., 1982), resulting in a decrease in vapor pressure of the soil water. Residues also decrease water vapor transport away from the soil surface by increasing the thickness of the nonturbulent air layer above the soil surface (Smika and Unger, 1986). Hanks et al. (1967) conducted experiments with wind and solar radiation to induce moisture evaporation from three soil types, and concluded that the evaporation rate was significantly higher for the wind treatment than for the radiated treatment in two of the three soils.

The ability of crop residue to reduce evaporation is generally limited to a few days after precipitation (Brun et al., 1986; Frye et al., 1988; Greb, 1966; Russel, 1939). After that time, the evaporation rate from soil with a surface mulch becomes similar to that of a bare soil (Adams et al., 1976; Brun et al., 1986). Aase and Tanaka (1987) found higher drying rates following rains greater than 3 mm from bare soils compared to plots with straw cover, however the differences in rates diminished 10 days after the rain. Steiner (1989) reported higher stage one evaporation rates from disc treatments compared to no-till treatments in wheat residue, however stage two evaporation from the disc treatments were lower than that from the no-till. From studies in North Dakota, Brun et al. (1986)

reported evaporation from a bare soil surface the day after rainfall at 0.168 cm day^{-1}, compared to 0.134 cm day^{-1} from a wheat stubble covered surface.

Willis (1962) derived an inverse linear relationship between initial rates of evaporative loss and percentage of surface area covered. He further characterized the most efficient covering for evaporation control as having large continuous cover with the least exposure of soil surface. Unger (1978b) and Greb et al. (1967) conducted studies, which showed a progressive increase of soil water storage during fallow with increasing amounts of crop residue on the soil surface. Triplett et al. (1968) also reported an increase in available soil moisture with increasing amounts of residue cover. Even small amounts of crop residue on the soil surface have been shown to be effective in decreasing moisture loss during first stage evaporation (Bond and Willis, 1970). Hill and Blevins (1973) observed that the presence of a killed grass sod residue prolonged stage one evaporation in zero tillage plots.

Vegetative residue maintained on the soil surface has been shown to reduce moisture evaporation by shading the soil from solar radiation, insulating soil from heat conduction via air, and slowing water vapor movement from the soil to the air by increasing the boundary layer (Bond and Willis, 1969). Potter et al. (1985) indicated that thermal diffusivity and thermal conductivity was greater under a no-tillage system than under conventional and chisel plow tillage systems. The influence on soil temperature and heat flux differences were attributed primarily to surface residue cover, and to a lesser extent, to soil thermal properties. Carter and Rennie (1985) cited soil temperature differences of 1°C to 5°C lower during the first 30 days of crop growth for spring wheat under no-till compared to conventional tillage systems, which was due primarily to surface wheat residues, and to a lesser extent to soil moisture. Johnson and Lowery (1985) cited a 28 % lower temperature in the upper soil profile (5 cm to 15 cm) with no-till compared to moldboard plow treatments. Gauer (1981) also measured lower soil temperatures, as well as increased soil moisture under no-till treatments compared to tilled treatments in which

2.5 to 5.0 cm of straw had been applied to the surface. No-till and conventional till treatments without surface applied straw (Gauer, 1981) had similar soil temperatures, however, the no-till treatments had higher soil moisture during the spring.

Although the effect of alfalfa residue to soil water conservation has not been previously documented, benefits of small grain surface residues for conserving soil water (Gauer, 1981) and increasing crop yields (Greb et al., 1967; Unger, 1978b; and Allen et al., 1980) have been observed. Smika and Wilkes (1968) found soil water storage to be highest with herbicide-only treatments compared to limited tillage and tillage, because of more surface residues which maintained water infiltration at a higher rate, and suppressed evaporation. Good and Smika (1978) suggested that a mix of standing and flat crop residue may be the most effective in reducing soil moisture loss. Greb (1979) summarized the progress in fallow systems, which showed a transformation from maximum tillage to zero tillage, resulting in both increased fallow water storage and wheat yield. Black and Bauer (1985) reported that the amount of water conserved under conservation tillage systems was a function of the amount of surface residue, and the precipitation amount and distribution. They concluded that 2.5 Mg ha^{-1} of small grain residue was required to suppress evaporation on the Great Plains during summer months. They also concluded that wetting the soil to depths greater than 10 cm by sufficient precipitation aids in suppressing evaporation. Duley and Russel (1939) found that water storage increased from 50 to 80 mm as a result of surface applied wheat straw compared to incorporated straw treatments.

Several studies indicated that soil water contents are higher with surface residues than without surface residues, providing the soil has the capacity to store the additional water (Myhre and Sanford, 1972; Onstad, 1972). For example, Tanaka (1985) confirmed that surface residues reduce evaporation losses by reducing the rate of evaporation, although total evaporation was not necessarily reduced. In that study, at least 2.5 mg ha^{-1} of wheat residue was needed to conserve a significant amount of soil moisture with no-tillage, as compared to stubble mulch tillage. Van Doren and Allmaras (1978) reported that surface residues significantly reduce evaporation, especially while ample moisture exists at the soil surface.

2.2.3 Tillage

No-tillage, or zero tillage, is the practice of directly planting a crop into the soil without previous seedbed preparation since the harvest of the last crop (Baeumer and Bakermans, 1973; Dregne and Willis, 1983). Wilkins et al. (1983) cited that tillage operations offered the best opportunity to control the amount of crop residue on the soil surface. Benoit and Lindstrom (1987) indicated that the physical conditions of a tilled soil are a function of tillage type, soil type, and soil moisture content at the time of tillage. The soil profile often dries out to the depth of cultivation, especially when inverted by tillage such as deep tillage, or discing (de Jong and Steppuhn, 1983).

Volumetric water content under no-tillage is usually greater than that under conventionally tilled soils (Gauer et al., 1982). This has been attributed to a reduction in evaporation, and greater water storage ability under no-tillage (Blevins et al., 1971; de Jong and Steppuhn, 1983; Lal, 1994; Thanh, 1993). Steiner (1994) concluded that each tillage event resulted in moisture movement to the soil surface, resulting in moisture loss from the subsoil. No-tillage has been found to result in higher volumetric moisture content than conventional tillage in the upper 30-60cm soil profile (Blevins et al., 1971; Jones et al., 1969), which has been the main reason for the shift in tillage systems from conventional to no-till (Weatherly and Dane, 1979). Lafond et al. (1992) reported a 9 % increase in soil water in the 0-60cm soil layer under stubble cropping by no-tillage compared to conventional tillage. During the growing season, tillage system had little influence on the soil moisture reserves below 60 cm depth (Blevins et al., 1971). However, Deibert et al. (1986) confirmed that continuous spring wheat in North Dakota was unable to utilize 12 % to 24 % of the precipitation received, regardless of the tillage system employed. Hamblin and Tennant (1981) indicated that during a wet year in the western Australian wheatbelt, the greatest loss of soil water from ploughed treatments would occur by means of drainage, whereas most soil moisture loss from no-tilled soil would take place through evaporation. They attributed this difference to the more rapid movement of water within the ploughed profile, and the greater retention of moisture near the surface in the no-till treatment.

Bertrand (1967) indicated that reduced tillage was an effective method of water conservation because the rough soil surface was able to store considerable quantities of water in microdepressions, which reduced runoff and prolonged infiltration. He cited data, which showed 7.5 cm of runoff water from conventional tillage compared to 4.7 cm of runoff from reduced tillage.

The vast majority of research on soil water conservation has been conducted in annual crop systems, however a limited amount of information on perennial forage systems does exist. Working in an alfalfa sod in Manitoba, Clayton (1982) found that zero till plots generally had a higher water content in the surface soil at seeding than tilled sod, and the increased moisture resulted in improved germination conditions for grains and oilseeds. Grass sod residues reduce water losses to a 30 cm depth from zero tillage plots (Shannholtz and Lillard, 1969). Hill and Blevins (1973) found that the presence of killed grass sod mulch in zero tilled plots had an advantage over conventional tillage plots since lower direct evaporation from the soil surface occurred during the early growing period. They also found that evaporative losses from both zero tilled and conventional tilled treatments were similar as the crop canopy developed, however, the sod residue gave the zero tilled plots an advantage in available soil moisture which was maintained throughout the growing season. The increase in water holding capacity of no-till sod has been shown to be related to organic matter content, since no-till sod retains much of its accumulation of organic matter near the soil surface (Baeumer and Bakermans, 1973).

2.3 Agronomic Responses

Including deep rooted perennial forages in crop rotations in the Black, Dark Gray, and Gray soils have generally provided beneficial attributes to the growth of the following crop (Zentner et al., 1990), however perennial forages were not recommended for use in cereal rotations in the Brown and Dark Brown soils because of competition for limited soil moisture.

Soil water availability is a major factor influencing crop production. Campbell et al. (1993) indicated that in a semi arid region, available water use was by far the most important factor influencing crop parameters, including straw yield, heads per plant, and kernel weight.

Crop growth response to no-till conditions has been shown by numerous studies to be either enhanced or retarded by the soil conditions (Baeumer and Bakermans, 1973). Moody et al. (1963) reported a depression of early season growth of corn under mulch conditions compared to unmulched conditions. However, beginning in late June, there was a significant increase in corn growth under mulch conditions which was attributed to greater moisture under the mulch.

2.3.1 Crop Establishment

Moody et al. (1963) attributed lower soil temperatures under straw spread crop residue in no-till systems to be a factor in delaying early growth and development of corn. In northern Indiana, Kohnke and Werkhoven (1963) estimated that favorable corn germination levels were attained two weeks later with mulched soil compared to bare soil. Ojeniyi (1986) reported that no-till plots had higher soil water content than tilled plots of grass fallow, but without significant differences in soil temperature. Experiments by Unger (1987a) indicated that dryland wheat straw yields of 4000 kg ha^{-1} had relatively minor effects on soil temperature, and generally did not significantly delay plant emergence.

Lafond et al. (1992) reported that spring wheat establishment was not affected by tillage system in experiments which employed no-, minimum, and conventional tillage. Clayton (1982), however, reported lower plant populations with no-till treatments compared to minimum and conventional tillage treatments after alfalfa. The importance of seedbed moisture and seed-soil contact has been emphasized by Carefoot et al. (1990). They suggested that consideration needs to be given to the type of seed drill used. Chevalier and Ciha (1986) indicated that stresses, which occur early in wheat seedling development under no-tillage at Pullman Washington, reduced early growth and vegetative development compared to conventional tillage, and that the wheat plants were unable to overcome those effects prior to maturity. Donaghy (1973) reported an increased number of fertile tillers in wheat (103 compared to 92 per 1.5 m row) under no-till treatments compared to conventional tillage.

2.3.2 Grain Yield

Grain yield is often affected by different management techniques when rotating crops. Corn development was shown to be consistently slower, and corn yield was lower with minimum tillage following corn as compared to conventional tillage in Ontario (Raimbault and Vyn, 1991). Other studies (Munawar et al., 1990) have shown that corn yields were equal to or better in no-till and conservation tillage systems, which was attributed to a higher soil moisture content. Barnett (1990) found that no-till corn production in an alfalfa-grass sod resulted in lower soil temperatures, reduced vegetative leaf number, dry weight, and plant height for the corn, as compared to moldboard plowing and discing. However, there were no observed differences in this study for stalk lodging and grain yield between treatments. Myhre and Sanford (1972) conducted studies, which indicated surface mulch and soil surface roughness both increased soil water content, however only surface mulch increased corn yield.

Research conducted by Agriculture Canada (1991) indicated a wheat yield advantage under plowing treatments of perennial sods, compared to other conventional tillage methods. In northern Alberta, Hoyt (1990) reported increased wheat yields of 66 % to 114 % for eight years following alfalfa compared to that following annual crops. Hoyt and Hennig (1971) measured increased wheat yields of 68 % to 82 % for the first five years following alfalfa compared to that after fallow. Conversely, Wheeler (1950) reported that the yield of crops was often decreased the first year following unirrigated alfalfa.

Yields of spring wheat grown under no-till and minimum till in Saskatchewan were increased by 21 % over that of conventional tillage (Lafond et al., 1992). Greater yields of winter wheat and barley under no-till at Lethbridge were attributed to greater soil water (0-120cm depth) conservation (Carefoot et al., 1990). Water availability was confirmed by Diebert et al. (1986) to be the primary factor influencing spring wheat yields in the Northern Great Plains. Johnson (1964) estimated that seeding-time increase in soil moisture from crop residue on the soil surface could result in increased wheat yield of 64.6 kg ha^{-1} cm^{-1}. Ciha (1982) cited wheat yields in the Pacific Northwest with no-tillage as having significantly greater yields, reduced spikelets per head, and increased kernel weight compared to that of conventional tillage. Donaghy (1973) reported similar wheat kernel weights and number of heads m^{-2} under no- and conventional tillage. He further indicated that wheat yield and barley yield did not differ between no-till and conventional tillage in 7 of 8 locations. Unger and Fulton (1990) reported that a no-tillage system did not affect soil physical conditions in a manner that wheat yields were adversely affected.

McKay et al. (1951) conducted experiments that indicated wheat yields were depressed when the previous sweetclover crop was allowed to grow for a longer duration the previous year. The depression was attributed to a greater extraction of subsoil moisture by the sweetclover crop. Clayton (1982) also reported lower yields of wheat with no-till treatments compared to conventional tillage. He attributed this to a decrease in wheat emergence, and incomplete kill of bromegrass, which competed for moisture and nutrients. Duley (1929) observed that reseeding old alfalfa fields immediately to alfalfa often resulted in failure, primarily due to a depletion of soil moisture by the previous alfalfa crop.

Triplett et al. (1979) conducted experiments in which alfalfa vegetation was killed with herbicides and left on the soil surface to decompose, or moldboard plowed to incorporate the alfalfa residue. Their experiments showed that where plots were nitrogen deficient, plowing did not improve the following corn yield, indicating that there was no detectable difference in mineralization of nitrogen due to tillage, however, water infiltration and grain yield were higher with the 80 % surface cover treatment than with the other treatments. Levin et al. (1987) also confirmed that there was no interaction between method of tillage and nitrogen response for corn crop yield following alfalfa. On the other hand, Mohr et al. (1997) observed lower nitrogen levels in the spring with herbicide termination of alfalfa compared to termination with tillage, however the lower N levels did not reduce grain yield.

2.3.3 Water Use Efficiency

Water use efficiency (WUE) is expressed as kilograms of dry weight produced per hectare-millimeter of evapotranspiration (Viets, 1967). WUE can be increased by soil management factors such as surface residue management, which decrease the moisture evaporation component, allowing a greater percentage of moisture to be utilized by the crop (Viets, 1967). Gardner (1983) suggested that greater WUE can only be achieved by considering each crop-soil combination separately. WUE can also be increased by crop management by utilizing selection of higher yielding varieties, plant population and spacing, ensuring adequate nutrients, and crop pest protection (Viets, 1967).

Shanholtz and Lillard (1969) confirmed an increase in WUE of corn grown under no-till soil conditions compared to that of conventional tillage, which they attributed to enhanced water extraction from the undisturbed soil by the corn. Steiner (1994) concluded that wheat residue on the soil surface during the growing season greatly enhanced WUE of both aerial biomass and grain yield of dryland sorghum. WUE of spring wheat in Saskatchewan was found to be 49.7 kg ha^{-1} cm^{-1} for all soil textures with conventional tillage, and varied from 53.7 to 186 kg ha^{-1} cm^{-1} for loam and heavy soil under no-tillage (Grevers et al., 1986). Under conditions in the Great Plains, Wittmuss and Yazar (1980) conducted cropping practices in which they found no apparent relationship between crop water use and tillage treatment, or water use efficiency and tillage treatment. In southwestern Saskatchewan, Campbell et al. (1992) estimated that the marginal wheat increase per unit of water increase in available water used varied between 5.4 kg ha^{-1} mm^{-1} to 14.6 kg ha^{-1} mm^{-1} for soil NO_3^-N values of 0 to 50 kg ha^{-1}.

2.4 Literature Review Summary

There is abundant literature dealing with soil water measurements in crop rotations, however few studies focus on soil moisture levels following alfalfa termination. Several studies have measured moisture extraction from the soil profile by alfalfa, which tends to dry the soil profile to a depth greater than that which annual crops can root. Few studies however, have focused on the impact that soil moisture depletion has on the crop following alfalfa. Since little can be done to alleviate the moisture depleting characteristics of alfalfa (except to terminate the alfalfa stand sooner), studies need to focus on methods of conserving current soil moisture at the date of termination, as well as conserve precipitation between the date of termination, and the subsequent cropping season.

In addition, few studies have focused on the ability of herbicides to terminate alfalfa in Western Canada. Variations of climatic, soil type, and alfalfa varieties necessitate further study with herbicide termination of alfalfa. If producers are to include perennial alfalfa in a rotational cropping system, additional study is necessary to alleviate current problems of alfalfa termination and soil moisture depletion by alfalfa.

3.0 Alfalfa Termination Date and Method Effects on Alfalfa Control and No-Till Wheat and Barley Establishment

3.1 Abstract

Crop rotations involving perennial alfalfa present the unique problem of terminating the alfalfa stand. Producer difficulty with alfalfa (*Meticago sativa* L.) termination has often resulted in severe competition to the following crop by alfalfa escapes. As well, the intensive tillage used in alfalfa termination results in the loss of many agronomic benefits that alfalfa could contribute to the cropping rotation. A series of field experiments were conducted at Portage la Prairie, Manitoba in 1992, and Glenlea, Manitoba in 1993 in order to (1) investigate the ability of different herbicides and rates of herbicides, for successful alfalfa termination, in comparison to tillage, (2) compare fall and spring alfalfa termination dates, (3) evaluate the performance of barley and wheat seeded into alfalfa residue, and (4) assess the need for post-emergence herbicide to control alfalfa escapes in a subsequent grain crop.

Alfalfa termination treatments were applied either in fall or in spring prior to grain crop seeding. Both fall and spring alfalfa termination with glyphosate at 1.78 kg a.i. ha^{-1} generally resulted in higher levels of soil moisture than tillage in the 0-10 cm increment at spring grain crop seeding. Alfalfa regrowth was assessed by measuring plant parameters during and after the following crop. Date of termination was not significant for alfalfa regrowth, or grain yield, however analysis of covariance suggested that similar basal area of fall terminated alfalfa was more competitive than spring terminated alfalfa with the following grain crop. Measurements indicated no differences for crop type, suggesting that alfalfa escapes competed similarly with barley and wheat. The only herbicide treatment that consistently rivaled tillage in terms of alfalfa suppression and grain yield of the subsequent crop was Glyphosate at 1.78 kg a.i. ha^{-1}. This herbicide treatment reduced post-grain harvest alfalfa basal area to 57 % that of tillage across all experiments in this

study. The 1.78 kg a.i. ha^{-1} glyphosate treatment also enabled from 55.3 % greater to 1.8 % less subsequent grain yield to occur with fall termination, than did the tillage treatment. The tillage treatment, however, increased grain yields from 17.3 % to 26.9 % above that of the herbicide treatments for spring termination. Termination treatment x post-emergence herbicide interactions occurred for both spring and fall termination for both sites, indicating that the post-emergence herbicide reduced the incidence of alfalfa escapes for ineffective alfalfa termination treatments, but to a lesser extent for the better alfalfa termination treatments. Results of a combined experiment analysis showed significant date x termination treatment x post-emergence herbicide interaction for alfalfa regrowth. This was attributed to an inability of the dying alfalfa to uptake the post-emergence herbicide in the better herbicide treatments with spring termination, but not with fall termination. Results of this study indicate that it is feasible to terminate alfalfa with herbicides, however an overall cropping strategy must be considered to deal with alfalfa escapes including competitiveness by the following crop, and post-emergence herbicide application.

3.2 Introduction

Tillage continues to be the most popular method of terminating forage stands in the Canadian Prairie region (Entz et al., 1995). However, termination of perennial alfalfa (*Meticago sativa* L.) stands on the Canadian Prairies by tillage has frequently proven unsatisfactory (Button, 1991; Clayton, 1982; Entz et al., 1995). Incomplete kill of the alfalfa stand (Sprague, 1952), loss of available soil moisture (Clayton, 1982), and increased vulnerability of the field to erosion were notable concerns by alfalfa producers employing tillage to remove forage stands (Entz et al., 1995). Also, alfalfa regrowth following initial suppression can result in considerable competition, reducing yields of following crops. Difficulty in forage stand termination is a major reason why many producers keep alfalfa stands longer than required for maximum rotational benefits (Entz et al., 1995). Adams et al. (1970), Carreker et al. (1972), Elkins et al. (1979), and Smith et al. (1992a) all stressed a need for no-till cropping systems to replace conventional methods of removing perennial sod. There is increasing interest among producers in the Canadian Prairies and northern US Great Plains in using herbicides instead of traditional tillage methods to suppress alfalfa stands (Anderson and Halvorson, 1996; Entz et al., 1995).

A number of trials have been conducted to support the concept that suppression of alfalfa by herbicides can reduce the number of tillage operations required to break up alfalfa stands (Button, 1991; Knake et al., 1986a; Koethe et al., 1988). Sprague (1952) concluded that 2 to 3 discings of a sodium trichloracetate and sodium arsenite treated (dead) Kentucky bluegrass (*Poa pratensis*) and white clover (*Trifolium repens*) sod produced essentially the same degree of successive crop establishment and yield as 10 to 12 discings of unsprayed sod. Buhler and Mercurio (1988) suggested that in order to control deep-rooted perennial species such as alfalfa, a translocated herbicide is required. Perennial alfalfa control and subsequent annual grain crop growth is influenced by herbicide type and application timing (Buhler and Mercurio, 1988; Button, 1991; Knake, 1984b). Herbicides shown to exhibit properties which inhibit growth of alfalfa include glyphosate [N-(phosphonomethyl) glycine] (Clayton, 1982; Davis et al., 1978), dicamba (3,6-dichloro-2-methoxybenzoic acid) (Button, 1991; Knake et al., 1986a), 2,4-D [(2,4-dichlorophenoxy) acetic acid] (Moomaw and Martin, 1976), and clopyralid (3,6-dichloropicolinic acid) (Button, 1991; Clayton, 1982).

Several workers have investigated the performance of herbicides on alfalfa sods. Button (1991) observed that alfalfa terminated with glyphosate at a rate of 0.89 kg a.i. ha^{-1} provided poor control of alfalfa. He also observed that dicamba applied at a rate of 0.139 kg a.i. ha^{-1} resulted in some alfalfa regrowth. Alfalfa has been shown to have partial tolerance to glyphosate (Davis et al., 1978; Dawson and Saghir, 1983; Dawson, 1989). Davis (1976) concluded that although many individual alfalfa plants were killed at rates of 0.8 kg ha^{-1} and 1.0 kg ha^{-1} of glyphosate, surviving plants escaped termination and eventually resumed growth in a normal manner. Moomaw and Martin (1976) reported that control of alfalfa with 1.12 kg a.i. ha^{-1} 2,4-D and 0.28 a.i. kg ha^{-1} dicamba was equivalent to ploughing.

The feasibility of growing no-till corn (*Zea mays* L.) after chemically suppressed alfalfa (Knake et al., 1986c) and meadow fescue (*Festuca elatior*) (Box et al., 1980) has been demonstrated. Krall et al. (1989) further substantiated the potential for no-till corn production into alfalfa sod, using herbicides to control weeds and alfalfa. Moomaw and Martin (1976) found a reduction in the yield of corn following alfalfa where alfalfa was not adequately controlled. Mercurio and Buhler (1985) indicated that greater than 90% alfalfa control during the first three weeks after corn planting is critical to corn development.

Under conventional tillage, few differences have been observed in the subsequent crop yield, due to the time of plowing to remove perennial alfalfa/grass vegetation (Moomaw and Martin, 1976; Smith et al., 1992a). Smith et al. (1992a) summarized that fall suppression of perennial alfalfa/grass produced grain yields of the subsequent corn crop comparable to conventional tillage, whereas spring suppression reduced grain yields by 10 to 50 percent. This yield reduction was attributed to delayed crop emergence and subsequent delayed development throughout the growing season. While spring herbicide termination offers producers more flexibility, sufficient alfalfa regrowth to intercept and absorb the herbicide is required, and this can reduce soil moisture reserves and delay seeding. Buhler and Mercurio (1988) noted that for 2,4-D, dicamba and glyphosate to be effective, the plant must have sufficient top growth to intercept the herbicide, and also be actively growing, while Davis et al. (1978) concluded that plant mass had no significant effect on glyphosate uptake or translocation of ^{14}C labeled glyphosate.

Weed control is also an important consideration when terminating alfalfa with herbicides, since at the time of termination, many alfalfa fields are infested with quackgrass (*Agropyron repens* [L.] Beauv.), dandelion (*Taraxacum officinale* Weber), and other perennial weeds. Buhler and Proost (1990) found that sequential herbicide treatments that included fall-applied glyphosate at 1.1 kg ha^{-1} provided the greatest control for alfalfa containing perennial weed species. In situations of good control, but poor weed control, weeds can become a major problem. Knake et al. (1984a) experienced vigorous quackgrass growth when alfalfa was terminated with 2,4-D. Herbicide treatments that include glyphosate have often been utilized to control a wide diversity of weed species (Buhler and Proost, 1990; Knake et al., 1984a).

The attributes of efficient shading of other plant species, and competition for soil moisture make alfalfa competitive against annual crops seeded into terminated alfalfa residue. Therefore, alfalfa regrowth can pose a serious risk to following crops. Using regression analysis, Krall et al. (1995) recorded a barley yield reduction of 87.75 kg ha^{-1} for every end-of-season alfalfa plants 0.5 m^{-2}.

In response to the widespread difficulty with alfalfa termination, and the lack of knowledge about this system in the alfalfa-grain crop rotations of western Canada and northern US Great Plains, experiments were initiated in pursuit of better methods of removing alfalfa stands in a cropping system. The objectives of this study were to 1) evaluate the effectiveness of herbicides and rates of herbicides, for alfalfa stand termination, in comparison to tillage, 2) compare different dates (fall or spring) of alfalfa termination, 3) evaluate the performance of wheat and barley establishment into alfalfa residue, and 4) assess the requirement of a post-emergence herbicide for in-crop control of alfalfa escapes. It was hypothesized that alfalfa termination by herbicides could have greater potential for alfalfa control than alfalfa removal by tillage, and that alfalfa termination by herbicides could result in equal or higher subsequent crop yields than removal of alfalfa by tillage.

3.3 Materials and Methods

3.3.1 General

The experiments were located at Portage la Prairie on a Dugas clay soil with the surface soil consisting of 5 % sand, 49 % silt, and 46 % clay, and at Glenlea on an Osborne clay soil with the surface soil consisting of 9 % sand, 26 % silt, and 66 % clay. Experiments were established on a two year alfalfa (cv. OAC Minto) stand at Portage la Prairie, and a six year alfalfa (cv. Beaver) stand at Glenlea. Both are tap-rooted cultivars in the medium maturing class (Seed Manitoba, 1997). The alfalfa suppression experiments were designed as a randomized complete block design arranged as a split-split-plot with four replications. The main plot was alfalfa termination treatment, the sub-plot was the annual spring seeded crop, and the sub-sub-plot was post-emergence herbicide treatment. Eight main plot treatments of alfalfa suppression methods included tillage (two passes with a rototiller at a 15 cm depth), glyphosate at 0.89 kg a.i. ha^{-1} and 1.78 kg a.i. ha^{-1}, clopyralid at 0.15 kg a.i. ha^{-1} and 0.30 kg a.i. ha^{-1}, dicamba at 0.36 kg a.i. ha^{-1} and 0.60 kg a.i. ha^{-1}, and an untreated control. Sub-plot treatments were spring crop of wheat (cv. Roblin) or barley (cv. Bedford). Sub-sub-plot treatments included post emergence herbicide sprayed with 0.11 kg a.i. ha^{-1} dicamba and 0.42 kg a.i. ha^{-1} MCPAK, and an unsprayed control. Sub-sub-plot size was 3.2 m x 1.8 m at Portage la Prairie and was 6 m x 1.8 m at Glenlea. The alfalfa termination experiment was conducted twice at each location; once with fall termination, and once with spring alfalfa termination (Table 3.01).

The tillage termination treatment involved two passes with a rotary tiller and harrowing in the fall in the case of the fall alfalfa termination experiment for the 1992 trial at Portage la Prairie. In the 1992 spring termination trial, tilled treatments were rototilled twice, harrowed and packed prior to seeding with a Fabro press drill. In the 1993 fall termination trial at Glenlea, alfalfa was rototilled twice in the fall, and cultivated to a depth of 6 to 8 cm with a 3-point hitch cultivator, harrowed, and packed in the spring. In the

1993 spring termination trial, alfalfa was rototilled twice, and packed prior to seeding using a Fabro press drill.

Table 3.01. Summary dates (Julian day of year) for agronomic treatments and parameters for fall and spring alfalfa termination trials at Portage la Prairie, MB. (1991-1992) and Glenlea, MB. (1992-1993).

	Portage la Prairie (1992)		Glenlea (1993)	
Termination trial	Fall	Spring	Fall	Spring
	Date (day of year)			
Treatment/Parameter				
Alfalfa termination	Sept 16, '91 (259)	May 26 (146)	Sept. 15, '92 (259)	May 21 (141)
Crop seeding	May 8 (129)	May 29 (150)	May 13 (133)	May 26 (146)
Alfalfa basal rating	May 13 (134)	-	May 13 (133)	-
Post-emergence herbicide application	May 28 (149)	June 26 (178)	June 17 (168)	June 23 (174)
In-crop aerial biomass	June 16 (168)	July 17 (199)	July 7 (188)	Aug 11 (223)
Grain harvest	Aug 26 (239)	Sept 16 (260)	Aug 26 (238)	Sept 29 (272)
Post-grain harvest alfalfa basal rating	Aug 27 (240)	Oct 13 (287)	Sept 24 (267)	Oct 1 (274)
Spring alfalfa aerial rating	May 28, '93 (153)	May 28, '93 (153)	-	-

All crop seeding was performed using a Fabro no-till offset disc press drill (Swift Machinery Co., Swift Current, SK) equipped with a cone seeder distributor. A row spacing of 15 cm was used in all trials. The Fabro no-till drill placed the wheat and barley at a uniform depth of 2.5 cm, and firmly packed the soil in each row. Certified wheat (cv. Roblin) was seeded at 275 viable seeds m^{-2} (98.9 kg ha^{-1} at 93 % germination) in 1992, and 275 viable seeds m^{-2} (93.9 kg ha^{-1} at 98% germination) in 1993. Certified barley (cv. Bedford) was seeded at 275 viable seeds m^{-2} (102.5 kg ha^{-1} at 99 % germination) for both years. Fertilizer (11-52-0) was applied with the seed via the no-till drill at a rate of 33.3

kg ha^{-1} actual P, and 7.1 kg ha^{-1} actual N for the four experiments. No additional nitrogen fertilizer was added to the cereal crops.

Foliar spray treatments for alfalfa termination at Portage la Prairie were applied in 107 L water ha^{-1} with a CO_2 pressurized bicycle sprayer. Alfalfa termination treatments at Glenlea were applied in 110 L water ha^{-1} by means of a 3-point hitch tractor mounted sprayer. Alfalfa height at the time of herbicide application (pre-bud stage) was 15 to 25 cm. Alfalfa height and environmental conditions at the time of alfalfa termination are summarized in Table 3.02. Post-emergence herbicide treatments were applied in 107 L water ha^{-1} with an air pressure bicycle sprayer.

Table 3.02. Alfalfa height and environmental conditions at the time of termination.

Location	Year	Termination date	Canopy height	Time of day	Tmax†	Tmin†	Relative humidity†
			(cm)		(°C)	(°C)	%
Portage la Prairie, MB.	1992	Fall	20 - 25	-	13.6	5.7	66 - 93
		Spring	20 - 25	7:00 am	20.7	0.9	‡
Glenlea, MB.	1993	Fall	18 - 25	11:00am	20.0	5.0	70
		Spring	15 - 20	1:00 pm	20.5	-3.5	66

† source Environment Canada
‡ some dew on alfalfa

Climatological weather data was recorded by the Environmental Canada stations at Portage la Prairie (1992), Winnipeg and Glenlea (1993). Monthly actual and long-term average precipitation and temperature are given in Table 3.03. Daily maximum, minimum, and mean air temperature at Portage la Prairie, and Glenlea are shown in Appendix A, Figure A.01.

Table 3.03. Monthly actual and long-term average precipitation and temperature at Portage la Prairie, MB. (1992) and Glenlea, MB. (1993).

		Portage la Prairie				Glenlea			
		Precipitation	Temperature			Precipitation	Temperature		
			Max	Min	Mean		Max	Min	Mean
		— mm —	— °C —			— mm —	— °C —		
May	Actual†	12.6	20.7	4.9	12.8	41.0	18.2	4.4	11.3
	Normal	56.8‡	18.3‡	4.8	11.6	56.8§	18.9§	4.8	11.9
June	Actual	44.0	22.0	9.0	15.4	72.8	20.5	8.8	14.6
	Normal	75.0	23.4	10.7	17.1	94.9	23.1	10.0	16.6
July	Actual	109.0	22.1	10.8	16.3	246.0	22.6	12.3	17.4
	Normal	76.9	26.1	13.5	19.8	70.6	26.1	12.7	19.4
August	Actual	49.0	23.2	9.9	16.3	160.0	23.0	12.6	17.8
	Normal	78.8	25.0	11.8	18.4	60.5	25.0	11.2	18.1
September	Actual	50.0	17.8	4.3	10.8	31.8	16.4	4.5	10.5
	Normal	50.1	18.6	6.3	12.5	52.9	18.8	5.7	12.3

† Source Environment Canada.
‡ Source Environment Canada long-term average 1941 to 1990
§ Source Environment Canada long-term average 1967 to 1990

3.3.2 Agronomic Measurements

Gravimetric soil moisture (g cm^{-3}) measurements at Portage la Prairie were determined from 5.5 cm diameter soil cores taken from depths of 0 - 10 cm and 10 - 30 cm at intervals throughout the spring from the tilled, 0.30 kg a.i. ha^{-1} clopyralid, 1.78 kg a.i. ha^{-1} glyphosate and untreated plots. Bulk density (g cm^{-3}) was determined at Portage la Prairie and Glenlea by excavating soil cores of known volume from depths of 0 - 10 cm and 10 - 30 cm. Volumetric soil moisture content (cm^3 cm^{-3}) was determined by multiplying the gravimetric moisture content by the bulk density of the soil. In 1993, volumetric surface soil moisture content at Glenlea (0-10 cm) was measured using a calibrated neutron moisture gauge (Troxler model 4300 moisture gauge, Troxler

Electronic Laboratories, Inc., Triangle Park, NC.) (Figure C.01) with a surface shield, as explained by Chanasyk and McKenzie (1986), and Chanasyk and Naeth (1988). Volumetric surface measurements at Glenlea were taken at intervals throughout the spring for the untreated, 1.78 kg a.i. ha^{-1} glyphosate, and tillage treatments.

Alfalfa recovery from termination treatments was assessed using a number of different methods at different times of the year. Alfalfa regrowth for the fall termination trials was determined for each sub-plot after spring seeding on May 11; (Julian date, day of year (DOY-132)) at Portage la Prairie, and on May 13 (DOY-133) at Glenlea using a basal quadrat containing a grid of 11 by 11 intersections 5 cm apart (Smith et al., 1992c). Basal area is the portion of the soil surface occupied by alfalfa crowns in contact with the soil surface, and is estimated by counting grid intersections directly over a crown as described in detail by Tothill and Peterson (1962). Total in-crop aerial alfalfa dry matter accumulation was determined by harvesting a 0.5 m^2 area within each sub-sub-plot. Alfalfa was hand sorted from wheat or barley, and weeds, oven dried at 80°C for 48 h, weighed, and mass was expressed on a dry weight basis. Post harvest assessment of alfalfa regrowth was determined by taking a basal quadrat measurement in each sub-subplot at Portage la Prairie for fall (August 27, DOY-240), and spring (October 13, DOY-287) alfalfa termination, and at Glenlea for fall (September 24, DOY-267), and spring (October 1, DOY-274) alfalfa termination. Alfalfa regrowth was also assessed in the spring of 1993 at Portage la Prairie (20 and 12 months after fall and spring termination of alfalfa, respectively) by removing 0.5 m^2 quadrats of above ground alfalfa biomass from each sub-sub-plot. The samples were dried at 80°C for 48 h, and weighed.

Wheat and barley establishment was assessed by measuring plant emergence two to three weeks after seeding. Plant counts were taken from four one meter lengths of row within each subplot. The data was expressed on a square meter basis.

Total in-crop aerial alfalfa, wheat or barley, and weed dry matter accumulation was determined by harvesting a 0.5 m^2 area within each sub-sub-plot. Time of sampling for the Portage la Prairie fall and spring termination trials was late crop tillering (June 16, DOY-168), and early crop stem elongation (July 17, DOY-199), respectively. Sampling dates for Glenlea were early crop heading (July 7, DOY-188), and crop heading (August 11, DOY-223) for the fall and spring termination trials, respectively. Alfalfa, wheat or barley, and weeds were hand sorted, and oven dried at 80°C for 48 h, weighed, and recorded on a dry weight basis.

Wheat and barley spike population density was determined by counting spikes in four, one meter row lengths taken from each subplot. Grain yield was determined in 1992 by removing a one square meter sample (7 rows x 1 m length) from each sub-subplot at Portage la Prairie, which was threshed with a stationary thresher. Grain yield was determined in 1993 at Glenlea by harvesting a 1.3 m width by 1.8 m length with a small plot combine. Grain samples from both years were oven dried at 65°C for 72 h, cleaned, and weighed.

3.3.3 Statistical Analysis

Statistical analysis of the data was conducted using analysis of variance (Statistical Analysis Systems, 1990). Each experiment (site and date) was analyzed separately with the appropriate error terms for alfalfa termination and crop type, and their interactions. The effect of the post-emergence herbicide treatment and its interactions were tested with the residual, as were the error terms. When the analysis of variance F statistic was significant ($P \leq 0.05$), Fisher's Least Significant Difference test was utilized in order to determine mean separation (Gomez and Gomez, 1984). Where interactions were significant ($P \leq 0.05$), analysis of significant interaction terms were conducted to determine differences between the interactive treatment components (Steel and Torrie, 1980). Dates of alfalfa termination were combined where error terms were found to be homogenous according to Bartlett's test (Steel and Torrie, 1980). Sites and dates were included in a combined analysis for post harvest alfalfa basal measurements.

Heterogeneity of error variance existed for other measurements, which were considered as combined dates, or independent experiments only. Combined site analysis assumed a mixed model with sites and dates as random effects, and alfalfa termination, crop type, and post herbicide treatments as fixed effects.

Linear regression analysis was utilized to determine significance of intercepts and slopes for alfalfa escapes in determining grain yield. Analysis of covariance (Statistical Analysis Systems, 1990) was performed to determine differences between date variables and crop variables in determining grain yield, as affected by regrowth of alfalfa escapes. The analysis of covariance variables were averaged over both sites, and derived from all alfalfa termination treatments, excluding the untreated check.

3.4 Results and Discussion

3.4.1 Soil Moisture

In the fall terminated alfalfa experiments, differences in soil moisture content between treatments were noted in the upper 10 cm soil profile (Figure 3.01a; Figure 3.02a). The 10-30 cm soil profile held similar soil moisture content for all treatments at Portage la Prairie (Figure 3.01b). Soil moisture content (0-10 cm) throughout the spring period for the fall applied 1.78 kg a.i. ha^{-1} glyphosate treatment was similar to the tillage treatment at Portage la Prairie (Figure 3.01a), but was greater than the tillage treatment at Glenlea (Figure 3.02a). This difference between sites may have been due to greater rainfall at Portage la Prairie in the week preceding DOY 134, which eliminated potential soil moisture differences between treatments at that time. Also, the higher clay content in the soil at Glenlea resulted in greater surface cracking, which may have allowed greater soil moisture loss in the exposed tillage plots than at Portage la Prairie. Greater soil moisture content ($P \leq 0.05$) in the 0-10 cm depth was generally noted in the 1.78 kg a.i. ha^{-1} glyphosate and 0.30 kg a.i. ha^{-1} clopyralid treatments, than in the untreated check for the fall alfalfa termination trial at Portage la Prairie (1992) (Figure 3.01a). Similarly, higher soil moisture content (0-10 cm) was also found in the 1.78 kg a.i. ha^{-1} glyphosate treatment over that of the untreated check for fall termination at Glenlea (Figure 3.02a).

Alfalfa has been documented as being capable of depleting subsoil moisture to the extent that the following crop became dependent on current rainfall (Grandfield and Metzger, 1936). Hanson et al. (1988) noted that water extraction by alfalfa initially occurs from the upper soil profile where the greatest alfalfa root density exists. The suppressive effect on alfalfa growth by the glyphosate (Clayton, 1982; Davis, 1976) and clopyralid (Button, 1991) may have contributed to a reduction in the ability of alfalfa to extract moisture from the soil compared to the untreated check. All treatments for fall terminated alfalfa retained similar soil moisture content for the 10-30 cm soil depth at

Portage la Prairie where actual precipitation received was considerably less than the long term average during the early growing season (Table 3.03). Second stage evaporation, being less dependent upon atmospheric and surface conditions (Idso et al., 1974; Unger, 1988) probably took effect as water loss occurred from the 10-30 cm soil profile depth, which negated differences in rate of soil moisture loss between treatments.

In the spring terminated alfalfa experiments, greater soil moisture content ($P \leq 0.05$) was observed in the 1.78 kg a.i. ha^{-1} glyphosate treatment compared to the tillage treatment at Portage la Prairie (Figure 3.01c; Figure 3.01d) and Glenlea (Figure 3.02b). Clayton (1982) also cited soil moisture conservation in the 0-10 cm soil profile with the use of no-till alfalfa removal, compared to tillage treatments. The glyphosate treated plots retained more residue on the soil surface than the tillage treatment, which has been found to decrease soil moisture loss due to first stage evaporation (Black and Bauer, 1985; Bond and Willis, 1970; Smika and Unger, 1986). Additional soil moisture in the herbicide killed (1.78 kg a.i. ha^{-1} glyphosate and 0.30 kg a.i. ha^{-1} clopyralid) vs. tilled alfalfa was also observed for several measurements during the early growing season at Portage la Prairie. Increased surface residue in the herbicide treated plots likely reduced first stage evaporation down to the 10-30 cm soil profile depth.

The timing of tillage may explain soil moisture content differences between herbicide and tillage treatments, which existed with the spring termination trials and not the fall termination trials. The tillage treatments for the fall termination experiments were not tilled in the spring at Portage la Prairie and only tilled once and then packed at Glenlea, which would tend to conserve overwinter moisture. The tillage plots for the spring termination trials were rototilled twice in the spring, which would contribute to evaporative moisture loss of overwinter moisture from upper soil profile, compared to the untilled herbicide plots. This amount of tillage, however, is required to kill the alfalfa plants.

Cereal crop type seeded into terminated alfalfa generally did not influence available water in 0-10, or 10-30 cm soil depths at either site or termination date (Appendix A: Table A.01; Table A.02; Table A.03; Table A.04). Wheat and barley have comparable fibrous root systems with similar early season growth characteristics and moisture extracting capability.

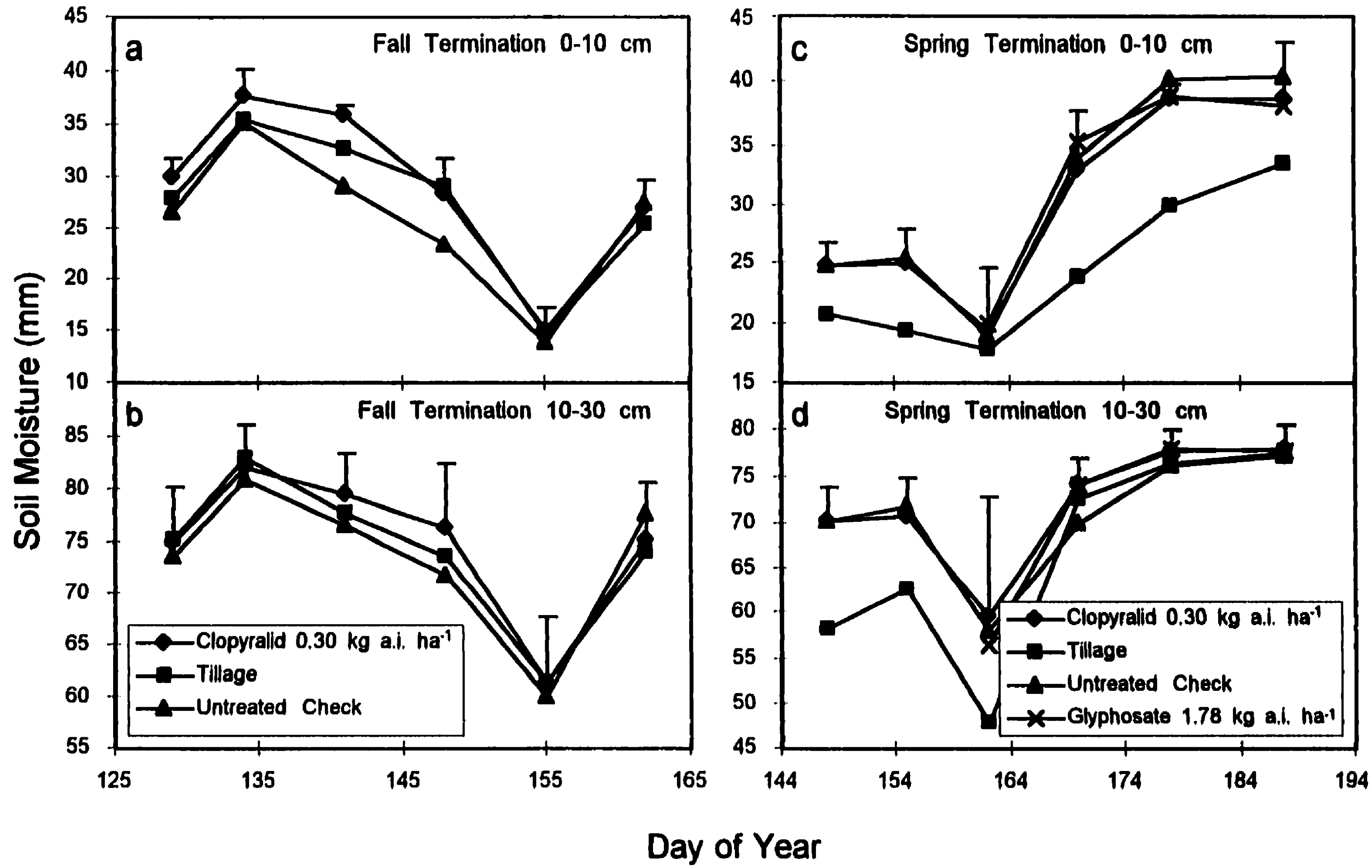

Figure 3.01. Soil water content at 0-10 cm and 10-30 cm for fall alfalfa termination (a and b), and spring alfalfa termination (c and d) treatments as affected by termination treatment at Portage la Prairie, MB., 1992. Error bars represent LSD (0.05).

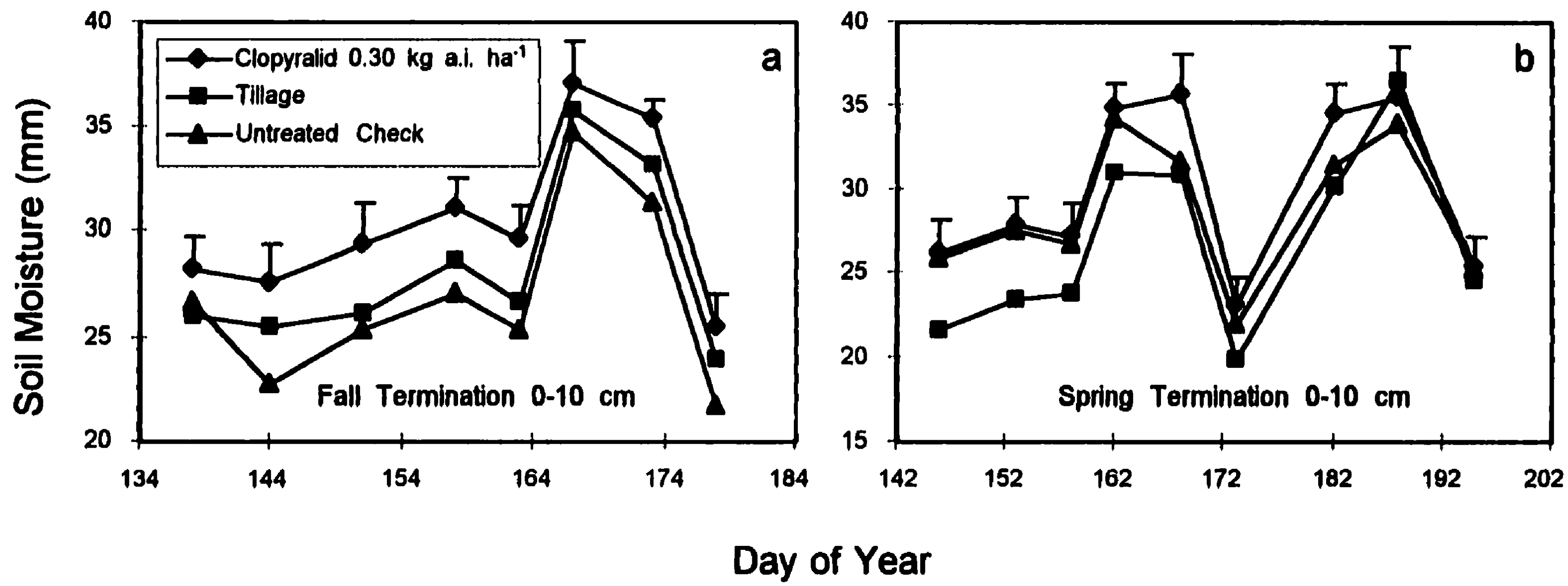

Figure 3.02. Soil water content at 0-10 cm for fall alfalfa termination (a), and spring alfalfa termination (b) treatments as affected by termination treatment at Glenlea, MB., 1993. Error bars represent LSD (0.05).

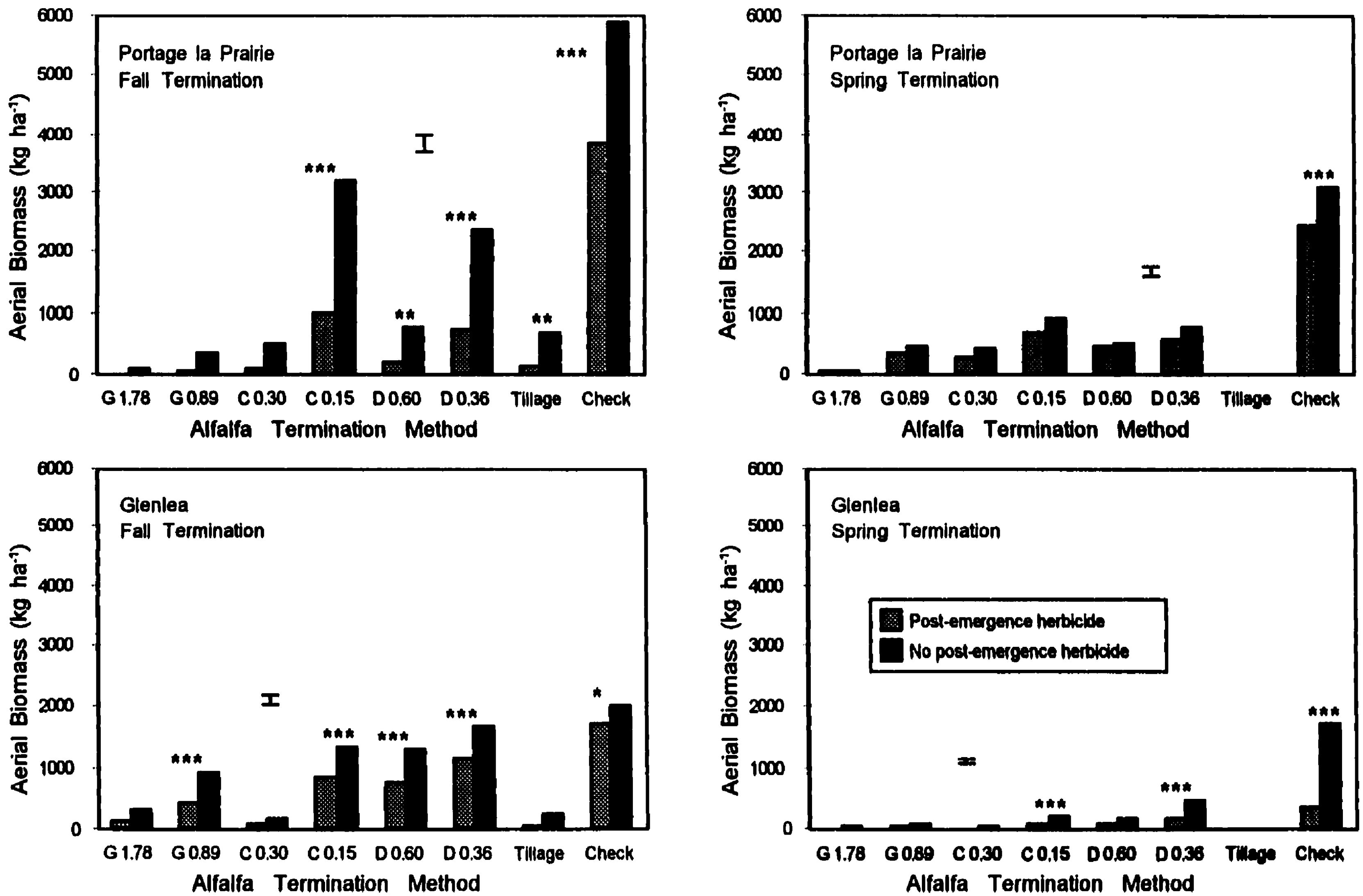

Figure 3.03. Alfalfa termination treatments, glyphosate (G), clopyralid (C), dicamba (D), and tillage ($p \leq 0.05, 0.01, 0.001$) contributing to alfalfa termination x post-emergence herbicide interactions on in-crop alfalfa aerial biomass accumulation at Portage la Prairie, MB., 1992, and Glenlea, MB., 1993, for fall and spring alfalfa termination. Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

3.4.2 Alfalfa Regrowth

3.4.2.1 Alfalfa Basal Crown Measurement at Spring Seeding

Alfalfa basal measurements give an indication of alfalfa regrowth potential. At both locations, alfalfa basal measurements taken just after the time of seeding were reduced to one-third or less than the untreated check for fall termination treatments at both locations, (Table 3.04). The herbicides utilized in these trials, namely glyphosate, clopyralid, and dicamba, have been shown to exhibit properties, which inhibit growth of alfalfa (Button, 1991; Clayton, 1982; Davis, 1976; Knake, 1986a). Few differences among fall termination treatments were noted. At Glenlea, fall tillage suppressed alfalfa regrowth in spring as well as most herbicide termination treatments, and resulted in better alfalfa suppression than 0.89 kg a.i. ha^{-1} glyphosate.

Low soil moisture levels coincided with spring alfalfa termination at both Portage la Prairie and Glenlea (Table 3.03). Soil moisture stress at the time of alfalfa termination has been shown to reduce the effectiveness of glyphosate activity on alfalfa (Davis, 1976). Air temperatures were also lower than normal during the period following spring alfalfa termination (Table 3.03), which may have also contributed to reduced ability of the herbicides to suppress the alfalfa. Moomaw and Martin (1976) suggested that daytime temperatures below 15.6°C may be detrimental to good alfalfa control with dicamba. Temperatures below 10°C were determined by Bula and Massengale (1972) to be associated with a reduction in translocation within alfalfa, therefore slowing herbicide movement within the plant.

3.4.2.2 In-Crop Alfalfa Regrowth

In-crop aerial biomass yield of alfalfa was measured to assess treatment effects on alfalfa competition to the cereal crop. All termination treatments reduced alfalfa aerial dry weight production below that of the untreated check (Table 3.04). Dicamba at 0.36 kg a.i. ha^{-1} did not suppress alfalfa to the same extent as 1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid, 0.60 kg a.i. ha^{-1} dicamba, and tillage (three of four experiments). The tillage termination treatment reduced alfalfa aerial regrowth to the same extent as the best herbicide treatment in three of four experiments. Application of a post-emergence herbicide treatment reduced alfalfa aerial biomass production by 56.7 % and 21.8 % for fall and spring alfalfa termination respectively, at Portage la Prairie, and by 35.8 % and 75.2 % for fall and spring alfalfa termination, respectively, at Glenlea (Table 3.04), however no differences ($P > 0.05$) were noted in alfalfa aerial dry weight with regard to crop type (Table 3.04).

Termination treatment x post-emergence herbicide interactions for in-crop alfalfa regrowth occurred ($P \leq 0.05$) for both fall and spring alfalfa termination at both sites (Figure 3.03). The termination treatment x post-emergence herbicide interaction for fall termination at the late crop tillering stage at Portage la Prairie, and the early crop heading stage at Glenlea indicated no effect of post-emergence herbicide for 1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, and 0.30 kg a.i. ha^{-1} clopyralid, while all other treatments benefited from the in-crop herbicide. Therefore, the treatments, which suppressed alfalfa to a greater extent, namely 1.78 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid, and tillage, did not benefit from the post-emergence herbicide in terms of alfalfa suppression.

The termination treatment x post-emergence herbicide interaction for spring termination at the early crop stem elongation stage at Portage la Prairie indicated a significant ($P \leq 0.05$) effect of post-emergence herbicide for the untreated check only. Visual assessment of spring herbicide treated alfalfa indicated a slow die back of the alfalfa plants, and an absence of abundant regrowth at the time of post-emergence herbicide application. Slow plant degradation has been noted for applications of the translocated herbicides; glyphosate (Cole, 1985), dicamba (Bromilow and Chamberlain, 1991), and clopyralid (Zollinger et al., 1992). The untreated check, having not been initially sprayed, was growing actively at the time of the post-emergence herbicide treatment, and therefore benefited most from herbicide. The tillage treatment contained virtually no alfalfa regrowth with or without the post-emergence herbicide treatment. The termination treatment x post-emergence herbicide interaction for spring termination at the crop heading stage at Glenlea indicated a similar response to that of Portage la Prairie. Significant effects of post-emergence herbicide were shown for the untreated check, 0.15 kg ha^{-1} clopyralid, and 0.36 kg ha^{-1} dicamba (Figure 3.03). Clopyralid at 0.15 kg ha^{-1} and dicamba at 0.36 kg ha^{-1} were the least effective treatments for terminating alfalfa, allowing the alfalfa to retain sufficient growth which enabled the post-emergence herbicide treatment to effectively reduce alfalfa regrowth. Overall, there was less alfalfa aerial dry matter for spring terminated vs. fall terminated alfalfa (Figure 3.03). This was probably due to the fact that the escapes in the fall terminated alfalfa resumed growth from early spring, while the spring suppressed escapes did not resume growth until late in the spring after recovery from initial herbicide or tillage treatments.

3.4.2.3 Post-Harvest Alfalfa Basal Crown Measurement

The effectiveness of alfalfa control treatments were determined by taking additional measurements of alfalfa basal area after the spring cereal crops had been harvested. The results indicated significant termination treatment and post-emergence herbicide application effects (Table 3.05), however no differences ($P > 0.05$) in post-harvest alfalfa regrowth due to crop type used were observed. The significant post-emergence herbicide effects across both dates for both sites emphasized the need for post-emergence herbicide treatment in an alfalfa termination management system. Owen et al. (1992) observed that single applications of herbicides to terminate alfalfa did not provide acceptable control, regardless of the date of spraying. Clayton (1982) also experienced inadequate alfalfa control with single applications of glyphosate, dicamba, and 2,4-D, and suggested that combinations of herbicides, rather than individual herbicide applications could improve the level of alfalfa control. However the control was still insufficient for crop production the following year. Knake et al. (1984b) found that control of alfalfa with glyphosate alone was only fair, however the addition of a post-emergence application of dicamba improved alfalfa control. These findings support the importance of post-emergence herbicide in addition to the initial herbicide treatment, to achieve adequate alfalfa termination.

All termination treatments suppressed alfalfa regrowth, as measured by alfalfa basal crown area, to one-half or less than that of the untreated check (Table 3.05). Based on measurements of alfalfa basal crown area, glyphosate at 1.78 kg a.i. ha^{-1} and clopyralid at 0.30 kg a.i. ha^{-1} were consistently among the better herbicide treatments for terminating alfalfa in all four experiments. Glyphosate at 0.89 kg a.i. ha^{-1} reduced the basal crown area of alfalfa as well as 0.30 kg a.i. ha^{-1} clopyralid for fall termination at both Portage la Prairie and Glenlea, and spring alfalfa termination at Glenlea. Glyphosate at 0.89 kg a.i. ha^{-1} terminated alfalfa as well as 1.78 kg a.i. ha^{-1} glyphosate for both fall and spring alfalfa termination at Glenlea. Dicamba at 0.60 kg a.i. ha^{-1} was as effective in reducing post-harvest alfalfa basal crown area as either glyphosate treatment, or 0.30 kg a.i. ha^{-1} clopyralid for spring alfalfa suppression at Glenlea only. Knake et al. (1986d) suggested that under actively growing conditions for alfalfa, fall application of 0.56 kg ha^{-1} dicamba should be effective in terminating alfalfa sufficiently. Clopyralid at 0.15 kg a.i. ha^{-1} and dicamba at 0.36 kg a.i. ha^{-1} consistently provided poor alfalfa control relative to the other termination treatments.

The tillage treatment suppressed alfalfa regrowth as measured by post-harvest alfalfa basal crown area to an extent comparable to that of the most effective herbicide treatments for three of four experiments. Tilling alfalfa in spring appeared more effective in terminating alfalfa (virtually reducing alfalfa basal crown area to 0 %) than fall tillage (Table 3.05).

Significant termination treatment x post-emergence herbicide interactions for fall basal crown area was observed for both fall and spring alfalfa termination at both sites (Table 3.05). Contributions to this interaction are shown in Figure 3.04. For fall termination at Portage la Prairie, all termination treatments displayed a significant response ($P \leq 0.05$) to the post-emergence herbicide. Differences in magnitude were noted however, with 1.78 kg a.i. ha^{-1} glyphosate displaying a lower magnitude interaction than the less effective herbicide treatments, tillage, or the untreated check. Similar results were observed for fall termination at Glenlea. All treatments were significant ($P \leq 0.05$), however, the magnitude of response by 1.78 kg a.i. ha^{-1} glyphosate, 0.30 a.i. ha^{-1} clopyralid, and tillage was less than that of the less effective herbicide treatments, and the untreated check.

Spring alfalfa termination at Portage la Prairie revealed different responses to post-emergence herbicide application, as measured by post harvest alfalfa basal crown area (Table 3.05). The tillage and 0.30 kg a.i. ha^{-1} clopyralid treatments displayed no increased alfalfa suppression with the application of the post-emergence herbicide. Glyphosate at 1.78 kg a.i. ha^{-1} displayed a lower response to the addition of the post-emergence herbicide than the remaining termination treatments, or the untreated check. Termination treatment x post-emergence herbicide interaction for spring termination at Glenlea also displayed differing responses to post-emergence herbicide application. The glyphosate treatments at 1.78 kg a.i. ha^{-1} and 0.89 kg a.i. ha^{-1}, 0.30 kg a.i. ha^{-1} clopyralid and tillage treatments gained no additional ability to suppress alfalfa with the addition of the post-emergence herbicide application. The less effective herbicide termination treatments and untreated check displayed a significant effect of post-emergence herbicide application. As with the in-crop alfalfa aerial biomass accumulation, the more effective spring termination herbicide treatments displayed no additional benefit from the addition of the post-emergence herbicide application.

Combined analysis of post harvest alfalfa basal crown area for both dates and sites indicated significance with regard to site (Table 3.06), suggesting that degree of alfalfa termination may differ across locations, perhaps due to alfalfa stand density and cultivar, environmental conditions, or soil type. Figure 3.04 clearly indicates that alfalfa basal area at Portage la Prairie maintained a basal crown area of 10 to 12 % as shown by the untreated check, whereas the alfalfa basal crown area at Glenlea was approximately 5.5 % in the untreated check. The alfalfa stand at Portage la Prairie was younger, hence healthier and more resilient than at Glenlea. The date of alfalfa termination did not affect post harvest alfalfa basal crown area, however termination treatments did. Glyphosate at 1.78 kg a.i. ha^{-1} was the most effective treatment for reducing alfalfa regrowth, although not better than tillage. On the other hand, Clayton (1982) found that glyphosate at 1.75 kg a.i. ha^{-1} provided insufficient alfalfa control for crop production. Davis (1976) observed partial glyphosate tolerance by alfalfa to rates of glyphosate at 1.5 kg a.e. ha^{-1}. Clopyralid at 0.30 kg a.i. ha^{-1} was as effective as tillage in terminating alfalfa. Crop type did not differ with regard to post harvest alfalfa basal crown area measurements. Post harvest alfalfa regrowth measurement was lower with the application of the post-emergence herbicide treatment.

Interactions of site, date, and termination were all significant for post-harvest basal crown area, indicating a variable response by the different termination treatments at the different sites and dates, possibly influenced by environmental conditions. Site x date, site x termination treatment, and site x date x termination treatment interactions existed, at least in part, as a result of different initial alfalfa basal area and different alfalfa cultivar at each location. Date x termination treatment interactions were probably a result of the increased effectiveness of the tillage treatment in the spring at both locations compared to the fall (Figure 3.04). Date x termination treatment x post-emergence herbicide was significant for alfalfa regrowth (Table 3.06), indicating an inability of the dying alfalfa to absorb the post-emergence herbicide for the better herbicide treatments with spring termination. Moomaw and Martin (1976) recorded better alfalfa control from spring termination than fall termination, except during one season when the temperature following spring termination was 3.3 °C cooler than normal. Knake et al. (1986c) suggested that fall termination of alfalfa was necessary in order to achieve better alfalfa control, and minimize herbicide residue, which may pose a problem for some crops following in the rotation. All crop interactions for the post harvest alfalfa basal crown area were non-significant, further strengthening the concept that the barley and wheat displayed similar competitiveness to the alfalfa regrowth.

Table 3.04. Alfalfa basal rating at spring and in-crop alfalfa aerial biomass accumulation response to alfalfa termination treatment, crop type, and post-emergence herbicide treatments at Portage la Prairie, MB (1992) and Glenlea, MB (1993).

	Spring alfalfa basal rating				Alfalfa aerial biomass yield			
	Portage la Prairie		Glenlea		Portage la Prairie		Glenlea	
Main effect Date sampled (DOY)	Fall May 11 (132)	Spring -§ -	Fall May 13 (133)	Spring - -	Fall June 16 (168)	Spring July 17 (199)	Fall July 7 (188)	Spring Aug 11 (223)
	%				kg ha^{-1}			
Termination treatment								
Glyphosate 1.78‡	0.8b†	-	1.0bc	-	35e	31e	204e	17c
Glyphosate 0.89	3.1b	-	2.0b	-	194de	406d	671d	42c
Clopyralid 0.30	1.9b	-	0.6bc	-	276de	333d	116e	19c
Clopyralid 0.15	6.0b	-	1.2bc	-	2,084b	800b	1,086bc	130c
Dicamba 0.60	1.4b	-	1.3bc	-	483d	485cd	1,025c	108c
Dicamba 0.36	4.9b	-	1.5bc	-	1,531c	667bc	1,395b	312b
Tillage	3.0b	-	0.0c	-	414d	1e	137e	3c
Untreated check	19.4a	-	6.9a	-	4,852a	2,761a	1,870a	1,021a
LSD (0.05)	5.5	-	1.6	-	355	238	332	149
Crop								
Wheat	-	-	-	-	1,249a	677a	860a	213a
Barley	-	-	-	-	1,218a	694a	766a	199a
LSD (0.05)	-	-	-	-	133	85	116	42
Post-emergence herbicide								
Sprayed	-	-	-	-	746b	601b	636b	82b
Unsprayed	-	-	-	-	1,721a	769a	991a	331a
LSD (0.05)	-	-	-	-	150	80	85	28
Source of variation				ANOVA (P > F)				
Termination (T)	<0.001	-	<0.001	-	<0.001	<0.001	<0.001	<0.001
Crop (C)	-	-	-	-	0.637	0.698	0.108	0.493
Post herbicide (P)	-	-	-	-	<0.001	<0.001	<0.001	<0.001
T x C	-	-	-	-	0.160	0.686	0.317	0.080
T x P	-	-	-	-	<0.001	0.007	0.049	<0.001
C x P	-	-	-	-	0.680	0.426	0.720	0.930
T x C x P	-	-	-	-	0.728	0.106	0.250	0.931

† Means within each date and location, followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

‡ kg a.i. ha^{-1}.

§ No basal measurements taken for spring alfalfa termination experiments.

Table 3.05. Alfalfa regrowth response to alfalfa termination treatment, crop type, and post-emergence herbicide treatments measured post-harvest to the grain crop and the following spring at Portage la Prairie, MB (1992) and Glenlea, MB (1993).

	Post-harvest alfalfa basal rating				Spring alfalfa aerial biomass yield			
	Portage la Prairie		Glenlea		Portage la Prairie§		Glenlea	
Main effect	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Date sampled	Aug 27	Oct 13	Sept 24	Oct 1	May 28	May 28	-¶	-
(DOY)	(240)	(287)	(267)	(274)	(148)	(148)	-	-
	%				kg ha^{-1}			
Termination treatment								
Glyphosate 1.78‡	0.4e†	0.6ef	0.7d	0.0d	274f	82e	-	-
Glyphosate 0.89	1.3d	2.5d	1.3cd	0.4cd	734de	543d	-	-
Clopyralid 0.30	1.1de	1.2e	0.8d	0.1d	652ef	208e	-	-
Clopyralid 0.15	3.5b	4.0bc	2.0bc	1.0bc	1,530bc	1,106c	-	-
Dicamba 0.60	2.3c	3.7c	1.9bc	0.6cd	1,040de	1,056c	-	-
Dicamba 0.36	3.5b	4.9b	2.8b	1.6b	1,642ab	1,444b	-	-
Tillage	2.2c	0.1f	0.5d	0.0d	1,163cd	17e	-	-
Untreated check	7.9a	9.7a	4.3a	4.2a	1,976a	2,331a	-	-
LSD (0.05)	0.7	1.0	0.9	1.0	447	332	-	-
Crop								
Wheat	2.7a	3.3a	1.9a	0.9a	1,194a	854a	-	-
Barley	2.8a	3.4a	1.7a	1.0a	1,058a	843a	-	-
LSD (0.05)	0.4	0.5	0.3	0.3	157	160	-	-
Post-emergence herbicide								
Sprayed	1.5b	2.1b	0.5b	0.6b	717b	371b	-	-
Unsprayed	4.0a	4.6a	3.1a	1.4a	1,535a	1,326a	-	-
LSD (0.05)	0.3	0.3	0.4	0.2	166	120	-	-
Source of variation				ANOVA (P > F)				
Termination (T)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-
Crop (C)	0.821	0.497	0.264	0.645	0.085	0.884	-	-
Post herbicide (P)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-	-
T x C	0.269	0.576	0.409	0.839	0.942	0.947	-	-
T x P	<0.001	<0.001	<0.001	<0.001	0.106	<0.001	-	-
C x P	0.200	0.069	0.617	0.920	0.632	0.865	-	-
T x C x P	0.777	0.385	0.289	0.972	0.590	0.717	-	-

† Means within each date and location, followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

‡ kg a.i. ha^{-1}.

§ Measurements taken the following spring DOY 148 (May 28), 474 and 368 days after initial termination treatment for fall and spring termination, respectively.

¶ No aerial biomass measurements taken for Glenlea site.

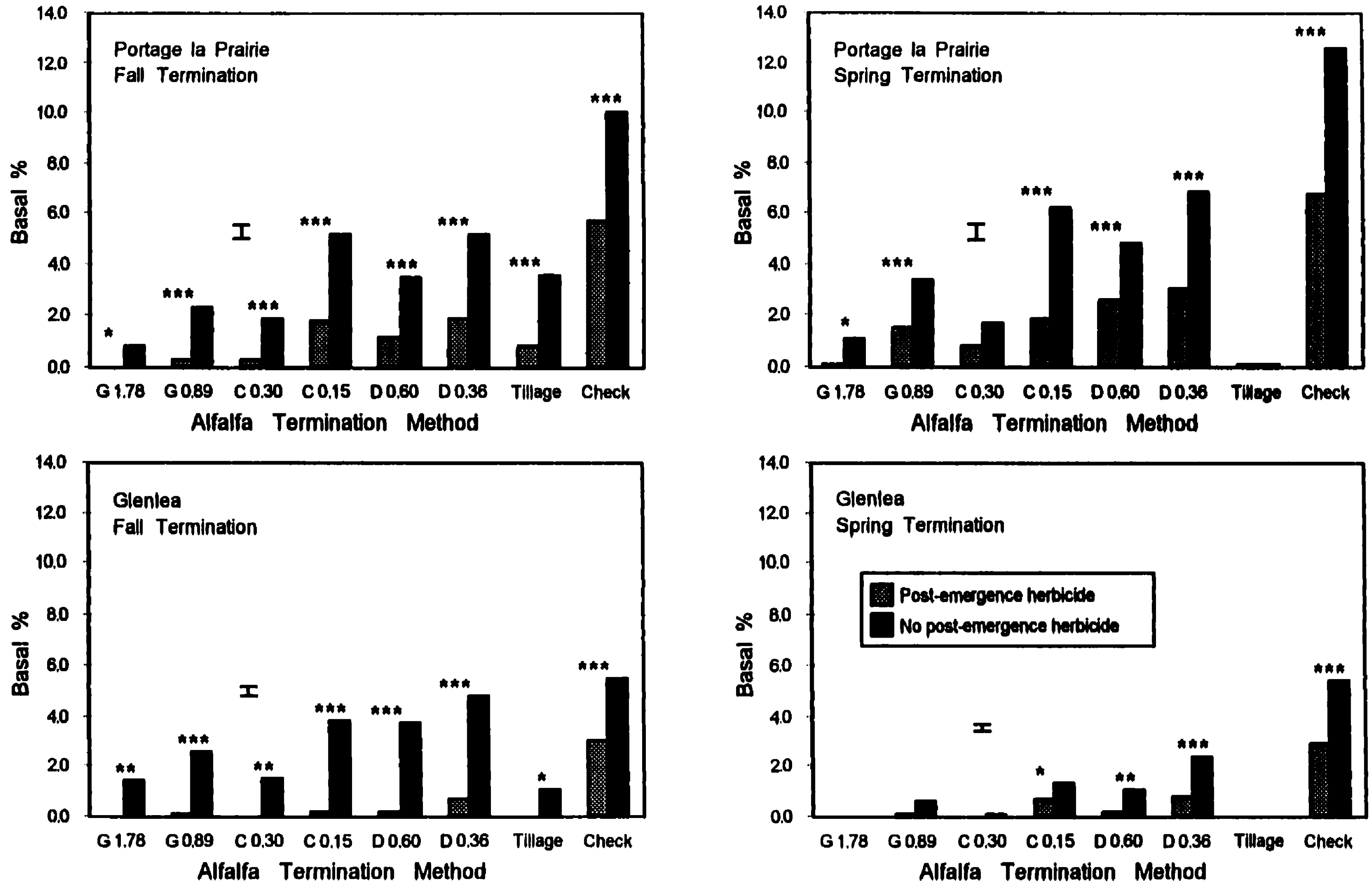

Figure 3.04. Alfalfa termination treatments, glyphosate (G), clopyralid (C), dicamba (D), and tillage ($p \leq 0.05, 0.01, 0.001$) contributing to alfalfa termination x post-emergence herbicide interactions on post-harvest alfalfa basal % at Portage la Prairie, MB., 1992, and Glenlea, MB., 1993, for fall and spring alfalfa termination. Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

Table 3.06. Combined analysis of post-grain harvest alfalfa basal crown area response to site, date, termination treatment, crop type, and post-emergence herbicide treatment effects at Portage la Prairie, MB and Glenlea, MB.

Main Effect	Post-grain harvest alfalfa basal rating	
	(%)	arcsin transformation§
Site		
Portage la Prairie	(3.0)	8.4a†
Glenlea	(1.4)	4.6b
LSD (0.05)		1.2
Date		
Fall	(2.3)	6.9a
Spring	(2.2)	6.0a
LSD (0.05)		1.2
Termination treatment		
Glyphosate 1.78‡	(0.4)	2.2g
Glyphosate 0.89	(1.4)	5.0e
Clopyralid 0.30	(0.8)	3.4f
Clopyralid 0.15	(2.6)	8.1c
Dicamba 0.60	(2.1)	6.9d
Dicamba 0.36	(3.2)	9.3b
Tillage	(0.7)	2.7fg
Untreated check	(6.5)	14.2a
LSD (0.05)		1.1
Crop		
Wheat	(2.2)	6.5a
Barley	(2.2)	6.4a
LSD (0.05)		0.4
Post-emergence herbicide		
Sprayed	(1.2)	4.1b
Unsprayed	(3.3)	8.9a
LSD (0.05)		0.3
Source of variation	df	ANOVA (P > F)
Replication	3	0.419
Site (S)	1	<0.001
Date (D)	1	0.151
S x D	1	0.029
pooled S x D error	9	
Termination (T)	7	<0.001
S x T	7	<0.001
D x T	7	<0.001
S x D x T	7	<0.001
pooled main plot error	84	
Crop (C)	1	0.878
S x C	1	0.438
D x C	1	0.158
T x C	7	0.459
S x D x C	1	0.864
S x T x C	7	0.433
D x T x C	7	0.125
S x D x T x C	7	0.645
pooled subplot error	96	
Post herbicide (P)	1	<0.001
S x P	1	0.928
D x P	1	<0.001
T x P	7	<0.001
C x P	1	0.246
S x D x P	1	<0.001
S x T x P	7	0.059
S x C x P	1	0.808
D x T x P	7	<0.001
D x C x P	1	0.832
T x C x P	7	0.193
S x D x T x P	7	0.028
S x D x C x P	1	0.765
S x T x C x P	7	0.434
D x T x C x P	7	0.890
S x D x T x C x P	7	0.929
pooled subsubplot error	192	

† Means (means from transformed data) followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

‡ kg a.i. ha^{-1}.

§ arcsin (sqrt(n/100)x180/PI.

3.4.2.4 Alfalfa Regrowth in the Following Spring

Alfalfa aerial biomass measurements at Portage la Prairie on May 28 (DOY-153) after the wheat and barley production year indicated significant termination treatment effects (Table 3.05). In the fall termination experiment, 1.78 kg a.i. ha^{-1} glyphosate and 0.30 kg a.i. ha^{-1} clopyralid continued to suppress alfalfa regrowth to a greater extent than the other treatments. In the spring termination experiment, tillage, 1.78 kg a.i. ha^{-1} glyphosate, and 0.30 kg a.i. ha^{-1} clopyralid suppressed alfalfa regrowth better than the other herbicide termination treatments. The post-emergence herbicide application suppressed 53.3 % of alfalfa escapes for fall termination, and 72.0 % of alfalfa escapes for spring termination, however, crop type did not significantly ($P > 0.05$) affect aerial dry matter.

Termination treatment x post-emergence herbicide interaction for alfalfa aerial regrowth the following May (DOY-153) at Portage la Prairie for spring termination indicated a differing response ($P \leq 0.05$) to the addition of post-emergence herbicide (Figure 3.05). Tillage, 1.78 kg a.i. ha^{-1} glyphosate, and 0.30 kg a.i. ha^{-1} clopyralid termination treatments showed no additional benefit to post-emergence herbicide application while the remaining termination treatments did.

3.4.3 In-Crop Weed Growth

Termination treatment was significant with regard to in-crop weed aerial biomass for the fall termination trial at Portage la Prairie, and both fall and spring termination trials at Glenlea (Table 3.07). In the fall alfalfa termination trial at Portage la Prairie, clopyralid at 0.30 kg a.i. ha^{-1} allowed greater annual weed growth to occur than the other termination treatments at the late crop tillering stage, except 0.89 kg a.i. ha^{-1} glyphosate, and 0.60 kg a.i. ha^{-1} dicamba. Greater annual weed growth for the 0.30 kg a.i. ha^{-1} clopyralid treatment was attributed to the fact that while it is more effective than most other treatments for terminating alfalfa, clopyralid is ineffective against certain weeds (MB

Agriculture, 1995). The most abundant weeds at the Portage la Prairie termination site were wild oats (*Avena fatua* L.), green foxtail (*Setaria viridis* (L.) Beauv.), lamb's quarters (*Chenopodium album* L.), and round leaved mallow (*Malva rotundifolia* L.). This ineffectiveness to control certain weeds, combined with the absence of abundant alfalfa to compete with the weeds, enabled greater weed growth to occur in this treatment. The suppressive effect of an alfalfa mulch against emerging weeds has been observed by Knake (1992). Knake (1984b) noted that the elimination of alfalfa allowed quackgrass to grow vigorously, adversely affecting corn growth. Moomaw and Martin (1990) also noted that successful alfalfa termination is a two fold process involving control of the alfalfa, and control of the subsequent invading grass and broadleaf weeds after the alfalfa is eliminated.

For the spring termination trial at Portage la Prairie, the 0.30 kg a.i. ha^{-1} clopyralid treatment allowed greater weed growth to occur than the untreated check at the early crop stem elongation stage (Table 3.07). The fall termination trial overall had greater weed growth compared to the spring trial, perhaps due to the suppressive effect of the alfalfa mulch on emerging weeds. The untreated check for both the fall and spring termination at Portage la Prairie had virtually no weed growth, probably because competition from the unsuppressed alfalfa reduced weed growth. For the fall termination trial at Glenlea, the 0.89 kg a.i. ha^{-1} glyphosate treatment allowed more weed growth to occur at early crop heading than the 1.78 kg a.i. ha^{-1} glyphosate, tillage, or untreated check treatments. The least amount of weed growth for the spring alfalfa termination at Glenlea occurred in the 0.30 kg a.i. ha^{-1} clopyralid, 0.15 kg a.i. ha^{-1} clopyralid, and tillage treatments at crop heading. The most abundant weed at the Glenlea site was dandelion (*Taraxacum officinale* Weber), which is effectively controlled with clopyralid (Hall and Sagan, 1993; Smith and Zollinger, 1993). The tillage treatment eliminated the dandelion population by destroying the entire plant and root system. The untreated check contained a high uncontrolled dandelion growth in the spring termination trial at Glenlea.

Crop type did not influence aerial weed dry weight accumulation for either fall or spring termination date, or either site (Table 3.07). Dew (1972) observed that barley was a more competitive crop against wild oats than wheat. The difference in results can be explained by the fact that the grain crops in the Portage la Prairie and Glenlea trials were influenced by a complex weed population, including alfalfa. Post-emergence herbicide application reduced weed growth for both fall and spring termination dates at both sites.

Significant termination treatment x post-emergence interactions for weed biomass were recorded for fall termination at Portage la Prairie and spring termination at Glenlea (Figure 3.06). Differences in herbicide effectiveness between sites may have been due to differences in the weed populations between sites. For the fall termination trial at Portage la Prairie, the 0.89 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid, and 0.60 kg a.i. ha^{-1} dicamba treatments benefited significantly from a post-emergence herbicide application. Less weed growth did not occur with the addition of the post-emergence herbicide treatment to the 0.15 kg a.i. ha^{-1} clopyralid and 0.36 kg a.i. ha^{-1} dicamba treatments, probably because these treatments were relatively ineffective for terminating alfalfa, therefore the alfalfa escapes suppressed weed growth without the addition of the post-emergence treatment. For the spring termination trial at Glenlea, the 0.89 kg a.i. ha^{-1} glyphosate, 0.60 kg a.i. ha^{-1} dicamba, and 0.36 kg a.i. ha^{-1} dicamba treatments significantly benefited from the addition of the post-emergence herbicide treatment. Adding the post-emergence herbicide to the 1.78 kg a.i. ha^{-1} glyphosate treatment did not reduce weed growth at either site. This treatment suppressed weed growth to the extent that the addition of the post-emergence herbicide treatment did not suppress weed growth further (Figure 3.06).

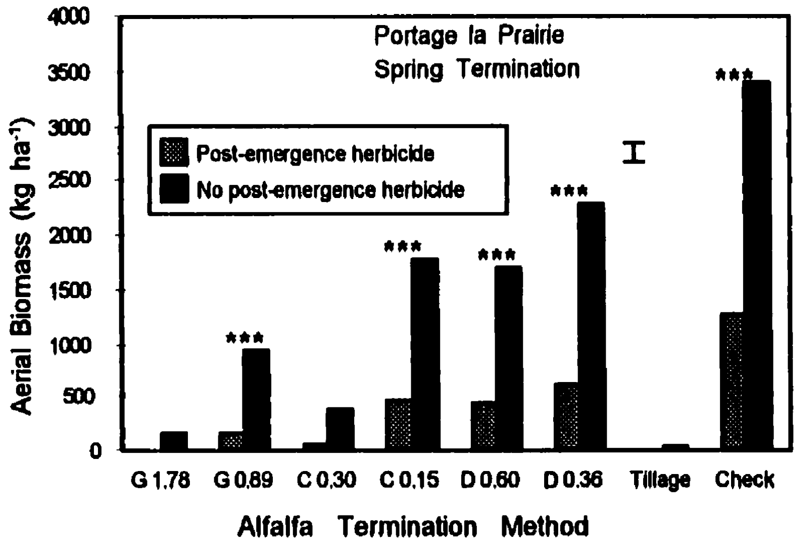

Figure 3.05. Alfalfa termination treatments, glyphosate (G), clopyralid (C), dicamba (D), and tillage ($p \leq 0.05, 0.01, 0.001$) contributing to alfalfa termination x post-emergence herbicide interactions on alfalfa aerial biomass accumulation in the following spring (DOY-153) for spring alfalfa termination at Portage la Prairie, MB., 1992. Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

Table 3.07. In-crop wheat and barley, and weed aerial biomass accumulation response to alfalfa termination treatment, crop type, and post-emergence herbicide treatments at Portage la Prairie, MB (1992) and Glenlea, MB (1993).

	Crop aerial biomass yield				Weed aerial biomass yield			
	Portage la Prairie		Glenlea		Portage la Prairie		Glenlea	
Main effect Date sampled (DOY)	Fall June 16 (168)	Spring July 17 (199)	Fall July 7 (188)	Spring Aug 11 (233)	Fall June 16 (168)	Spring July 17 (199)	Fall July 7 (188)	Spring Aug 11 (223)
	kg ha^{-1}				kg ha^{-1}			
Termination treatment								
Glyphosate 1.78‡	1,610a†	1,149a	2,417a	3,106b	37b	5ab	189bc	263b
Glyphosate 0.89	1,621a	924b	1,152b	3,026b	68ab	7ab	468a	274ab
Clopyralid 0.30	1,495ab	737c	1,173b	2,600b	125a	13a	265ab	11c
Clopyralid 0.15	604d	579d	406cd	1,917c	18b	8ab	299ab	71c
Dicamba 0.60	1,350b	522d	753bc	1,684c	67ab	10ab	325ab	383ab
Dicamba 0.36	834c	577d	300cd	1,858c	26b	4ab	337ab	335ab
Tillage	1,515a	1,220a	2,717a	4,086a	21b	5ab	23c	32c
Untreated check	21e	15e	24d	349d	0b	0b	133bc	409a
LSD (0.05)	146	123	635	527	71	12	222	140
Crop								
Wheat	976b	618b	1,101a	2,231a	56a	8a	251a	216a
Barley	1,287a	813a	1,134a	2,426a	35a	5a	258a	229a
LSD (0.05)	83	76	171	209	22	6	87	73
Post-emergence herbicide								
Sprayed	1,145a	713a	1,172a	2,396a	5b	2b	201b	147b
Unsprayed	1,117a	717a	1,063a	2,261a	85a	11a	309a	298a
LSD (0.05)	68	51	129	163	30	4	62	44
Source of variation				ANOVA (P > F)				
Termination (T)	<0.001	<0.001	<0.001	<0.001	0.033	0.492	0.015	<0.001
Crop (C)	<0.001	<0.001	0.694	0.066	0.067	0.226	0.651	0.713
Post herbicide (P)	0.422	0.869	0.094	0.102	<0.001	<0.001	0.003	<0.001
T x C	0.068	0.020	0.578	0.218	0.155	0.222	0.277	0.641
T x P	0.022	0.849	0.253	0.558	0.005	0.498	0.199	<0.001
C x P	0.863	0.383	0.656	0.673	0.251	0.106	0.669	0.662
T x C x P	0.645	0.621	0.649	0.809	0.432	0.616	0.883	0.287

† Means within each date and location, followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).
‡ kg a.i. ha^{-1}.

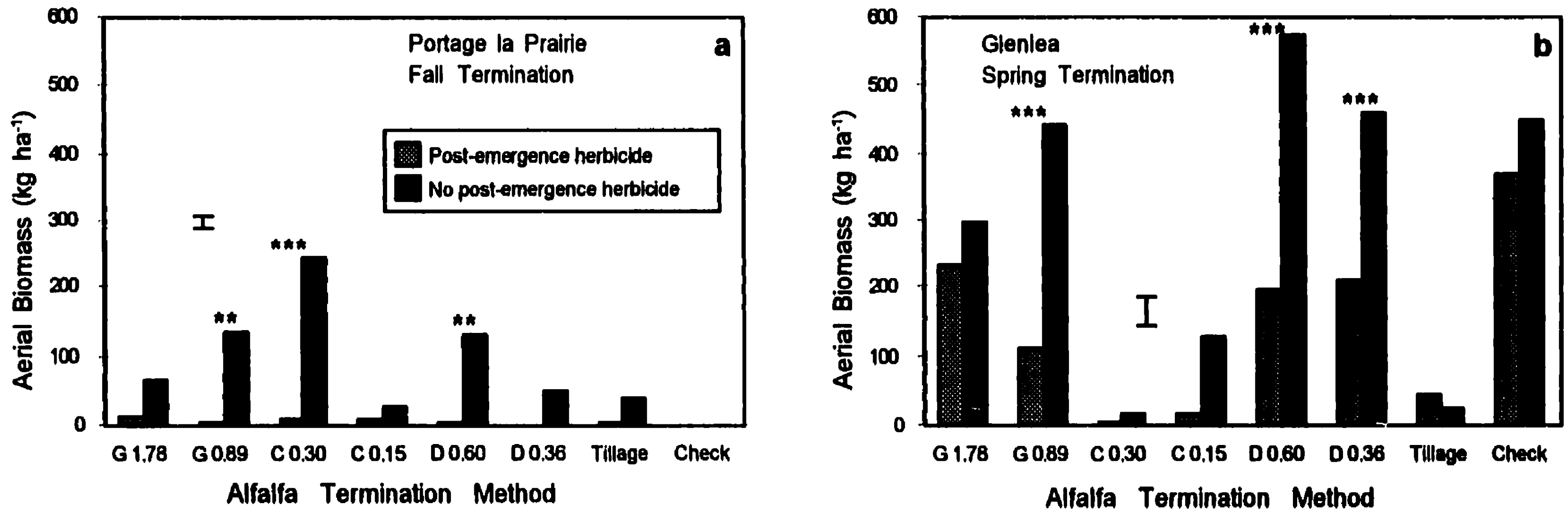

Figure 3.06. Alfalfa termination treatments, glyphosate (G), clopyralid (C), dicamba (D), and tillage ($p \leq 0.05, 0.01, 0.001$) contributing to alfalfa termination x post-emergence herbicide interactions on in-crop weed aerial biomass accumulation at late crop tillering for fall alfalfa termination at Portage la Prairie, MB., 1992 (a), and at early crop heading for spring alfalfa termination at Glenlea, MB., 1993 (b). Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

3.4.4 Crop Parameters

3.4.4.1 Crop Emergence

Crop emergence was influenced by termination treatment in all experiments (Table 3.08). As expected, the untreated check resulted in the lowest crop establishment for both dates at both sites. Untreated alfalfa is known to compete vigorously with the emerging crop for available light and soil moisture, resulting in decreased crop establishment (Sprague, 1952). The 1.78 kg a.i. ha^{-1} glyphosate treatment provided better crop emergence than 0.15 kg a.i. ha^{-1} clopyralid for fall termination at Portage la Prairie, probably because of better alfalfa suppression. For the spring alfalfa termination at Portage la Prairie, all herbicide termination treatments provided better crop emergence than tillage, possibly due to higher seedbed moisture content in the herbicide treatments compared to the tillage. The fall terminated alfalfa at Glenlea had better crop emergence with the 0.30 kg a.i. ha^{-1} clopyralid and tillage treatments, compared to 0.15 kg a.i. ha^{-1} clopyralid, 0.60 kg a.i. ha^{-1} dicamba, and 0.36 kg a.i. ha^{-1} dicamba, possibly due to better alfalfa suppression. Higher plant populations of barley compared with wheat were observed for spring alfalfa termination at both sites. This was probably due to the late May planting date, which may have been less favorable to wheat emergence. No termination treatment x crop interactions were observed in that trial.

Combined analysis of fall and spring termination indicated that date of termination was significant for crop establishment at both Portage la Prairie (Table 3.10) and Glenlea (Table 3.11). Fall termination resulted in better emergence than spring termination at Portage la Prairie, whereas the opposite trend was observed at Glenlea. Dry soil conditions at the time of planting for the spring termination experiment at Portage la Prairie (Table 3.03) may have been a factor in reducing crop emergence at that time. Results compiled by Smith et al. (1992a) indicated that delayed crop emergence and subsequently delayed development was associated with spring alfalfa/grass termination with herbicides. Greater crop emergence in the spring termination experiment at Glenlea compared to the fall trial, may have been due to warmer soil conditions associated with later seeding in the heavy clay soil.

3.4.4.2 In-Crop Aerial Biomass Yield

In-crop aerial crop dry weight accumulation was influenced by termination treatment for both termination dates at both sites (Table 3.07). In general, the two glyphosate treatments, as well as the tillage resulted in the highest crop aerial biomass production in these trials. Glyphosate at 1.78 kg a.i. ha^{-1} and 0.89 kg a.i. ha^{-1}, and tillage enabled higher aerial crop dry weight accumulation than 0.15 kg a.i. ha^{-1} clopyralid, 0.60 kg a.i. ha^{-1} dicamba, and 0.36 kg a.i. ha^{-1} dicamba at late tillering for fall alfalfa termination at Portage la Prairie. The glyphosate at 1.78 kg a.i. ha^{-1} and tillage treatments enabled greater aerial crop growth to occur than the remaining termination treatments for spring alfalfa termination at early stem elongation at Portage la Prairie, and fall alfalfa termination at early crop heading at Glenlea. For the Glenlea spring termination, tillage termination resulted in the highest ($P \leq 0.05$) crop aerial biomass levels at heading, followed by a number of the more effective herbicide treatments (1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, and 0.30 kg a.i. ha^{-1} clopyralid), followed by all other treatments (Table 3.07). As expected, the untreated check produced less crop aerial dry weight than the termination treatments in most cases. In the fall termination treatment at Glenlea, the 0.15 kg a.i. ha^{-1} clopyralid and 0.36 kg a.i. ha^{-1} dicamba treatments produced similar aerial crop dry weight accumulation as the untreated control, indicating the weakness of these herbicide treatments.

Crop type influenced in-crop aerial dry weight accumulation at Portage la Prairie ($P \leq 0.05$), but not at Glenlea. Barley produced greater aerial dry weight than wheat for both fall and spring termination treatments at Portage la Prairie (Table 3.07). There was no influence by post-emergence herbicide on in-crop aerial biomass ($P > 0.05$).

The only termination treatment x crop type interaction for in-crop aerial crop biomass was recorded for the spring alfalfa termination at Portage la Prairie (Figure 3.07b). In this case, barley produced more aerial dry weight than wheat in the tillage and 1.78 kg a.i. ha^{-1} glyphosate treatments only. Therefore, it appeared that the greater biomass advantage of barley over wheat was expressed only in the two most effective alfalfa termination treatments. A termination treatment x post-emergence herbicide interaction for late tillering aerial crop biomass occurred for fall termination at Portage la Prairie (Figure 3.07a). Clopyralid at 0.15 kg a.i. ha^{-1} was the only termination treatment excluding the untreated check that benefited from the addition of post-emergence herbicide, probably because the initial herbicide treatment resulted in inferior alfalfa control.

3.4.4.3 Spike Population Density

Spike density is an important determinant of grain yield in cereal crops (Hay and Walker, 1989). Spike density was influenced by termination treatment for both termination dates at both sites (Table 3.09). The untreated check had the lowest spike density in all four experiments. Glyphosate at 1.78 kg a.i. ha^{-1} was among the best alfalfa termination treatments with regard to high spike number, in all four experiments. Both 0.60 kg a.i. ha^{-1} dicamba and 0.89 kg a.i. ha^{-1} glyphosate treatments enabled a similar spike density to that of 1.78 kg a.i. ha^{-1} glyphosate for spring termination at Portage la Prairie, and Glenlea. Clopyralid at 0.30 kg a.i. ha^{-1} provided a similar spike density to that of 1.78 kg a.i. ha^{-1} glyphosate for spring termination at Portage la Prairie, and for both fall and spring termination at Glenlea. Dicamba at 0.60 kg a.i. ha^{-1} provided a similar spike density to that of 1.78 kg a.i. ha^{-1} glyphosate for spring termination at both Portage la Prairie and Glenlea.

Spike density was influenced by crop type for fall termination at both Portage la Prairie and Glenlea, and spring termination at Glenlea (Table 3.09). Barley produced a higher spike density for fall termination at Portage la Prairie, while wheat produced higher spike densities for both fall and spring termination at Glenlea. The post-emergence herbicide treatment influenced spike number such that all four experiments had higher spike densities when the post-emergence herbicide was added (Table 3.09).

A termination treatment x crop type interaction for spike densities for the fall termination at Portage la Prairie (Figure 3.08d), indicated that 0.15 kg a.i. ha^{-1} clopyralid and the untreated check were the only treatments in which barley produced a greater spike count than wheat (Figure 3.08d). Barley was perhaps better able to cope with the higher competition from alfalfa in these treatments than wheat. A second termination treatment x crop type interaction for spring termination at Glenlea (Figure 3.09) showed that wheat produced more spikes m^{-2} than barley for all termination treatments except 0.15 kg a.i. ha^{-1} clopyralid and the untreated check. This is a similar response to that of fall termination at Portage la Prairie such that wheat tended to produce similar, or higher spike number than barley under less alfalfa competition, and similar or lower spike number than barley under higher alfalfa competition.

Termination treatment x post-emergence herbicide interactions for spike density occurred for fall (Figure 3.08a) and spring (Figure 3.08b) termination at Portage la Prairie, and spring termination at Glenlea (Figure 3.08c). For fall termination at Portage la Prairie, this interaction showed that adding post-emergence herbicide increased spike densities in all termination treatments except 1.78 kg a.i. ha^{-1} glyphosate. This observation suggests that 1.78 kg a.i. ha^{-1} glyphosate was one of the best treatments for terminating alfalfa, therefore the application of the post-emergence herbicide treatment provided no additional benefit. The termination treatment x post-emergence herbicide interaction for spring termination at Portage la Prairie was attributed to the fact that adding post-emergence herbicide only increased spike density for the weaker treatments (0.15 kg a.i. ha^{-1} clopyralid and untreated control) (Figure 3.08b). A similar observation was made for the spring alfalfa termination at Glenlea (Figure 3.08c). Without the post-emergence herbicide treatment, the termination treatments (0.89 kg a.i. ha^{-1} glyphosate, 0.60 kg a.i. ha^{-1} dicamba, and 0.36 kg a.i. ha^{-1} dicamba) provided the lowest spike count of all the termination treatments excluding the untreated check.

Crop spike densities were similar for fall and spring alfalfa termination in the combined analysis of the Portage la Prairie data (Table 3.10). The 1.78 kg a.i. ha^{-1} glyphosate termination treatment provided the greatest spike density, although not different than the 0.89 kg a.i. ha^{-1} glyphosate treatment, followed by 0.30 kg a.i. ha^{-1} clopyralid and tillage treatments. The lowest spike densities were a result of the 0.36 kg a.i. ha^{-1} dicamba and 0.15 kg a.i. ha^{-1} clopyralid treatments. No effect of crop type was indicated by the combined analysis for crop spike density ($P > 0.05$). Post-emergence herbicide was effective for increasing spike density at Portage la Prairie (Table 3.10). Date x termination treatment interactions significantly affected spike density ($P \leq 0.05$) at Portage la Prairie, indicating a different response by treatments for each date of termination (Table 3.10). The more effective herbicide treatments (1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, and 0.30 kg a.i. ha^{-1} clopyralid) produced greater spike density than the tillage treatment for fall alfalfa termination, however the opposite occurred for spring alfalfa termination (Table 3.09). Date x crop interactions for spike density (Table 3.10) occurred as a result of a greater barley spike density for the fall termination trial, and a greater wheat spike density for the spring termination trial (Table 3.09). The occurrence of date x post-emergence herbicide application interactions (Table 3.10) was a result of post-emergence herbicide application being considerably more effective for the fall alfalfa termination trial, than for the spring termination experiment (Table 3.09).

Combined analysis for fall and spring alfalfa termination at Glenlea indicated that spike density was influenced by the date of alfalfa termination (Table 3.11), where spring termination provided a greater spike density. All termination treatments provided greater spike density than the untreated check. The greatest spike densities occurred with the

1.78 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid and tillage treatments. Crop type was significant at Glenlea indicating that wheat had higher spike counts than barley. The post-emergence herbicide treatment effectively increased spike density (Table 3.11). Significant date x termination treatment interactions were likely a result of greater spike densities for all termination treatments in the spring alfalfa suppression trial (Table 3.11; Table 3.09). Interactions of date x crop at the Glenlea trials occurred as a result of a much greater wheat spike density increase over barley for the spring termination trial, than for the fall termination trial (Table 3.09). Date x post-emergence herbicide interactions were significant (Table 3.11), which may have been due to a greater increase in spike density with the post-emergence herbicide application than without it, in the fall termination trial compared to the spring termination trial (Table 3.09).

3.4.4.4 Grain Yield

Grain yield differed significantly with termination treatment (Table 3.09). All treatments gave significantly higher grain yields than the untreated check for both dates at both sites except for the fall termination at Glenlea where the 0.36 kg a.i. ha^{-1} dicamba achieved a similar grain yield to that of the untreated check. Competition from non-terminated perennial sod, including alfalfa has been found to substantially reduce yields of corn (Buhler et al., 1988; Carreker et al., 1972; Elkins et al, 1978) and wheat (Clayton, 1982).

For fall alfalfa termination, the highest grain yield was attained with treatments of 1.78 kg a.i. ha^{-1} glyphosate at Portage la Prairie, and with 1.78 kg a.i. ha^{-1} glyphosate, and tillage at Glenlea. For spring alfalfa termination, the highest grain yield at both sites was achieved by the tillage treatment, followed by both glyphosate treatments, and the high rate of clopyralid. Dicamba at 0.60 kg a.i. ha^{-1} and 0.36 kg a.i. ha^{-1}, and clopyralid at 0.15 kg a.i. ha^{-1} resulted in the lowest grain yields.

Grain yield was affected by crop type as shown by greater barley yield than wheat for both dates at both sites (Table 3.09). Grain yield was also consistently increased by the application of the post-emergence herbicide treatment (Table 3.09). Knake et al. (1984) observed that the greatest corn yields were derived from an alfalfa termination treatment, which included a post-emergence treatment with dicamba at 0.56 kg ha^{-1}, in addition to the initial 2.24 kg ha^{-1} glyphosate application.

Termination treatment x crop type interactions for grain yield were observed in three of four trials (Table 3.09). The termination treatment x crop type interaction for fall termination at Glenlea indicated that barley yielded more than wheat in the better termination treatments (Figure 3.10c). The significant termination treatment x crop type interactions for grain yield at both Portage la Prairie and Glenlea spring termination trials were attributed to higher yields for barley in all treatments except the untreated check, where wheat and barley yields were similar (Figure 3.10b; Figure 3.10d). Among termination treatments, the tillage treatment resulted in the greatest yield advantage of barley over wheat.

Termination treatment x post-emergence herbicide interactions for grain yield were observed for both dates at Portage la Prairie (Figure 3.07c; Figure 3.07d). Mercurio and Buhler (1985) recommended that no-till corn production required sod species to be controlled nearly completely, and they suggested that fall and early preplant herbicide termination would accomplish adequate sod control, unlike that of preplant termination alone. In the case of fall termination, all treatments with the exception of 1.78 kg a.i. ha^{-1} glyphosate, had higher grain yields where post-emergence herbicide was used (Figure 3.07c). A similar observation for the spring termination date at Portage la Prairie indicated that for 1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid, and 0.60 kg a.i. ha^{-1} dicamba, adding a post-emergence herbicide treatment did not increase yield (Figure 3.07d).

A significant crop x post-emergence herbicide interaction for grain yield for fall alfalfa termination at Portage la Prairie indicated that adding the post-emergence herbicide increased grain yield more for barley than for wheat (Figure 3.10a), probably because barley has a greater yield capability than wheat.

Combined analysis for fall and spring alfalfa termination for grain yield at Portage la Prairie indicated that no yield difference between termination dates existed (Table 3.10). Date of alfalfa termination was however, significant at Glenlea, indicating a higher yield potential for fall termination (Table 3.11). Termination treatment was significant for grain yield at both Portage la Prairie (Table 3.10) and Glenlea (Table 3.11), and showed that all termination treatments enabled significantly higher grain yield to occur than with the untreated check. Glyphosate at 1.78 kg a.i. ha^{-1} provided the highest grain yield of all termination treatments, including tillage (Portage la Prairie trials only), which is an indication that grain crop yield can be maintained by the use of herbicides to terminate alfalfa. Glyphosate at 0.89 kg a.i. ha^{-1}, 0.30 kg a.i. ha^{-1} clopyralid, and the tillage termination treatments achieved similar grain yields at the Portage la Prairie trials, which further supports the role of herbicides in alfalfa termination.

Date x termination treatment in the combined analysis for grain yield was significant at the Portage la Prairie experiments (Table 3.10). The better herbicide treatments, namely 1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid, and 0.60 kg a.i. ha^{-1} dicamba achieved greater crop yields for fall termination than for spring termination, however the opposite occurred for the weaker herbicide treatments (0.15 kg a.i. ha^{-1} clopyralid, and 0.36 kg a.i. ha^{-1} dicamba) and tillage treatments (Table 3.09). This may have been due to the competition by the slowly dying alfalfa to the grain crop in the spring termination trial during the time span in which the herbicides translocated within the alfalfa. This did not occur with the tillage treatment in the spring termination trial because alfalfa kill was not extended over a period of time. The less effective herbicide treatments (clopyralid 0.15 kg a.i. ha^{-1}, and dicamba 0.36 kg a.i. ha^{-1}) had greater grain yield in the spring termination treatments, probably because some die back of alfalfa occurred before alfalfa regrowth resumed, whereas with the fall suppression, alfalfa regrowth occurred immediately in the spring at the time of crop seeding. Significant date x post-emergence herbicide application (Table 3.10) occurred as a result of a greater yield increase in fall suppression with the addition of a post-emergence herbicide treatment, compared to that of spring suppression (Table 3.09). This was probably due to the interference of the spring applied herbicide treatments with the post-emergence herbicide, in which the alfalfa could not absorb nor translocate the post-emergence herbicide, due to the prolonged suppressive effect from the initial termination treatment.

Significant date x termination interactions for grain yield at Glenlea (Table 3.11) also displayed higher yield potential for fall alfalfa termination with the better herbicide treatments (1.78 kg a.i. ha^{-1} glyphosate, 0.89 kg a.i. ha^{-1} glyphosate, 0.30 kg a.i. ha^{-1} clopyralid, and 0.60 kg a.i. ha^{-1} dicamba), similar to that of the Portage la Prairie trials (Table 3.09). However, unlike the Portage la Prairie experiments, the tillage treatment at the Glenlea trials enabled a higher grain increase to occur with fall suppression (Table 3.09). Date x post-emergence herbicide application interactions did not occur ($P>0.05$) at Glenlea (Table 3.11), indicating that post-emergence herbicide application increased yield similarly but significantly for both dates (Table 3.09). Date x crop interactions occurred for grain yield at Glenlea (Table 3.11) due to a greater increase in barley yield over that of wheat for the fall termination trial, compared to the spring termination trial (Table 3.09).

Table 3.08. Crop emergence response to alfalfa termination treatment, crop type, and post-emergence herbicide treatments at Portage la Prairie, MB (1992) and Glenlea, MB (1993).

	Crop emergence			
	Portage la Prairie		Glenlea	
Main effect	Fall	Spring	Fall	Spring
	plants m^{-2}			
Termination treatment				
Glyphosate 1.78‡	214.6a†	178.6ab	193.3ab	208.7a
Glyphosate 0.89	196.2ab	181.2a	182.5ab	199.9a
Clopyralid 0.30	196.2ab	168.1ab	205.2a	195.6ab
Clopyralid 0.15	193.3b	166.0ab	173.2b	184.5ab
Dicamba 0.60	207.9ab	158.6b	169.3b	197.8a
Dicamba 0.36	200.5ab	171.2ab	168.5b	173.8ab
Tillage	200.5ab	107.0c	202.1a	195.2ab
Untreated check	172.4c	125.9c	125.3c	158.1b
LSD (0.05)	19.1	20.4	27.1	37.7
Crop				
Wheat	194.8a	148.0b	172.3a	176.4b
Barley	200.6a	166.2a	182.6a	202.0a
LSD (0.05)	8.3	9.0	19.0	13.3
Post-emergence herbicide				
Sprayed	-§	-	-	-
Unsprayed	-	-	-	-
LSD (0.05)	-	-	-	-
Source of variation	ANOVA (P > F)			
Termination (T)	0.011	<0.001	<0.001	0.181
Crop (C)	0.163	<0.001	0.278	<0.001
Post herbicide (P)	-	-	-	-
T x C	0.933	0.939	0.714	0.821
T x P	-	-	-	-
C x P	-	-	-	-
T x C x P	-	-	-	-

† Mean plant number within each date and location, followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).
‡ kg a.i. ha^{-1}.
§ Crop emergence was evaluated prior to post-emergence herbicide application.

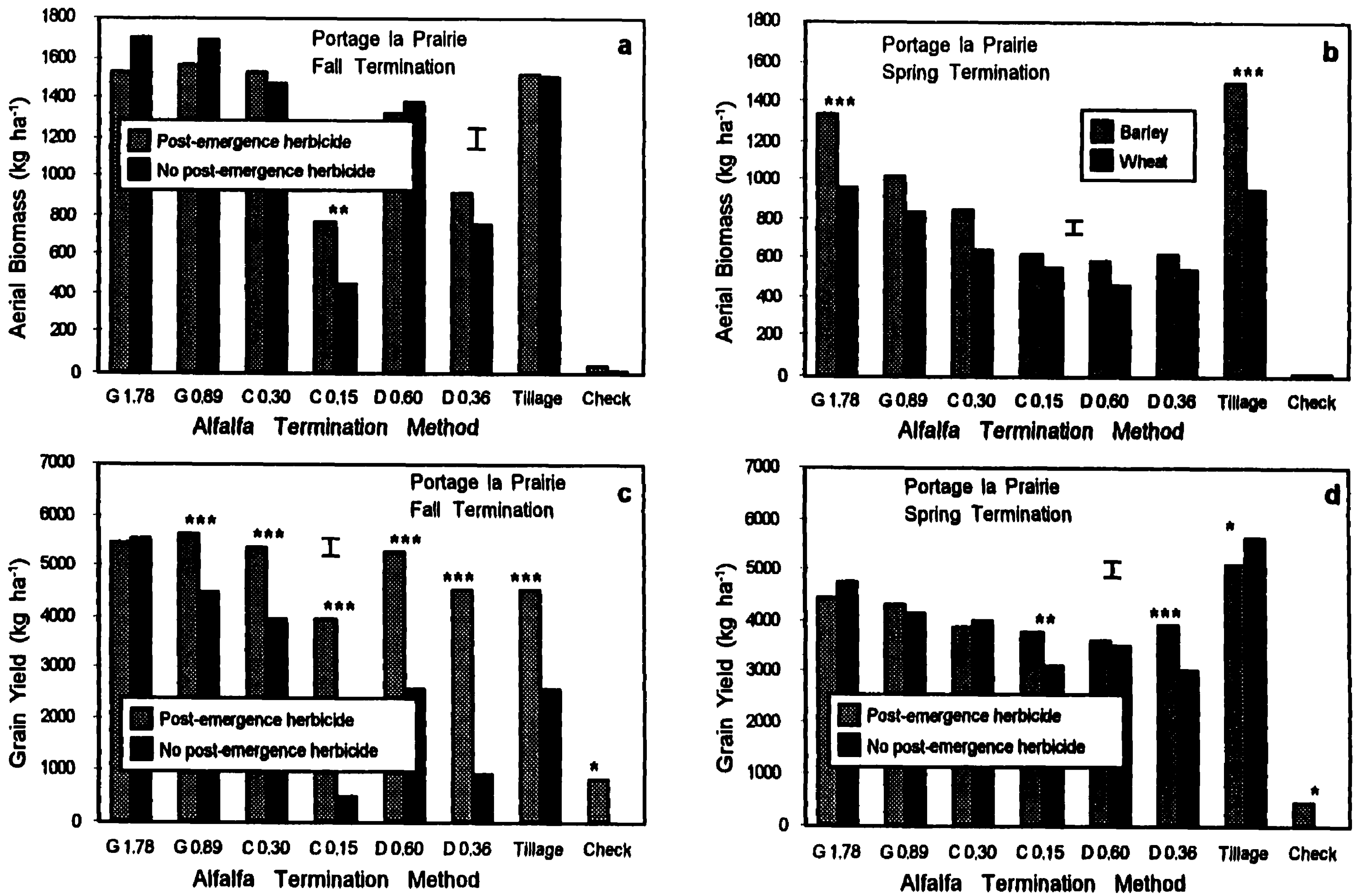

Figure 3.07. Alfalfa termination treatments at Portage la Prairie, MB., 1992, contributing to alfalfa termination x post-emergence herbicide interactions ($p \leq 0.05$, 0.01, 0.001) on crop aerial biomass at late tillering for fall alfalfa termination (a), and grain yield for fall (c) and spring (d) alfalfa termination; alfalfa termination x crop interactions on crop aerial biomass at early stem elongation for spring alfalfa termination (b). Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

Table 3.09. Spike density and grain yield response to alfalfa termination treatment, crop type, and post-emergence herbicide treatments at Portage la Prairie, MB (1992) and Glenlea, MB (1993).

	Spike density				Grain yield			
	Portage la Prairie		Glenlea		Portage la Prairie		Glenlea	
Main effect	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
	no. m^{-2}				kg ha^{-1}			
Termination treatment								
Glyphosate 1.78‡	530.1a†	468.2ab	367.8a	472.3abc	5,474a	4,570b	2,400a	1,346b
Glyphosate 0.89	484.7b	488.3a	273.0b	441.1bcd	5,052ab	4,210bc	1,622b	1,145b
Clopyralid 0.30	487.1b	446.2b	356.9a	528.9a	4,640b	3,917cd	1,763b	1,233b
Clopyralid 0.15	295.1e	413.3c	257.6b	420.0bcd	2,228d	3,424e	866c	740c
Dicamba 0.60	430.2c	435.9bc	239.1b	389.2cd	3,913c	3,541de	825cd	807c
Dicamba 0.36	341.6d	449.5b	171.5c	381.7d	2,719d	3,465e	368de	655c
Tillage	426.8c	497.5a	366.2a	478.3ab	3,525c	5,360a	2,444a	1,708a
Untreated check	93.2f	57.1d	105.0d	123.6e	419e	228f	47e	60d
LSD (0.05)	41.2	32.6	57.4	83.3	587	428	465	289
Crop								
Wheat	376.9b	414.1a	282.2a	455.5a	2,910b	2,968b	883b	700b
Barley	395.3a	399.9a	252.1b	353.3b	4,082a	4,211a	1,701a	1,224a
LSD (0.05)	17.6	18.0	22.8	27.5	307	169	1.6	143
Post-emergence herbicide								
Sprayed	464.3a	423.8a	312.5a	419.1a	4,437a	3,666a	1,364a	1,007a
Unsprayed	307.9b	390.2b	221.7b	389.6b	2,555b	3,513b	1,220b	916b
LSD (0.05)	21.4	15.9	18.4	14.5	225	150	122	48
Source of variation	ANOVA (P > F)							
Termination (T)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Crop (C)	0.040	0.117	0.012	<0.001	<0.001	<0.001	<0.001	<0.001
Post herbicide (P)	<0.001	<0.001	<0.001	<0.001	<0.001	0.045	0.021	<0.001
T x C	0.049	0.562	0.332	0.037	0.370	<0.001	<0.001	0.012
T x P	<0.001	0.033	0.288	0.023	<0.001	<0.001	0.158	0.212
C x P	0.072	0.369	0.180	0.969	0.019	0.113	0.229	0.577
T x C x P	0.102	0.722	0.673	0.155	0.185	0.876	0.193	0.381

† Means within each date and location, followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

‡ kg a.i. ha^{-1}.

Table 3.10. Combined analysis of crop emergence, crop spike density, and grain yield response to date, termination treatment, crop type, and post-emergence herbicide treatment effects at Portage la Prairie, MB (1992).

Main effect	Crop emergence	Crop spike density	Grain yield
	no. m^{-2}		kg ha^{-1}
Date			
Fall	197.7a†	386.1a	3496a
Spring	157.1b	407.0a	3589a
LSD (0.05)	16.0	54.7	285
Termination treatment			
Glyphosate 1.78‡	196.6a	499.2a	5022a
Glyphosate 0.89	188.7ab	486.5ab	4631b
Clopyralid 0.30	182.1b	466.6b	4279b
Clopyralid 0.15	179.7b	354.2e	2826d
Dicamba 0.60	183.3ab	433.1c	3727c
Dicamba 0.36	185.8ab	395.6d	3092d
Tillage	153.7c	462.2b	4442b
Untreated check	149.2c	75.1f	323e
LSD (0.05)	13.6	25.5	353
Crop			
Wheat	171.4b	395.5a	2939b
Barley	183.4a	397.6a	4147a
LSD (0.05)	6.0	12.2	171
Post-emergence herbicide			
Sprayed	-§	444.1a	4052a
Unsprayed	-	349.1b	3034b
LSD (0.05)	-	13.2	133
Source of variation		ANOVA (P > F)	
Date (D)	0.004	0.311	0.373
Termination (T)	<0.001	<0.001	<0.001
D x T	<0.001	<0.001	<0.001
Crop (C)	<0.001	0.724	<0.001
D x C	0.041	0.010	0.679
T x C	0.809	0.160	0.022
D x T x C	0.997	0.143	0.117
Post herbicide (P)	-	<0.001	<0.001
D x P	-	<0.001	<0.001
T x P	-	<0.001	<0.001
C x P	-	0.046	0.004
D x T x P	-	<0.001	<0.001
D x C x P	-	0.351	0.264
T x C x P	-	0.518	0.573
D x T x C x P	-	0.072	0.162

† Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

‡ kg a.i. ha^{-1}.

§ Crop emergence was evaluated prior to post-emergence herbicide application.

Table 3.11. Combined analysis of crop emergence, spike density, and grain yield response to date, termination treatment, crop type, and post-emergence herbicide treatment effects at Glenlea, MB (1993).

Main effect	Crop emergence	Crop spike density	Grain yield
	no. m^{-2}	no. m^{-2}	kg ha^{-1}
Date			
Fall	177.4b†	267.1b	1292a
Spring	189.2a	404.4a	962b
LSD (0.05)	8.7	61.3	194
Termination treatment			
Glyphosate 1.78‡	201.0a	420.1a	1873a
Glyphosate 0.89	191.2ab	357.0b	1384b
Clopyralid 0.30	200.4a	442.9a	1498b
Clopyralid 0.15	178.9ab	338.8b	803c
Dicamba 0.60	183.6ab	314.2bc	816c
Dicamba 0.36	171.2b	276.6c	511d
Tillage	198.6a	422.3a	2076a
Untreated check	141.7c	114.3d	54e
LSD (0.05)	22.5	49.1	266
Crop			
Wheat	174.3b	368.8a	791b
Barley	192.3a	302.7b	1463a
LSD (0.05)	11.3	17.4	107
Post-emergence herbicide			
Sprayed	-§	365.8a	1186a
Unsprayed	-	305.7b	1068b
LSD (0.05)	-	11.6	65
<u>Source of variation</u>		<u>ANOVA (P > F)</u>	
Date (D)	0.023	0.006	0.012
Termination (T)	<0.001	<0.001	<0.001
D x T	0.495	0.014	<0.001
Crop (C)	0.003	<0.001	<0.001
D x C	0.178	<0.001	0.008
T x C	0.797	0.013	<0.001
D x T x C	0.707	0.331	0.223
Post herbicide (P)	-	<0.001	<0.001
D x P	-	<0.001	0.414
T x P	-	0.019	0.086
C x P	-	0.276	0.184
D x T x P	-	0.438	0.257
D x C x P	-	0.298	0.358
T x C x P	-	0.275	0.136
D x T x C x P	-	0.568	0.287

† Means (means from transformed data) followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test (P ≤ 0.05).
‡ kg a.i. ha^{-1}.
§ Crop emergence was evaluated prior to post-emergence herbicide application.

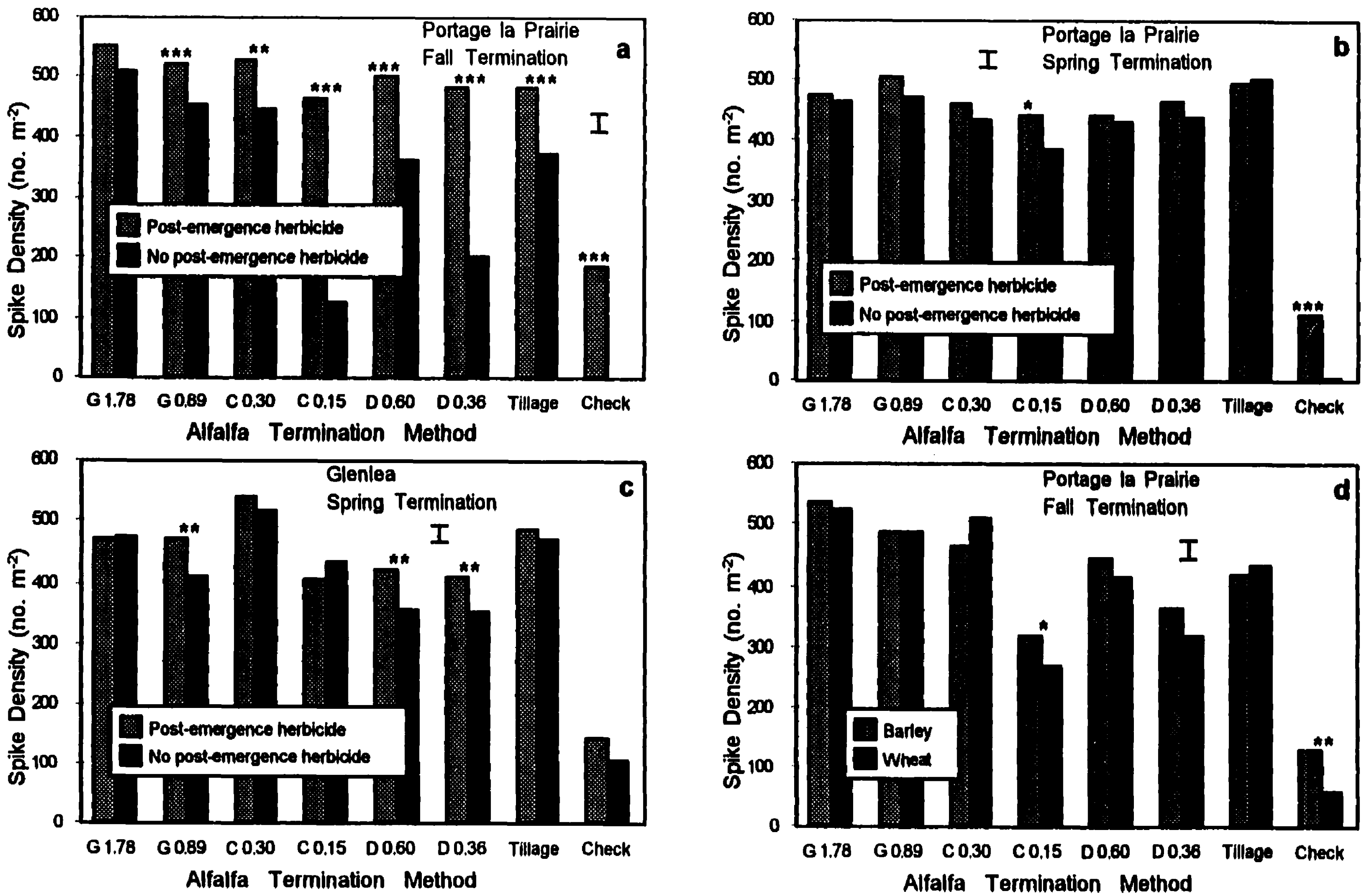

Figure 3.08. Alfalfa termination treatments, glyphosate (G), clopyralid (C), dicamba (D), and tillage ($p \leq 0.05$, 0.01, 0.001) contributing to alfalfa termination x post-emergence herbicide interactions (a, b, and c) and alfalfa termination x crop interactions (d) on crop spike density (no. m^{-2}) at Portage la Prairie, MB., 1992, and Glenlea, MB., 1993, for fall and spring alfalfa termination. Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

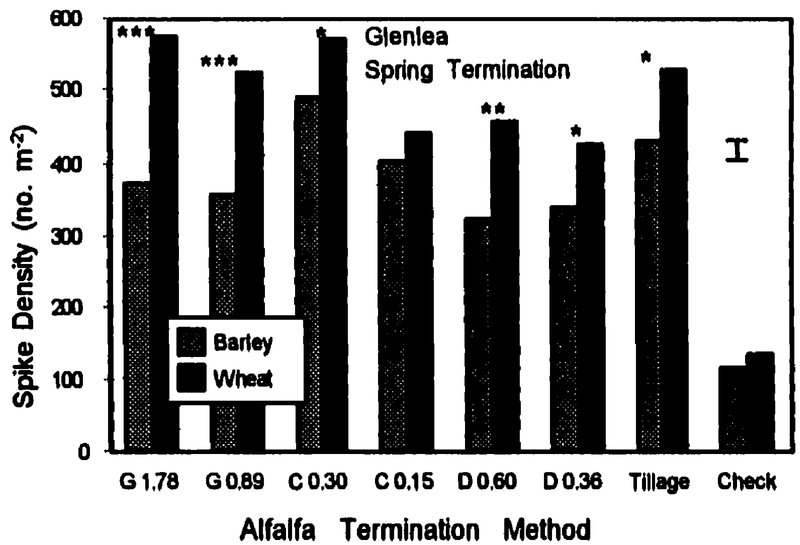

Figure 3.09. Alfalfa termination treatments, glyphosate (G), clopyralid (C), dicamba (D), and tillage ($p \leq 0.05$, 0.01, 0.001) contributing to alfalfa termination x crop interactions on crop spike density (no. m^{-2}) for spring alfalfa termination at Glenlea, MB., 1993. Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

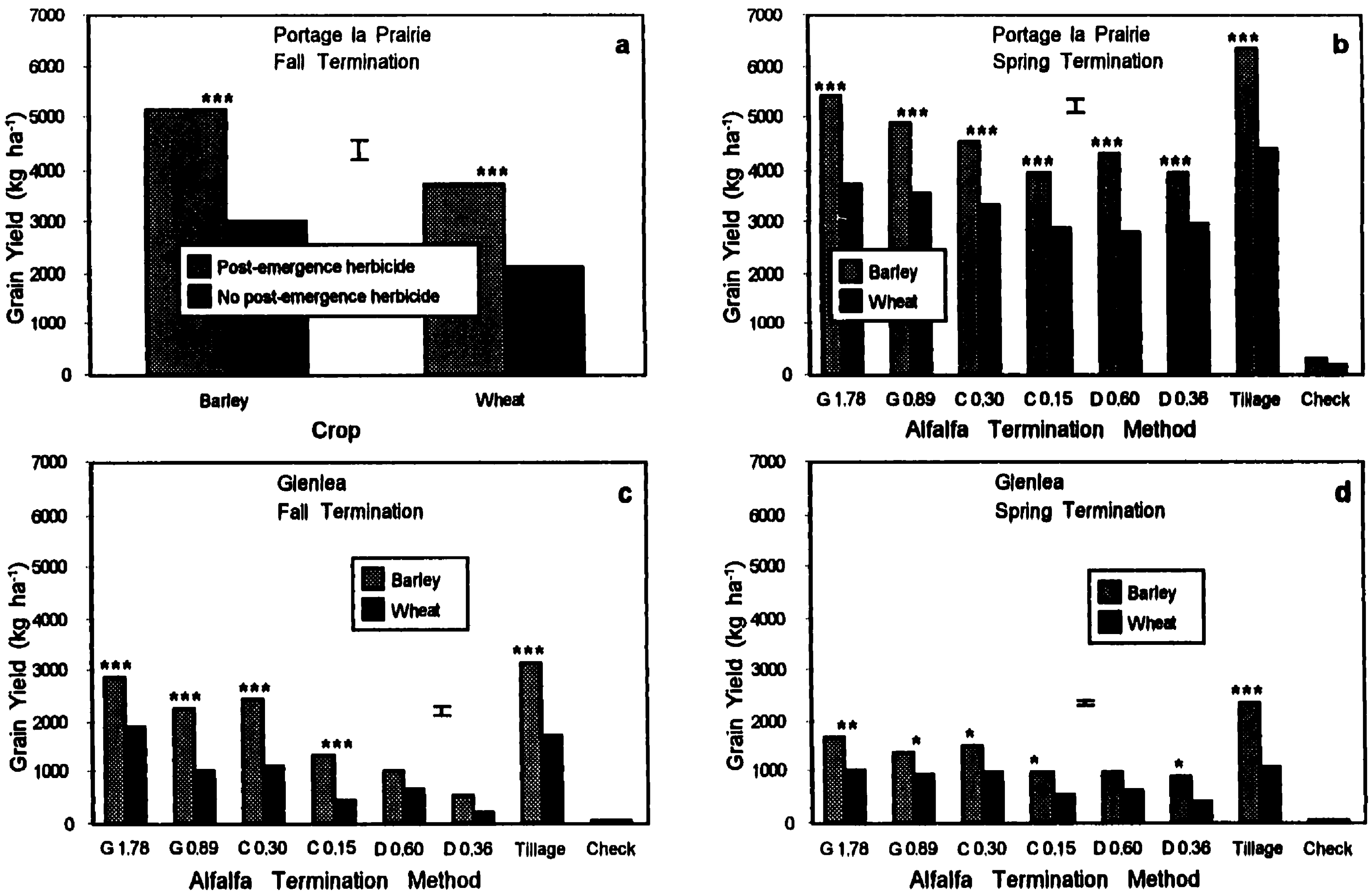

Figure 3.10. Alfalfa termination treatments contributing to termination x crop interactions ($p \leq 0.05, 0.01, 0.001$) on grain yield (kg ha^{-1}) at Portage la Prairie, MB., 1992, and Glenlea, MB., 1993, for fall (c) and spring (b + d) termination. Contribution by crop type to crop x post-emergence herbicide interactions on grain yield (a) at Portage la Prairie for fall termination. Herbicide rates in kg a.i. ha^{-1}. Error bars represent the pooled standard error of the mean.

3.4.4.5 Effect of Alfalfa Escapes on Grain Yield

The effect of alfalfa escapes, as characterized by basal crown area, on wheat and barley grain yield (Portage la Prairie and Glenlea combined) is shown in Figure 3.11. Significance of linear regression y-intercepts and slopes for alfalfa escapes on wheat and barley grain yield is shown in Table 3.12. Although barley attained a significantly higher intercept than wheat for both fall and spring terminated alfalfa, the difference in slope between the two crops was non-significant for both dates, indicating that alfalfa escapes affected grain yield of both crops similarly (Figure 3.11). The significance of the slope values indicate a decrease in crop yield with increasing alfalfa basal crown area. For fall alfalfa termination, grain yield of barley was reduced by 1174.4 kg ha^{-1}, and grain yield of wheat was reduced by 811.8 kg ha^{-1} for each percent increase in alfalfa basal crown area that escaped termination and was allowed to compete with the grain crop for the duration of the growing season (Table 3.12). Krall et al. (1995) also realized decreasing barley yield with increasing alfalfa yield or increasing alfalfa stand. As well, Wilkinson et al. (1987) also observed reduced grain yield with each increase in level of competition from sod species.

Table 3.12. Combined site linear regression y-intercepts and slopes for grain yield response to alfalfa escapes at Portage la Prairie, MB and Glenlea, MB.

Treatment†		Grain yield				
Date	Crop	Intercept		Slope		r^2
		kg ha^{-1}	P > F	kg ha^{-1}	P > F	
Fall	Barley	5196	<0.001	-1174.4	0.002	0.88
Fall	Wheat	3563	<0.001	-811.8	0.001	0.91
Spring	Barley	3806	<0.001	-457.6	0.008	0.78
Spring	Wheat	2515	<0.001	-318.3	0.007	0.79

† Control treatment removed from data set.

In the present study, fall terminated alfalfa resulted in higher grain yields for both wheat and barley than spring terminated alfalfa. However, this advantage was only achieved with the better termination treatments capable of lowering alfalfa basal crown area ≤ 2 % (Figure 3.12). Smith et al. (1992a) realized higher grain yields in three of four years with fall alfalfa/grass herbicide termination compared to spring alfalfa/grass herbicide termination. However, no differences in crop yield were noted between fall and spring alfalfa/grass termination by tillage.

Once the basal crown area exceeded 2 % in the present study, higher crop yields occurred under spring terminated alfalfa than fall terminated alfalfa (Figure 3.12). The steeper yield loss curve associated with the fall terminated alfalfa was probably due to the actively growing alfalfa for the entire duration of the growing period of the grain crop. Spring terminated alfalfa resulted in grain yield loss of 39 % that of fall terminated alfalfa for each percent increase in alfalfa basal crown area (Table 3.12). The alfalfa associated with spring termination was probably not as competitive as the fall terminated alfalfa for the entire length of the growing season, because the spring terminated alfalfa regrowth occurred later in the season. Higher grain yield for fall alfalfa termination associated with basal crown area ≤ 2 % may also be explained by the earlier planting of the grain crop, and consequently higher yield potential.

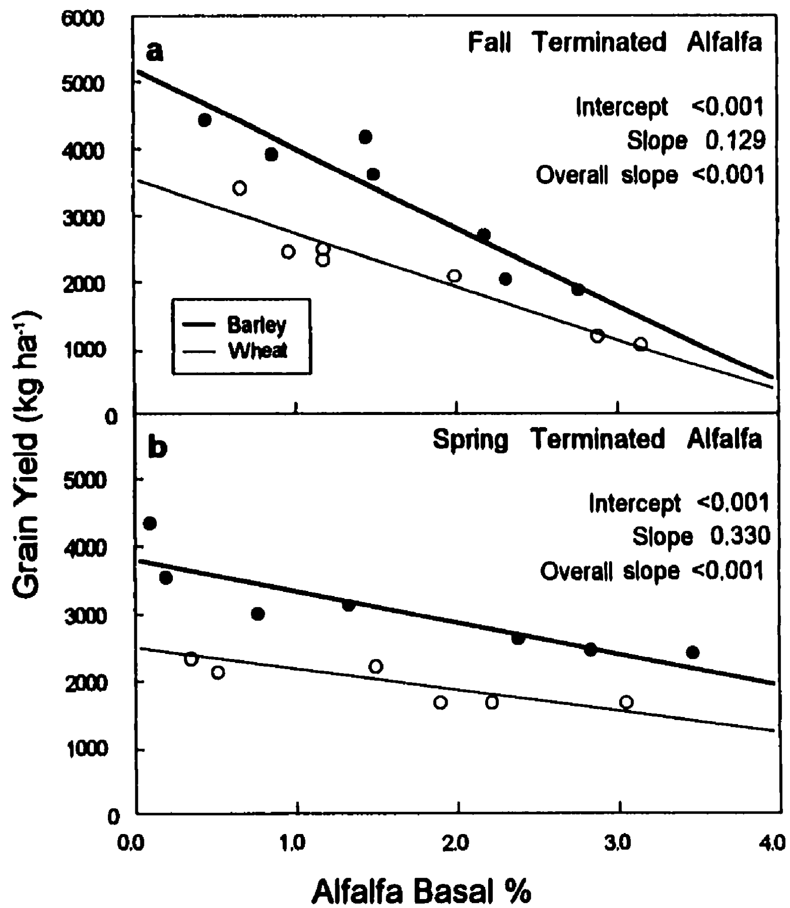

Figure 3.11. Effect of crop type and alfalfa escapes (post-harvest basal crown area) for determining grain yield averaged across both sites for fall terminated alfalfa (a), and spring terminated alfalfa (b). Difference between regression line intercepts and slopes is indicated ($P > F$). Significance of the overall slope from zero is shown where the regression line slopes are not different from each other ($P > F$).

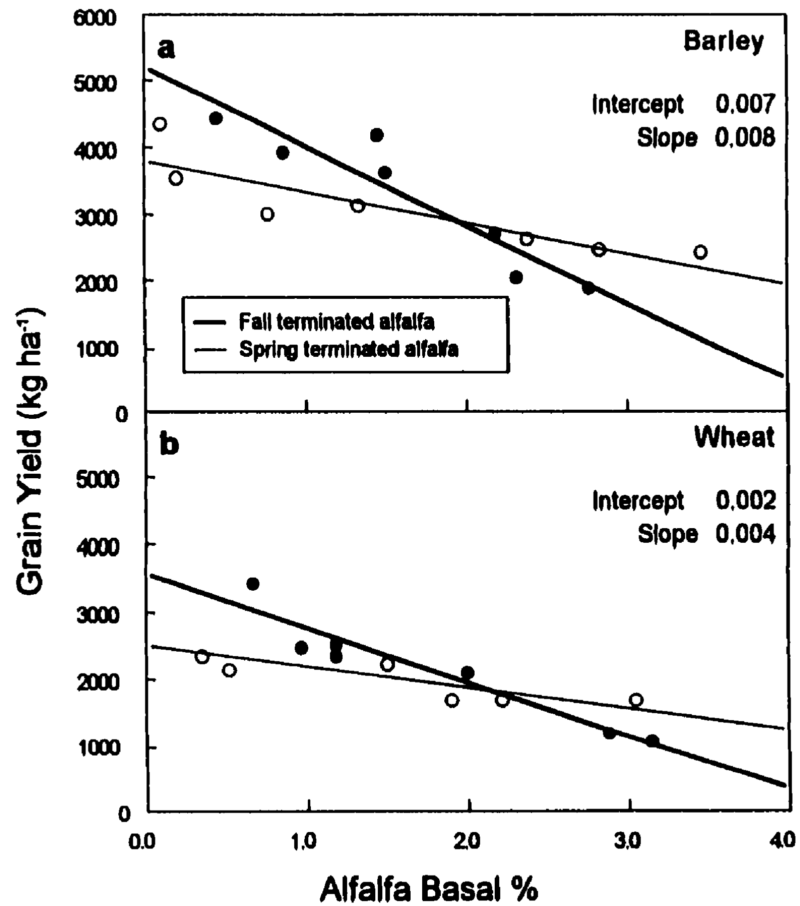

Figure 3.12. Effect of date of alfalfa termination and alfalfa escapes (post-harvest basal crown area) for determining grain yield averaged across both sites for barley (a), and wheat (b). Difference between regression line intercepts and slopes for date of alfalfa termination is indicated ($P > F$).

3.5 Summary and Conclusions

Alfalfa termination involves several management components including initial termination, successive crop competition, and post-emergence herbicide application. The success of individual management strategies will determine the overall success of the termination process. The choice of termination method and date of initial termination affect interactions of these management components. Alfalfa termination with herbicides appears to be a viable option for crop managers currently employing tillage to remove alfalfa from the crop rotation. Herbicide termination, particularly glyphosate at 1.78 kg a.i. ha^{-1}, reduced post-grain harvest alfalfa basal area to 57 % that of tillage across all experiments for this study. The 1.78 kg a.i. ha^{-1} glyphosate treatment also enabled from 55.3 % greater to 1.8 % less subsequent grain yield to occur with fall termination, than did the tillage treatment. The tillage treatment, however, resulted in 17.3 % greater to 26.9 % greater grain yields than the herbicide treatments for spring termination.

Spring termination with herbicides presents the problem with slow die back of alfalfa, and competition from alfalfa on the emerging grain crop. That is, alfalfa die back will continue well into the late spring from spring termination, therefore herbicide damaged plant tissue may not sufficiently absorb the post-emergence herbicide. However, due to the slow die back from termination, spring terminated alfalfa is relatively less competitive than fall terminated alfalfa. Fall termination with herbicides avoids this problem, as well as the problem of interference with the post-emergence herbicide application. Fall alfalfa termination also enables earlier seeding of the spring seeded grain crop to take better advantage of early spring soil moisture, as well as the full duration of the growing season, resulting in increased yield potential. Spring alfalfa termination, and consequently spring crop seeding, however, is often delayed to allow for sufficient alfalfa growth to enable adequate herbicide uptake by the plants.

No differences between barley or wheat competitiveness existed with alfalfa, as measured by alfalfa regrowth either post-harvest, or the spring following barley and wheat production. Also, no difference in relative yield potential for wheat or barley existed across the range of alfalfa basal crown area. Post-emergence herbicide application was beneficial in both reducing overall alfalfa basal crown area 63.6 % averaged across all experiments, as well as contributing to a 33.6 % increase in grain yield at Portage la Prairie, and an 11.0 % increase in grain yield at Glenlea.

From the data in this study, it appears that termination of alfalfa with herbicides is a feasible alternative to conventional tillage, however the type and rate of herbicide used is important. The only herbicide treatment that consistently rivaled tillage in terms of alfalfa suppression and grain yield of the following crop, was glyphosate at 1.78 kg a.i. ha^{-1}. It would appear that producers looking for an alternative to terminating alfalfa with tillage, should plan to terminate in the fall with glyphosate at 1.78 kg a.i. ha^{-1}, and as well, plan for rotation to a competitive crop that enables an effective post-emergence herbicide to be used to control alfalfa escapes.

4.0 Soil Moisture Conservation Following Alfalfa as Influenced by Alfalfa Termination Date and Method

4.1 Abstract

Experiments were established on perennial alfalfa stands at Carman, Glenlea, and Holland, Manitoba in 1992, and Carman and Winnipeg, Manitoba in 1993, to evaluate the effectiveness of soil moisture conservation under different alfalfa stand termination dates and methods; and to assess the extent to which termination dates and methods affected the establishment and yield of a following spring wheat crop.

Fall and spring groundcover percent was highest where alfalfa was terminated using herbicides, and lowest where tillage was used. Herbicide treated alfalfa plots conserved greater fall soil moisture content in the upper soil profile than either tillage or herbicide plus delayed tillage treatments. Differences in soil moisture due to the method of alfalfa termination were significant to the 30 cm soil depth at spring seeding in four of five experimental sites. Herbicide termination treatments had lower mean crop emergence densities than either herbicide plus delayed tillage or tillage treatments. Grain yield was 320 kg ha^{-1} greater, and aerial biomass yield was 1,080 kg ha^{-1} larger with alfalfa termination by herbicide in July (date 1) than by tillage (date 1). Grain water use efficiency was 0.6 kg ha^{-1} mm^{-1} higher, and aerial biomass WUE was 2.0 kg ha^{-1} mm^{-1} greater when alfalfa was terminated with herbicide (date 1) than by tillage (date 1). Alfalfa termination in late summer (date 2) with herbicide conserved from 78 mm less to 166 mm greater fall and 36 to 61 mm greater spring soil moisture, as well as 26 kg ha^{-1} to 548 kg ha^{-1} more grain yield than termination by tillage on date 1. Terminating alfalfa on date 2 with herbicide also resulted in greater grain yield than terminating with tillage on date 2. Results from these experiments indicate that additional soil moisture can be conserved in the soil profile after alfalfa termination by utilizing herbicides instead of tillage, especially on date 1. The practical benefit for producers who terminate alfalfa stands with herbicides

are increased yields of grain and aerial biomass of the crop following alfalfa, primarily resulting from the conservation of additional soil moisture, as well as increased water use efficiency.

4.2 Introduction

The success of dryland cropping on the Canadian Prairies is primarily dependent on the conservation and efficient utilization of available soil moisture. Perennial alfalfa is not as well adapted as annual crops to dryland crop rotations because of its soil moisture depleting characteristics (Zentner et al., 1990). The attribute of efficient moisture extraction by alfalfa from the soil profile often results in low moisture reserves for successive crops in the rotation (Duley, 1929; Hobbs, 1953). Over the period of several years, perennial alfalfa often depletes soil moisture to a level below that which annual crops are able to extract moisture (Duley, 1929; Hobbs, 1953; Voorhees and Holt, 1969). Consequently, successive crops in rotation with alfalfa are often water stressed due to insufficient moisture reserves in their rooting zone, and are therefore dependent on current rainfall for growth.

Conventional termination of alfalfa stands involve numerous tillage passes, often resulting in further depletion of soil moisture (Coburn, 1906), as well as growth and yield inhibition to the following crop in the rotation (Duley, 1929; Coburn, 1906, Wheeler, 1950; Zentner et al., 1990). More recently, crop production systems have been developed which can minimize the moisture depletion effect on the following crop caused by alfalfa. The premise of these systems, namely conservation tillage and no-tillage cropping practices, is to increase the efficiency of soil moisture by increasing moisture recharge, and reducing moisture loss by means of crop residue retention on the soil surface. Conservation and no-tillage practices can reduce evaporative soil moisture loss, however, the amount of crop residue residing on the surface often influences the success of these tillage systems (Gauer et al., 1982; Greb et al., 1967).

Kohl and Kolar (1976) measured soil water uptake by alfalfa from July 8 to July 22 which showed that four-fifths of the water extracted from the top 2.3 m of soil came from the first meter. Hoyt and Leitch (1983) concluded that soil moisture to 120 cm depth was 1.1 to 3.7 cm lower during the spring following 2-3 years of alfalfa than after a fallow control. They also noted that the alfalfa caused no appreciable change in soil moisture used by the following barley crop. Grandfield and Metzger (1936) concluded that 2 years of fallow were necessary to restore subsoil moisture in an old alfalfa stand to a point where the roots of a newly seeded crop could penetrate through moist soil. These observations suggest that in order to optimize crop production in alfalfa containing crop rotations, moisture conservation must be a high priority.

The replenishment of soil moisture reserves following alfalfa can be influenced by the way in which alfalfa is removed from the rotation. Hennig and Rice (1977) found that the later the forage stand was removed in the season, the lower the level of available water in the upper 120 cm of the soil at spring seeding. Hoyt and Leitch (1983) studied the effect of soil moisture reserves of legumes in cereal rotations in the Black soil zone. They concluded that alfalfa depleted the moisture reserves in the subsoil at depths of 60-135 cm for two succeeding crop years. However, the yield of the subsequent barley (*Hordeum vulgare* L.) crops was not affected by the moisture deficit. Entz et al. (1992) confirmed this result in a Portage la Prairie rotation study, in which alfalfa used significantly more water than annual crops below 120 cm. However, the risk for drought in wheat in the year following alfalfa was no greater than that following an annual crop. By the end of the second growing season, the small decrease in soil water level in the annual crop rooting zone (upper 100 cm soil profile) by alfalfa compared to an annual cropping rotation was reduced due to a recharging by fall rainfall and snowfall accumulation. In the drier environment of Colorado, Coburn (1906) concluded that terminating an alfalfa stand by tillage in September or October would render the soil extremely loose, and vulnerable to drying out rapidly, which would be problematic for the following wheat crop.

Snow management by maintaining standing residues on the soil is an important aspect of water conservation in the prairie region, since snow can constitute a significant portion (approximately 30%) of the total annual precipitation (de Jong and Steppuhn, 1983; Greb, 1975; Smika and Unger, 1986; Steppuhn, 1981;). Snow management has been estimated to add 3 cm of additional soil water to the next crop (de Jong and Cameron, 1980. Staple et al. (1960) reported that additional water from snowmelt appeared to be more beneficial in drier fields. It follows, therefore, that fields previously in alfalfa should benefit even more from additional snow cover since infiltration rate is higher in terminated alfalfa sod, and the soil is more receptive to water because it is usually drier.

Sources of soil water loss after alfalfa termination include water loss by evaporation in the fall, and evaporation between snowmelt and crop emergence in spring. Crop residue has been found to generally increase water conservation by increasing infiltration, reducing runoff, and reducing the rate of evaporation (Bond and Willis, 1969; Frye et al., 1988; Smika and Unger, 1986).

Volumetric water content under no-tillage is usually greater than that under conventionally tilled soils (Gauer et al., 1982). This has been attributed to a reduction in evaporation, and greater water storage ability under no-tillage (de Jong and Steppuhn, 1983; Lal, 1994; Thanh, 1993). Steiner (1994) concluded that each tillage event resulted in moisture movement to the soil surface, resulting in subsoil moisture loss. No-tillage has been found to result in higher volumetric moisture content than conventional tillage in the upper 30-60cm soil profile (Blevins et al., 1971; Jones et al., 1969). Lafond et al. (1992) reported a 9% increase in soil water in the 0-60cm soil layer under stubble cropping by no-tillage compared to conventional tillage. During the growing season, tillage system had little influence on the soil moisture reserves below 60 cm depth (Blevins et al., 1971).

Working in an alfalfa sod in Manitoba, Clayton (1982) found that zero till plots generally had higher water content in the surface soil at seeding than tilled sod, and the increased moisture resulted in improved germination conditions for the following wheat crop. Hill and Blevins (1973) found that the presence of killed grass sod mulch in zero tilled plots had an advantage over conventional tillage plots since lower direct evaporation from the soil surface occurred during the early growing period. They also found that evaporative losses from both zero tilled and conventional tilled treatments were similar as the crop canopy developed, however, the sod residue gave the zero tilled plots an advantage in available soil moisture which was maintained throughout the growing season.

Grain yield is often affected by different management techniques when rotating crops. Barnett (1990) found that no-till corn production in an alfalfa-grass sod resulted in no observed differences for stalk lodging and grain yield between treatments. Wheeler (1950) reported that the yield of crops was often decreased the first year following unirrigated alfalfa. McKay et al. (1951) conducted experiments that indicated wheat yields were depressed when the previous sweetclover crop was allowed to grow for a longer duration the previous year. The depression was attributed to a greater extraction of subsoil moisture by the sweetclover crop. Clayton (1982) also reported lower yields of wheat following alfalfa with no-till treatments compared to conventional tillage. He attributed this to a decrease in wheat emergence, and incomplete kill of alfalfa, which competed for moisture and nutrients.

Steiner (1994) concluded that wheat residue on the soil surface during the growing season greatly enhanced WUE of both aerial biomass and grain yield of dryland sorghum. WUE of spring wheat in Saskatchewan was found to be 49.7 kg ha^{-1} cm^{-1} for all soil textures with conventional tillage, and varied from 53.7 to 186 kg ha^{-1} cm^{-1} for loam and heavy soil under no-tillage (Grevers et al., 1986).

There is abundant literature dealing with soil water measurements in crop rotations, however few studies focus on soil moisture levels following alfalfa termination. Several studies have measured moisture extraction from the soil profile by alfalfa, which tends to dry the soil profile to a depth greater than that which annual crops can root. Few studies however, have focused on the impact that soil moisture depletion has on the crop following alfalfa. Since little can be done to alleviate the moisture depleting characteristics of alfalfa (except to terminate the alfalfa stand sooner), studies need to focus on methods of conserving current soil moisture at the date of termination, as well as conserve precipitation between the date of termination, and the subsequent cropping season.

In addition, few studies have focused on the ability of herbicides to terminate alfalfa, particularly in Western Canada. Variations of climatic, soil type, and alfalfa varieties necessitate further study with herbicide termination of alfalfa. If producers are to include perennial alfalfa in a rotational cropping system, additional study is necessary to alleviate current problems of alfalfa termination and soil moisture depletion by alfalfa. To address this concern, experiments were initiated in pursuit of better methods of terminating alfalfa stands in a cropping system. The objectives of this study were to 1) evaluate the effectiveness of soil moisture conservation under different alfalfa stand termination dates and methods, and 2) to assess the extent to which termination date and method affect the establishment and yield of a subsequent spring wheat crop. It was hypothesized that alfalfa termination by herbicides could have greater potential for soil moisture conservation than alfalfa termination by tillage, and that the additional moisture could result in increased subsequent crop yields.

4.3 Materials and Methods

4.3.1 General

The soil moisture conservation trials (1992-1993) were located in southern Manitoba at Carman on a Denham clay loam soil with the surface soil consisting of 50 % sand, 21 % silt, and 30 % clay; at Glenlea on an Osborne clay soil with the surface soil consisting of 9 % sand, 26 % silt, and 66 % clay; and at Holland on a Stockton sandy loam soil consisting of 50 % sand, 28 % silt, and 22 % clay. The soil moisture conservation experiments (1993-1994) were located at Carman on a Hochfeld fine sandy loam soil consisting of 78 % sand, 9 % silt, and 13 % clay; and at Winnipeg on a Riverdale silty clay consisting of 13 % sand, 45 % silt, and 42 % clay. Establishment of the experiments took place on a two year alfalfa (cv. Arrow) stand at Carman (1992), a two year alfalfa stand (cv. Algonquin) at Holland, a six year alfalfa stand (cv. Beaver) at Glenlea, a three year alfalfa stand (cv. Arrow) at Carman (1993), and three year alfalfa (cv. OAC Minto) at Winnipeg.

Experimental design of the soil moisture conservation experiments was a randomized complete block design with four replications. In 1992, the seven alfalfa termination treatments consisted of alfalfa termination by herbicides, tillage, herbicides plus delayed tillage after the first alfalfa cut (date 1 termination), and by herbicides, tillage, herbicides plus delayed tillage after the second alfalfa cut (date 2 termination), and herbicide termination during the spring of 1993 (date 3 termination) prior to crop seeding. Plot size was 12 m x 12 m at Carman, Glenlea, and Holland for 1992, and Carman for 1993. Plot size at Winnipeg (1993) was 5.5 m x 16 m. One 190 cm neutron access tube was positioned in the center of each plot at Carman, Glenlea, and Holland in 1992, for the purpose of soil moisture measurements. At the Carman site in 1993, soil profile access tubes were installed to a depth of 150 cm. The Winnipeg site (1993) had two access tubes installed in each plot to a depth of 190 cm.

Summary of alfalfa cutting regime (Table 4.01) and alfalfa termination dates and treatment schedule (Table 4.02) are shown for both years. The alfalfa was cut and removed from the plot area at all sites. Herbicide treatments involved initial spraying with 1.78 kg ha^{-1} glyphosate followed by 0.89 kg ha^{-1} glyphosate later in the season (Table 4.02). Tillage treatments were performed with a chisel plow and tandem discer. The herbicide plus delayed tillage treatment included spraying with 0.89 kg ha^{-1} glyphosate followed later by two passes with a tandem discer (Table 4.02). During 1993, five main plots were initiated in an experiment at Carman, including termination by herbicide, and tillage, after the first cut (date 1 termination) and after the second cut (date 2 termination); and herbicide termination treatment the following spring (date 3 termination). At Winnipeg (1993), three main plots were initiated in an experiment including herbicide and tillage termination, after the second alfalfa cut (date 2 termination), as well as a herbicide termination treatment in the following spring (date 3 termination). All tillage, and herbicide plus delayed tillage treatments were harrowed in October for both years.

Table 4.01 Alfalfa cutting regime for Carman, Glenlea, and Holland, MB. (1992), and Carman and Winnipeg, MB. (1993).

		Alfalfa aerial harvest	
Location	Year	Harvest	Date (day of year)
Carman	1992	1st cut	June 28 (180)
		2nd cut	Aug 10 (223)
Glenlea	1992	1st cut	June 20 (172)
		2nd cut	July 31 (213)
Holland	1992	1st cut	June 29 (181)
		2nd cut	Aug 9 (222)
Carman	1993	1st cut	July 9 (191)
		2nd cut	Aug 6 (219)
Winnipeg	1993	2nd cut	Aug 5 (218)

Table 4.02 Alfalfa termination treatment descriptions for Carman, Glenlea, and Holland, MB. (1992), and Carman and Winnipeg, MB. (1993).

		Alfalfa termination treatments			
Location	Year	Date	Method	Treatment	Date (day of year)
Carman	1992	post-1st cut (date 1)	herbicide	glyphosate 1.78†	July 22 (204)
				glyphosate 0.89	Sept 10 (254)
			tillage	chisel plow (1)‡	July 22 (204)
				chisel plow (1)	Aug 1 (214)
				chisel plow (2)	Aug 15 (228)
				tandem discer (1)	Aug 29 (242)
				tandem discer (1)	Oct 2 (276)
				harrow (1)	Oct 2 (276)
			herbicide + tillage	glyphosate 0.89	July 22 (204)
				tandem discer (2)	Aug 29 (242)
				harrow (1)	Oct 2 (276)
	1992	post-2nd cut (date 2)	herbicide	glyphosate 1.78	Sept 10 (254)
			tillage	chisel plow (1)	Aug 15 (228)
				tandem discer (1)	Aug 29 (242)
				tandem discer (1)	Sept 14 (258)
				tandem discer (1)	Oct 2 (276)
				harrow (1)	Oct 2 (276)
			herbicide + tillage	glyphosate 0.89	Sept 10 (254)
				tandem discer (2)	Oct 2 (276)
				harrow (1)	Oct 2 (276)
	1993	spring (date 3)	herbicide	glyphosate 0.66 + clopyralid 0.08	May 4 (124)
Glenlea	1992	post-1st cut (date 1)	herbicide	glyphosate 1.78	July 21 (203)
				glyphosate 0.89	Sept 8 (252)
			tillage	chisel plow (1)	July 10 (192)
				chisel plow (1)	July 21 (203)
				chisel plow (2)	Aug 11 (224)
				tandem discer (1)	Aug 28 (241)
				tandem discer (1)	Oct 1 (275)
				harrow (1)	Oct 1 (275)
			herbicide + tillage	glyphosate 0.89	July 21 (203)
				tandem discer (2)	Aug 28 (241)
				harrow (1)	Oct 1 (275)
	1992	post-2nd cut (date 2)	herbicide	glyphosate 1.78	Sept 8 (252)
			tillage	chisel plow (1)	Aug 11 (224)
				tandem discer (1)	Aug 28 (241)
				tandem discer (1)	Sept 14 (258)
				tandem discer (1)	Oct 1 (275)
				harrow (1)	Oct 1 (275)
			herbicide + tillage	glyphosate 0.89	Sept 8 (252)
				tandem discer (2)	Oct 1 (275)
				harrow (1)	Oct 1 (275)
	1993	spring (date 3)	herbicide	glyphosate 0.66 + clopyralid 0.08	May 4 (124)

(continued)

Table 4.02 (continued) Alfalfa termination treatment descriptions for Carman, Glenlea, and Holland, MB. (1992), and Carman and Winnipeg, MB. (1993).

		Alfalfa termination treatments			
Location	Year	Date	Method	Treatment	Date (day of year)
Holland	1992	post-1st cut (date 1)	herbicide	glyphosate 1.78	July 27 (209)
				glyphosate 0.89	Sept 10 (254)
			tillage	chisel plow (1)	July 27 (209)
				chisel plow (1)	Aug 3 (216)
				chisel plow (2)	Aug 14 (227)
				tandem discer (1)	Aug 31 (244)
				tandem discer (1)	Oct 4 (278)
				harrow (1)	Oct 4 (278)
			herbicide + tillage	glyphosate 0.89	July 27 (209)
				tandem discer (2)	Aug 31 (244)
				harrow (1)	Oct 4 (278)
	1992	post-2nd cut (date 2)	herbicide	glyphosate 1.78	Sept 10 (254)
			tillage	chisel plow (1)	Aug 14 (227)
				tandem discer (1)	Aug 31 (244)
				tandem discer (1)	Sept 13 (257)
				tandem discer (1)	Oct 4 (278)
				harrow (1)	Oct 4 (278)
			herbicide + tillage	glyphosate 0.89	Sept 10 (254)
				tandem discer (2)	Oct 4 (278)
				harrow (1)	Oct 4 (278)
	1993	spring (date 3)	herbicide	glyphosate 0.66 + clopyralid 0.08	May 5 (125)
Carman	1993	post-1st cut (date 1)	herbicide	glyphosate0.66§	July 26 (207)
				glyphosate0.66§	Sept 10 (253)
			tillage	chisel plow (2)	July 30 (211)
				tandem discer (2)	July 30 (211)
				tandem discer (2)	Sept 11 (254)
				tandem discer (1)	Oct 8 (281)
				harrow (2)	Oct 8 (281)
	1993	post-2nd cut (date 2)	herbicide	glyphosate0.66§	Sept 10 (253)
			tillage	chisel plow (2)	Sept 11 (254)
				tandem discer (2)	Sept 11 (254)
				tandem discer (2)	Oct 8 (281)
				harrow (2)	Oct 8 (281)
Winnipeg	1993	post-2nd cut (date 2)	herbicide	glyphosate0.66§	Aug 26 (238)
				glyphosate0.66§	Sept 11 (254)
			tillage	rototiller (2)	Sept 9 (252)
				rototiller (1)	Oct 12 (285)

† kg a.i. ha^{-1}.
‡ number of passes with tillage implement.
§ 0.66 kg a.i. ha^{-1} glyphosate + 0.60 kg a.i. ha^{-1} dicamba + 0.50 kg a.i. ha^{-1} 2,4-D.

Crop seeding for 1993 involved pre-seeding application of 0.66 kg ha^{-1} glyphosate plus 0.08 kg ha^{-1} clopyralid. Spring herbicide treatment plots were sprayed with two applications of 0.66 kg ha^{-1} glyphosate plus 0.08 kg ha^{-1} clopyralid. Plots which had received the tillage and herbicide plus delayed tillage treatments the previous fall were cultivated to a depth of 6 to 8 cm with a 3-point hitch cultivator, harrowed, and packed in spring prior to seeding. Seeding was performed with a Fabro no-till press drill, with 15 cm row spacing. Certified wheat (cv. Katepwa) was planted to a 2.5 cm soil depth, and then firmly packed. Wheat (cv. Katepwa) was seeded at a rate of 275 viable seeds m^{-2} (95.2 kg ha^{-1} at 97 % germination) on May 6 (DOY 126) at Carman and Holland, and May 13 (DOY 133) at Glenlea in 1993. Plots were fertilized at the Holland site with a blend (34.5-0-0 + 12-51-0 + 20-0-0-24) of 40.8 kg ha^{-1} actual nitrogen, 14.2 kg ha^{-1} actual P, and 8.3 kg ha^{-1} actual sulfur. No nitrogen was added at Carman and Glenlea, due to the absence of N deficiency for spring cereal crop production, and also in order to accommodate future nitrogen uptake experiments (Mohr et al., 1997). Fertilizer (0-46-0) was placed in the seed row at all sites with the no-till drill at a rate of 40.2 kg ha^{-1} actual phosphate.

The post-emergence foliar herbicide treatment for Carman and Holland was 0.28 kg ha^{-1} bromoxynil plus 0.28 kg ha^{-1} MCPA ester plus 0.2 kg ha^{-1} tralkoxydim. Adjuvant was added at a rate of 0.5 L 100 L^{-1} spray solution. The herbicide treatment was applied at the four leaf stage of wheat on June 1 (DOY 152). Post-emergence herbicide (0.11 kg ha^{-1} dicamba plus 0.42 kg ha^{-1} MCPAK) was applied at the early tillering stage of wheat at Glenlea on June 15 (DOY 166). All post-emergence herbicide treatments were applied at a rate of 110 L ha^{-1} water with a 3-point hitch tractor mounted sprayer.

Climatological weather data was obtained from Environment Canada for Carman, Glenlea, Holland, and Winnipeg. Monthly actual and long-term average precipitation and temperature are shown in Table 4.03 and Table 4.04.

Table 4.03 Monthly actual and long-term average precipitation and average temperature at Carman, Glenlea, and Holland, MB. (1992-1993).

		Carman				Glenlea				Holland			
		Precip	Temp			Precip	Temp			Precip	Temp		
			Max	Min	Mean		Max	Min	Mean		Max	Min	Mean
		mm	°C			mm	°C			mm	°C		
May 1992	Actual†	35.0	20.4	5.5	13.0	28.0	19.9	5.6	12.8	37.6	19.9	5.8	12.9
	Normal	52.7‡	18.3‡	4.8	11.6	56.8§	18.9§	4.8	11.9	59.1¶	18.6¶	4.8	11.7
June 1992	Actual	128.6	21.2	9.6	15.4	106.6	20.4	9.5	15.0	73.8	21.4	9.3	15.4
	Normal	72.8	23.4	10.7	17.1	94.9	23.1	10.0	16.6	80.7	23.5	10.1	16.8
July 1992	Actual	116.2	20.9	10.1	15.5	86.8	21.2	10.4	15.8	89.5	21.5	10.1	15.8
	Normal	69.1	26.1	13.5	19.8	70.6	26.1	12.7	19.4	77.4	26.3	12.7	19.5
August 1992	Actual	64.9	21.7	9.8	15.8	69.2	22.3	10.1	16.2	49.8	22.5	9.2	15.9
	Normal	65.5	25.0	11.8	18.4	60.5	25.0	11.2	18.1	76.2	25.3	11.1	18.2
September 1992	Actual	38.4	17.8	4.6	11.2	70.0	17.4	4.4	10.9	31.8	17.6	4.8	11.2
	Normal	49.0	18.6	6.3	12.5	52.9	18.8	5.7	12.3	49.5	18.7	5.6	12.2
October 1992	Actual	4.2	12.0	-2.0	5.0	3.8	11.5	-2.5	9.0	11.8	11.9	-1.7	5.1
	Normal	34.0	11.6	0.5	6.1	37.9	10.7	-0.9	4.9	29.0	11.8	0.0	5.9
November 1992	Actual	21.1	-0.9	-7.4	-4.2	33.1	-2.0	-8.5	-5.3	33.2	-1.4	-7.1	-4.3
	Normal	18.6	0.0	-8.8	-4.3	19.7	-0.6	-9.8	-5.1	20.5	0.1	-9.2	-4.5
December 1992	Actual	35.6	-12.1	-21.3	-16.7	44.2	-12.5	-22.0	-17.3	40.8	-12.1	-21.3	-16.7
	Normal	20.8	-9.0	-18.5	-13.7	19.5	-10.0	-20.3	-15.1	21.4	-9.1	-18.8	-13.9
January 1993	Actual	17.6	-10.1	-22.0	-16.1	16.4	-12.0	-24.5	-18.3	9.4	-10.8	-21.7	-16.3
	Normal	18.5	-12.2	-22.3	-17.2	23.7	-13.0	-24.3	-18.6	25.8	-12.2	-22.6	-17.3
February 1993	Actual	0.2	-8.0	-18.6	-13.3	0.0	-10.5	-22.0	-16.3	1.4	-7.6	-19.3	-13.5
	Normal	17.7	-8.6	-19.4	-13.9	17.1	-9.5	-21.6	-15.5	21.0	-8.5	-19.4	-14.0
March 1993	Actual	9.0	-0.3	-8.7	-4.5	8.6	-1.5	-12.0	-6.8	16.8	0.4	-8.9	-4.3
	Normal	21.7	-1.2	-11.7	-6.4	22.0	-1.8	-13.2	-7.4	24.5	-1.2	-12.1	-6.6
April 1993	Actual	17.4	10.4	-2.0	4.2	22.8	11.0	-2.0	4.5	27.2	10.4	-2.1	4.2
	Normal	42.5	9.7	-2.2	3.8	29.5	10.3	-2.0	4.2	40.5	9.9	-1.8	4.1
May 1993	Actual	70.0	18.6	4.3	11.5	41.0	18.2	4.4	11.3	57.2	18.8	4.0	11.4
	Normal	52.7	18.3	4.8	11.6	56.8	18.9	4.8	11.9	59.1	18.6	4.8	11.7
June 1993	Actual	120.0	20.8	9.2	15.0	72.8	20.5	8.8	14.7	112.0	20.9	8.3	14.6
	Normal	72.8	23.4	10.7	17.1	94.9	23.1	10.0	16.6	80.7	23.5	10.1	16.8
July 1993	Actual	152.8	22.0	12.1	17.1	246.0	22.6	12.3	17.5	157.6	22.0	11.2	16.6
	Normal	69.1	26.1	13.5	19.8	70.6	26.1	12.7	19.4	77.4	26.3	12.7	19.5
August 1993	Actual	114.0	23.1	11.8	17.5	160.0	23.0	12.6	17.8	126.2	23.4	11.2	17.3
	Normal	65.5	25.0	11.8	18.4	60.5	25.0	11.2	18.1	76.2	25.3	11.1	18.2
September 1993	Actual	28.8	16.9	4.3	10.6	31.8	16.4	4.5	10.5	17.2	17.0	3.8	10.4
	Normal	49.0	18.6	6.3	12.5	52.9	18.8	5.7	12.3	49.5	18.7	5.6	12.2

† Source Environment Canada.
‡ Source Environment Canada long-term average 1941 to 1990
§ Source Environment Canada long-term average 1967 to 1990
¶ Source Environment Canada long-term average 1904 to 1990

Table 4.04 Monthly actual and long-term average precipitation and average temperature at Carman and Winnipeg, MB. (1993-1994).

		Carman				Winnipeg			
		Precipitation	Temperature			Precipitation	Temperature		
			Max	Min	Mean		Max	Min	Mean
		mm	°C			mm	°C		
May 1993	Actual†	12.6	20.7	4.9	12.8	43.9	18.8	6.1	12.5
	Normal	52.7‡	18.3§	4.8	11.6	56.8¶	18.9¶	4.8	11.9
June 1993	Actual	44.0	22.0	9.0	15.4	111.8	21.0	10.6	15.9
	Normal	72.8	23.4	10.7	17.1	94.9	23.1	10.0	16.6
July 1993	Actual	109.0	22.1	10.8	16.3	307.6	23.6	14.2	18.6
	Normal	69.1	26.1	13.5	19.8	70.6	26.1	12.7	19.4
August 1993	Actual	49.0	23.2	9.9	16.3	265.9	24.2	14.0	18.8
	Normal	65.5	25.0	11.8	18.4	60.5	25.0	11.2	18.1
September 1993	Actual	50.0	17.8	4.3	10.8	39.9	16.3	5.6	10.9
	Normal	49.0	18.6	6.3	12.5	52.9	18.8	5.7	12.3
October 1993	Actual	30.6	9.8	-2.9	3.5	32.6	8.5	-3.0	2.5
	Normal	34.0	11.6	0.5	6.1	37.9	10.7	-0.9	4.9
November 1993	Actual	25.0	-1.6	-10.4	-6.0	15.8	1.0	-11.0	-5.0
	Normal	18.6	0.0	-8.8	-4.3	19.7	-0.6	-9.8	-5.1
December 1993	Actual	13.9	-6.8	-17.1	-12.0	20.2	-8.0	-17.0	-12.5
	Normal	20.8	-9.0	-18.5	-13.7	19.5	-10.0	-20.3	-15.1
January 1994	Actual	12.9	-18.1	-27.5	-22.8	11.2	-19.0	-30.0	-24.5
	Normal	18.5	-12.2	-22.3	-17.2	23.7	-13.0	-24.3	-18.6
February 1994	Actual	5.4	-12.6	-23.6	-18.1	7.2	-13.0	-25.0	-19.0
	Normal	17.7	-8.6	-19.4	-13.9	17.1	-9.5	-21.6	-15.5
March 1994	Actual	13.6	3.1	-5.8	-1.4	3.2	2.5	-8.5	-3.0
	Normal	21.7	-1.2	-11.7	-6.4	22.0	-1.8	-13.2	-7.4
April 1994	Actual	11.2	11.0	-2.3	4.4	10.0	11.0	-3.5	4.0
	Normal	42.5	9.7	-2.2	3.8	29.5	10.3	-2.0	4.2
May 1994	Actual	39.1	20.8	4.9	12.9	150.7	20.2	5.0	12.6
	Normal	52.7	18.3	4.8	11.6	56.8	18.9	4.8	11.9
June 1994	Actual	53.5	23.6	11.7	17.7	94.7	24.0	11.7	17.9
	Normal	72.8	23.4	10.7	17.1	94.9	23.1	10.0	16.6
July 1994	Actual	48.0	24.0	11.9	18.0	96.7	24.1	12.1	18.1
	Normal	69.1	26.1	13.5	19.8	70.6	26.1	12.7	19.4
August 1994	Actual	102.6	23.4	10.2	16.8	100.8	23.1	10.6	16.5
	Normal	65.5	25.0	11.8	18.4	60.5	25.0	11.2	18.1
September 1994	Actual	54.8	22.0	7.6	14.8	73.2	21.0	7.9	14.5
	Normal	49.0	18.6	6.3	12.5	52.9	18.8	5.7	12.3

† Source Environment Canada.
‡ Source Environment Canada long-term average 1964 to 1990.
§ Source Environment Canada long-term average 1941 to 1990.
¶ Source Environment Canada long-term average 1967 to 1990.

4.3.2 Agronomic Measurements

Volumetric soil moisture content (cm^3 cm^{-3}) measurements from a depth of 10 cm below the soil surface to a depth of 190 cm were determined in 20 cm increments by means of a calibrated neutron moisture gauge (Troxler model 4330, Triangle Park, NC.). Soil moisture in 1992 to a 10 cm depth was determined gravimetrically by extracting two 5.5 cm diameter soil cores from each plot. Bulk density (g cm^{-3}) was determined at each site in 1992. Volumetric soil moisture content (cm^3 cm^{-3}) was calculated by multiplying the bulk density of each soil by the gravimetric moisture content. In 1993, volumetric surface soil moisture (0 - 10 cm depth) was measured using a calibrated neutron moisture gauge (Troxler model 4300 moisture gauge, Troxler Electronic Laboratories, Inc., Triangle Park, NC.) (Appendix C, Figure C.01) with a surface shield, as illustrated by Chanasyk and McKenzie (1986), and Chanasyk and Naeth (1988). Soil moisture measurements were taken at various intervals throughout the season and the following cropping season (Table 4.05 and 4.06).

Groundcover was determined across each plot by laying a diagonal line transect with 15 cm increments, as outlined by Laflen et al. (1981), and Richards et al. (1984. Two groundcover counts were measured at right angles, averaged, and converted to a percentage basis.

Crop emergence was measured three to four weeks after seeding. Wheat establishment was based on four-one meter lengths of row within each plot, and converted to a square meter basis. Grain yield was determined in 1993 with a small plot combine by harvesting two 1.33 m widths of wheat 7 m in length. Grain harvest occurred at Carman on August 25 (DOY 237), at Holland on August 31 (DOY 243), and at Glenlea on September 1 (DOY 244). Grain samples were oven dried at 65°C for 72 h, cleaned, and weighed. Total above ground aerial biomass was measured at the time of grain harvest by removing six-one meter lengths of row. The straw and grain was oven dried at 65°C for 72 h, and weighed.

4.3.3 Statistical Analysis

Statistical analysis for the soil moisture conservation data utilized analysis of variance (Statistical Analysis Systems, 1990). Each experiment was analyzed separately with analysis of variance ($P \leq 0.05$) as a two (date) by three (method) factorial (excluding spring herbicide termination), to determine main effects for date, method, and date x method interactions of alfalfa termination. Orthogonal contrasts were utilized to determine differences between specific treatments. The data were reanalyzed with analysis of variance ($P \leq 0.05$) for the date (herbicide only) including herbicide termination on date 1, date 2, and date 3 (spring). Crop parameter data from 1992-1993 sites were combined since error terms were found to be homogenous according to Bartlett's test (Steel and Torrie, 1980).

Table 4.05 Schedule of soil moisture profile sampling (0-190 cm) for Carman, Glenlea, and Holland, MB. (1992-1993).

Year	Field measurement	Date		
		Calendar (day of year)		
		Carman	Glenlea	Holland
1992	post-1st cut (date 1)	July 22 (204)	July 21 (203)	July 24 (206)
	post-2nd cut (date 2)	Aug 21 (234)	Aug 20 (233)	Aug 25 (238)
	late fall	Oct 20 (294)	Oct 19 (293)	Oct 21 (295)
1993	spring (date 3)	May 10 (130)	May 14 (134)	May 11 (131)
	late spring	May 28 (148)	June 4 (155)	June 12 (163)
	fall (harvest)	Aug 27 (239)	Sept 1 (244)	Aug 31(243)

Table 4.06 Schedule of soil moisture profile sampling at Carman (0-150 cm), and Winnipeg, MB. (0-190 cm) for 1993-1994.

Year	Field measurement	Date	
		Calendar (day of year)	
		Carman	Winnipeg
1993	post-1st cut (date 1)	July 30 (211)	-
	post-2nd cut (date 2)	Sept 17 (260)	Sept 15 (258)
	late fall	Oct 15 (288)	Oct 14 (287)
1994	spring (date 3)	May 3 (123)	May 13 (133)

4.4 Results and Discussion

4.4.1 Soil Moisture: Conservation Period

4.4.1.1 Soil Moisture Reserves on First Termination Date

Soil moisture levels in the profile between treatments for alfalfa termination on date 1 were generally similar at all sites since first termination treatments were just being initiated (Figure 4.01; Figure 4.02a). Soil moisture levels between treatments at all locations were not different for profile increments of 0-30 cm, 30-90 cm, and 90-190cm (Figure 4.10 through Figure 4.13). Orthogonal contrasts for soil moisture levels also revealed no differences between treatments for any profile increment (Table 4.07).

4.4.1.2 Soil Moisture Reserves on Second Termination Date

Differences in soil moisture levels between treatments became apparent primarily in the upper soil profile at the time of date 2 alfalfa termination (Figure 4.03; Figure 4.02b; Figure 4.02c). Soil moisture differences at Carman (1992) and Glenlea were due to the date of alfalfa removal, with date 1 terminated alfalfa treatments conserving more soil moisture to a depth of 30 cm at Carman, and to a depth of 70 cm at Glenlea (Figure 4.03). Soil moisture differences between treatments after date 2 alfalfa termination at Holland and Carman (1993) were due to both the date and method of alfalfa termination. In the upper soil increment, herbicide-killed alfalfa conserved more moisture than all other treatments. However, deeper in the soil profile, both date and method of alfalfa termination influenced soil moisture retention at Holland (Figure 4.03) and Carman (Figure 4.02b). The method of alfalfa termination alone influenced differences in soil moisture between treatments at Winnipeg, since there were no date 1 termination treatments, however, this influence existed only in the upper 10 cm soil depth.

Reserves of soil moisture in the upper 30 cm profile on date 2 were generally greater for the date 1 than date 2 treatments (Figure 4.10 through Figure 4.14). The 30-90 cm soil depth also maintained greater moisture reserves for date 1 treatments at Glenlea (Figure 4.11), and Holland (Figure 4.12). There were no differences in soil moisture among the treatments below the 90 cm depth at any of the locations, which implied that no water percolated below 30 cm between the first and second alfalfa termination. Orthogonal contrasts for the date 2 termination soil moisture measurement showed differences primarily in the 0-30 cm soil depth (Table 4.08). Herbicide terminated alfalfa (date 1) conserved more moisture than tillage terminated alfalfa on date 1 at Glenlea (Figure 4.11), and Carman (1993) (Figure 4.13). Herbicide terminated alfalfa on date 1 had greater soil moisture than alfalfa sprayed at the second date for the 0-30 cm soil profile at all locations (Table 4.08). This difference extended to the 30-90 cm soil depth at Glenlea. Similarly, tillage terminated alfalfa on date 1 conserved more moisture than alfalfa tilled after the second date in the 0-30 cm soil depth at all locations (Table 4.08). This difference also occurred in the 30-90 cm soil increment at the Holland site.

Tillage termination following the first alfalfa cutting is a traditional practice in the Canadian Prairies (Entz et al., 1995). Producers using this practice sacrifice a second alfalfa cut in an attempt to conserve soil moisture for the following crop. Comparisons were made between date 2 termination with herbicides and date 1 termination with tillage; it was hoped that using the herbicide, a second alfalfa cut could be taken without sacrificing water conservation. However, herbicide termination of alfalfa at the second date conserved less moisture in the 0-30 cm increment than either tillage or herbicide plus delayed tillage at the first date. Also, less moisture was found in the 30-90 cm increment with date 2 herbicide than tillage on date 1 termination at Glenlea and Holland.

The change in soil moisture among treatments from the first to second termination date differed in the 0-30 cm and 30-90 cm increments at all locations (Figure 4.10 through Figure 4.13). However, the significance of soil moisture change in the 90-190 cm increment differed only at Glenlea (Figure 4.11) and Holland (Figure 4.12). Soil moisture change in the 0-30 cm soil increment between treatments from the first alfalfa termination to the second termination were further substantiated by orthogonal contrasts (Table 4.09). Herbicide terminated alfalfa on date 1 conserved more soil moisture than the tillage treatment. Both herbicide and tillage alfalfa termination on date 1 conserved greater soil moisture than herbicide and tillage treatments on date 2. The second date termination treatments generally conserved less soil moisture in the 0-30 cm soil depth, as well as the 30-90 cm depth, compared to the first date termination treatments, probably due to the longer duration of water usage by the alfalfa plants in the second cut treatments.

4.4.1.3 End of Season Soil Moisture Reserves

Soil moisture differences between treatments in mid-October occurred in the upper soil profile at all five locations (Figure 4.04; Figure 4.05). Similar to the previous observations, soil moisture deeper in the profile was influenced more by date than by method of alfalfa termination, as noted at three locations. The date of alfalfa termination alone influenced soil moisture at Carman (1992). The date of herbicide method (herbicide only) influenced soil moisture in the profile similarly to the date of alfalfa termination. Treatment differences in soil profile moisture in October extended to a 30 cm depth at Carman (1992) and Winnipeg, 50 cm at Carman (1993), 90 cm at Holland, and 150 cm at Glenlea (Figure 4.04; Figure 4.05).

Soil moisture reserves in the 0-30 cm soil depth at the end of the season (mid-October) were significantly different among the treatments at all locations (Figure 4.10 through Figure 4.14). Differences due to the date of alfalfa termination existed for soil moisture in the 0-30 cm increment at all locations; the method of alfalfa termination influenced soil moisture at all sites except Carman (1992). The 30-90 cm soil increment also had differences in soil moisture among treatments at all locations except Carman (1992). Differences in soil moisture at the 30-90 cm depth were due to the date of alfalfa termination at all sites, and due to both date and method of alfalfa termination at Holland. No differences in soil moisture between treatments were found below 90 cm except at Glenlea (Figure 4.11).

Orthogonal contrasts for soil moisture levels between alfalfa termination treatments in October (Table 4.10) showed significance primarily for the 0-30 cm soil increment, some significant treatments in the 30-90 cm depth, and almost no significant treatments below the 90 cm depth. Alfalfa termination by herbicide on date 1 conserved more soil moisture in the 0-30 cm depth than that by tillage at 4 of 4 sites. There was no difference between first date termination by herbicide vs. first date termination by tillage below the 30 cm depth (Table 4.10). Alfalfa termination on date 2 by herbicide also conserved more soil moisture in the upper 30 cm profile than the date 2 tillage treatment at 4 of 5 locations (Table 4.10). Below 30 cm, there were no significant differences in soil moisture. Herbicide terminated alfalfa at the first date conserved more soil moisture than herbicide terminated alfalfa at the second date in the 0-30 cm depth at 3 of 4 locations, and in the 30-90 cm depth, at 2 of 4 locations.

The soil moisture change from the time of measurement at the second termination date until the end of season (mid-October) was significantly different between treatments for the 0-30 cm increment at all sites except Winnipeg, and the 30-90 cm increment at all sites (Figure 4.10 through Figure 4.14). During this period, no differences in soil moisture change below 90 cm between treatments were found. Soil moisture differences for the 0-30 cm soil increment were due to both date and method of termination, except Carman (1992) which was due to date of herbicide method (herbicide only). Differences in soil moisture for the 30-90 cm increment were due only to date of termination.

Orthogonal contrasts between treatments for dynamic soil moisture differences from the second termination date until the end of season are shown in Table 4.11. In the 0-30 cm profile increment, alfalfa termination by herbicide on date 1 conserved greater soil moisture than termination by tillage on date 1 for 3 of 4 locations (Table 4.11). More soil moisture was conserved by the alfalfa suppression with herbicide on the second termination date than either tillage or herbicide plus delayed tillage treatments on the first termination date. These results suggest that alfalfa producers are able to obtain a second cut in a no-till system, and still conserve a greater level of soil water than with a tillage system. Also, the conservation of additional soil moisture has implications for growing winter cereals no-tilled into terminated alfalfa sod. The herbicide treatment on the first termination date conserved more moisture than herbicide terminated alfalfa on the second termination date for the 30-90 cm soil increment for 3 of 4 experiments. Therefore, terminating alfalfa earlier can conserve greater subsoil moisture, which is beneficial for the most annual crops, since their rooting zone occupies the 90 cm depth. No significant difference between treatments existed below the 90 cm soil depth implying that no leaching occurred below the root zone of annual crops.

4.4.2 Soil Moisture: Overwinter Recharge Period

Soil moisture reserves for all treatments were greater in spring than in the previous fall for the 0-30 cm soil increment at all locations, except Winnipeg (Figure 4.10 through Figure 4.14). Aase and Tanaka (1987) estimated that under fallow conditions, 50 to 70 % of soil water recharge occurs between harvest and the following spring. The 30-90 cm increment showed increased soil moisture for all treatments at all locations. Below 90 cm, moisture levels did not consistently show an increase at all locations.

Soil moisture recharge from fall until spring seeding was significantly affected by both the date and method of alfalfa termination at 3 of 5 locations for both the 0-30 cm and 30-90 cm increments (Figure 4.10 through Figure 4.14). Below 90 cm, no difference in moisture recharge occurred between treatments.

Orthogonal contrasts for the dynamic soil moisture recharge over winter indicated significant differences between treatments for the 0-30 cm and 30-90 cm soil increments (Table 4.12). Date 1 alfalfa termination by tillage for the 0-30 cm soil increment gained more moisture over winter than date 1 alfalfa termination by herbicide for 2 of 4 locations, however the herbicide treatment conserved greater total soil moisture during both fall and spring. The efficiency of soil water storage from rain and snow is partially dependent on the preceding soil water level (Greb, 1979; Staple et al., 1960), that is, treatments with higher soil moisture in the fall, such as date 1 herbicide termination in the present study, are not inclined to gain as much moisture overwinter as drier treatments. Grevers et al. (1986), however, observed autumn to spring seeding soil water recharge averaging 6.2 cm with zero tillage compared to 1.7 cm with conventional tillage. Grevers et al. (1986) noted that much of the difference was due to greater soil water losses between snow-melt and seeding with conventional tillage than with zero tillage.

The second date alfalfa termination by tillage also gained more soil moisture than the second date alfalfa termination by herbicide at one location for the 0-30 cm soil increment. The date 2 herbicide terminated alfalfa recharged soil moisture at a greater rate than the date 1 herbicide terminated alfalfa for the 0-30 cm profile at 3 of 4 locations, probably since it was drier at the time of the date 2 termination treatment, and therefore the date 2 termination treatment had a greater capacity to store additional moisture (Table 4.12). A similar additional increase in soil moisture by the date 2 tillage treatment over that of the date 1 tillage treatment was observed at only one location. The date 2 herbicide treatment gained more soil moisture overwinter for the 0-30 cm soil profile than the date 1 tillage treatment at Carman in 1992 and 1993, however the opposite was true for the Glenlea location. For the 30-90 cm soil increment, the second termination herbicide treatment gained more soil moisture than the first termination herbicide treatment at 2 of 4 locations. The second termination herbicide treatment gained more moisture for the 30-90 cm soil increment than either the first termination tillage or first termination herbicide plus delayed tillage treatments at 2 locations (Table 4.12). Lindwall and Anderson (1981) observed that fall tillage of chemically fallowed fields tended to decrease the amount of soil water stored over winter compared to no-till fields.

4.4.3 Soil Moisture: Evapotranspiration Period

4.4.3.1 Soil Moisture at Spring Seeding

Soil moisture differences in the profile at the time of spring seeding were primarily due to the method of alfalfa termination (Figure 4.06; Figure 4.07). These differences were observed only in the upper soil profile, and not below a 30 cm soil depth. The date of alfalfa termination influenced several individual soil moisture increments in the profile at some locations.

When larger soil depth increments were considered, soil moisture differences between treatments at the time of spring seeding occurred at 4 of 5 locations (Figure 4.10 through Figure 4.14). Differences in soil moisture occurred primarily in the 0-30 cm soil profile and were once again due to the method of alfalfa termination.

Orthogonal contrasts showed an increase in spring soil moisture with the herbicide termination compared to the tillage termination for the 0-30 cm soil increment (Table 4.13). Shanholtz and Lillard (1969) also measured greater available soil moisture at spring planting under a killed sod with a no-tillage system compared to that with conventional tillage. Brun et al. (1986) reported that under dryland conditions on the Great Plains, evaporation in April and May in a no-till crop production system was one cm less than in a conventional tilled system.

Soil moisture differences between herbicide vs. tillage treatments occurred at 3 of 4 locations for date 1 alfalfa termination, and 2 of 5 locations for date 2 alfalfa termination. The date 2 herbicide terminated alfalfa had greater moisture reserves in the 0-30 cm soil increment than date 1 alfalfa termination by tillage at 2 of 4 locations, and date 1 alfalfa terminated by herbicide plus delayed tillage at 1 of 3 locations. No differences in soil moisture occurred for alfalfa termination by either herbicide or tillage due to date of alfalfa termination (Table 4.13). Below 30 cm, no apparent differences in soil moisture existed between any contrasted treatments (Table 4.13). These results differ from those of Hennig and Rice (1977) who measured decreasing levels of available water at spring seeding to 120 cm soil depth, as the forage crop was terminated later in the season.

4.4.3.2 Late Spring Soil Moisture

Soil moisture measurements during late spring (late May to early June) at the four leaf to early tillering stage of wheat revealed similar patterns to those observed in early spring (Figure 4.08). The method of alfalfa termination influenced soil moisture to a 10 cm depth at two of three locations, whereas the date of alfalfa termination influenced several soil increments deeper in the profile.

When larger soil depth increments were considered, differences in late spring soil moisture between treatments were observed at the Holland site for the 0-30 cm soil increment only; the difference was due to the method of alfalfa termination (Figure 4.12). At the Holland site, alfalfa termination by herbicide on the first termination date maintained higher soil moisture levels during late spring than termination by tillage on the first date. Alfalfa termination by herbicide on date 2 had greater soil moisture reserves than termination by herbicide plus delayed tillage on the first date. Shanholtz and Lillard (1969) found that differences in soil moisture between no-till and conventionally tilled sod gradually decreased after planting, but continued to differ throughout the growing season. Clayton (1982) also observed soil moisture differences between no-till and tillage treatments in the upper 20 cm, but only for the first two months of the growing season. Orthogonal comparison between treatments revealed significantly higher moisture only at the Holland site for the 0-30 cm soil increment (Table 4.14). Jones et al. (1969) also found soil moisture differences to a 30 cm depth during the growing season by a no-tillage treatment with killed sod mulch compared to a conventional treatment with no mulch.

Almost no differences existed between treatments for the change in soil moisture from spring seeding till late spring (Figure 4.10; Figure 4.11; Figure 4.12). Late spring and summer of the cropping season has been documented as being the period of lowest soil moisture storage efficiency (Aase and Tanaka, 1987; Black et al., 1974; Greb, 1979; Smika and Wicks, 1968). Hill and Blevins (1973) concluded that soil moisture loss by evaporation was virtually eliminated during the early growing season from a corn crop grown under zero-tillage production with a killed sod mulch, however moisture losses after crop canopy closure equaled that of conventional tillage. Orthogonal contrasts indicated treatment differences at Carman in which the first termination tillage treatment lost less soil moisture during the spring than the second termination tillage treatment in the 0-30 cm profile (Table 4.15).

4.4.3.3 Soil Moisture at Grain Harvest

At the time of harvest, no differences between treatments existed in soil moisture in the upper soil profile (Figure 4.09). Soil moisture content at grain harvest increased over the duration of the evapotranspiration period at all three sites due to high amounts of precipitation that replenished moisture levels (Figure 4.10; Figure 4.11; Figure 412). Soil moisture levels between treatments at the time of harvest were significant only at Glenlea (Figure 4.11). No differences in soil moisture between treatments were shown by orthogonal contrasts, except for the 90-190 cm soil increment at Glenlea (Table 4.16). The date 1 termination treatment with herbicide had greater soil moisture reserves in the 90-190 cm soil increment than the second termination treatment (Table 4.16). The date 1 alfalfa termination treatment by tillage conserved greater moisture reserves than the date 2 herbicide termination treatment (Table 4.16). No consistent differences with moisture retention from late spring till harvest existed among treatments over the different sites (Table 4.17). Grevers et al. (1986) found that the pattern of soil water depletion over the growing season with spring wheat was similar with conventional and no-till systems.

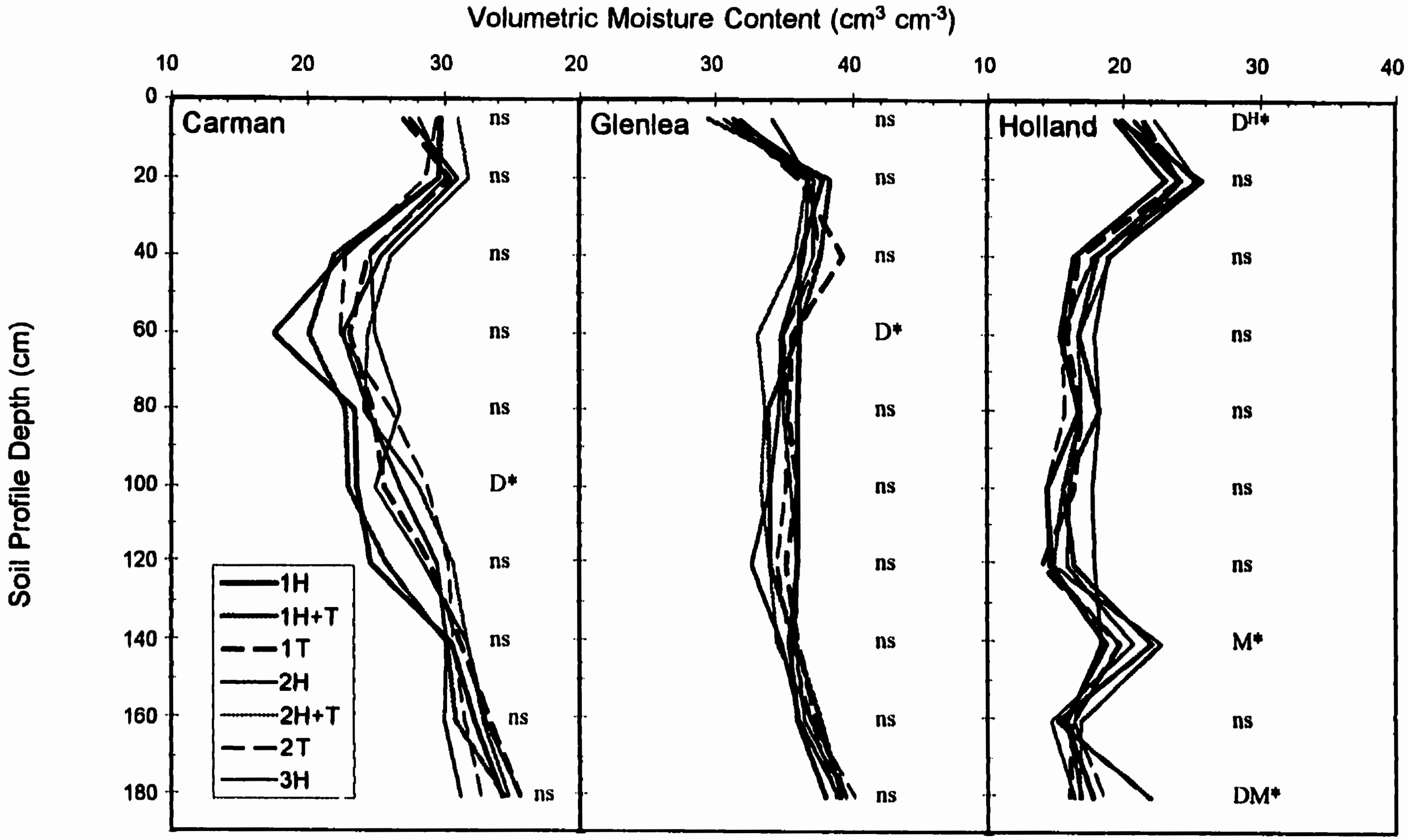

Figure 4.01. Soil profile moisture content (cm^3 m^{-3}) in mid-July (1992) at date 1 alfalfa termination at Carman, Glenlea, and Holland, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, significant at 0.05 probability level; ns, nonsignificant).

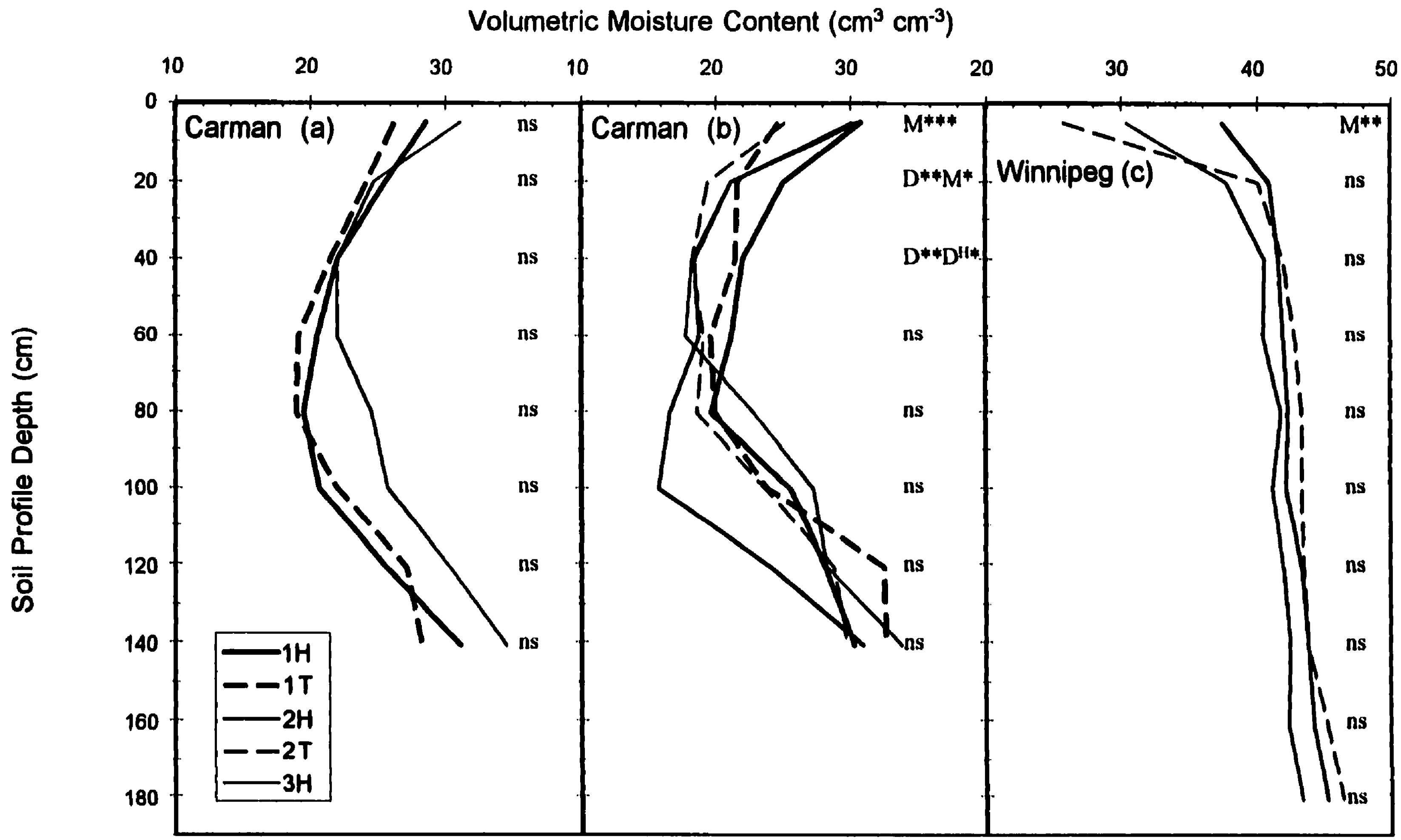

Figure 4.02. Soil profile moisture content (cm^3 m^{-3}) in late July (1993) at date 1 alfalfa termination at Carman, MB. (a), and mid-September (1993) at date 2 alfalfa termination at Carman (b) and Winnipeg, MB. (c), as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

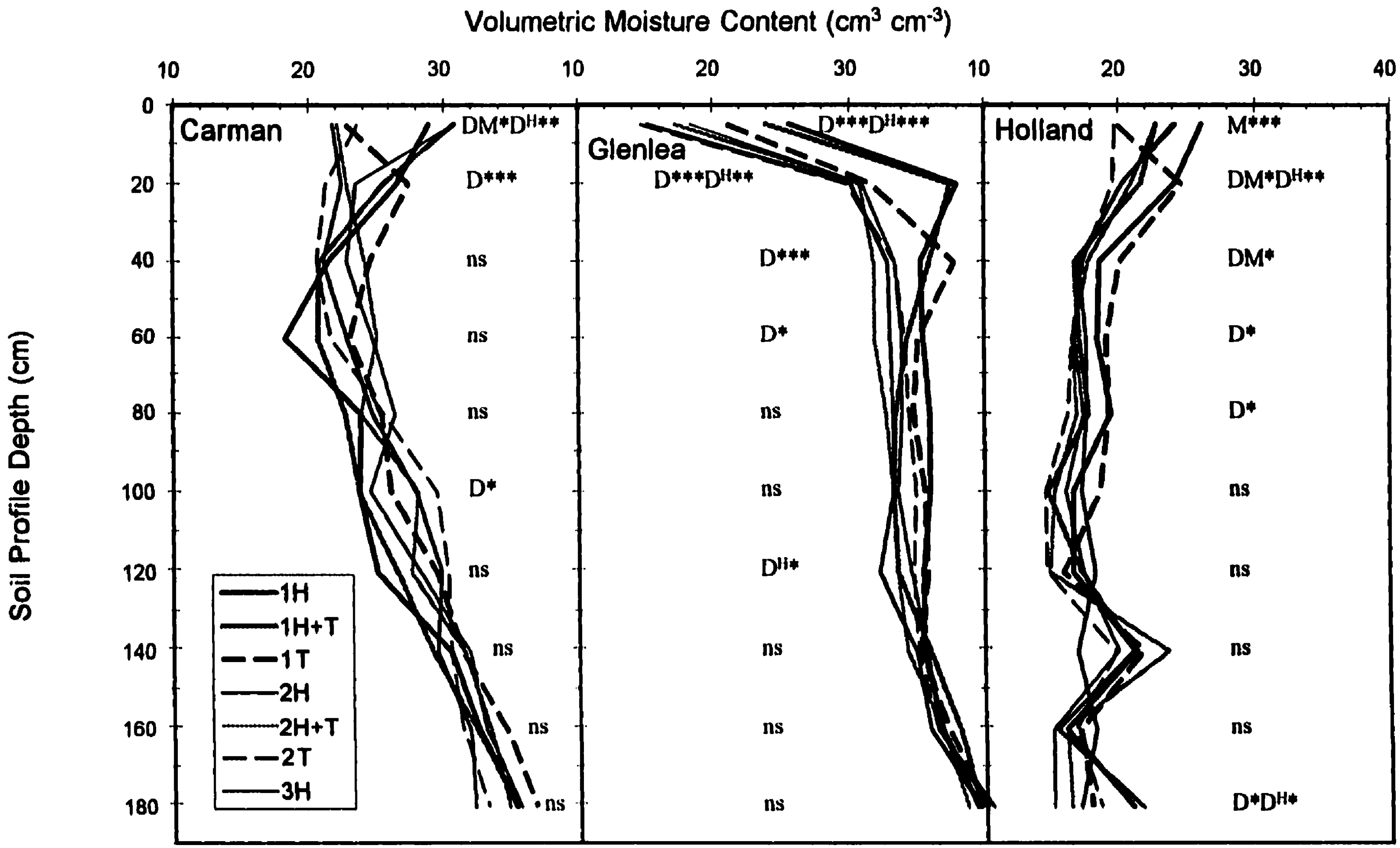

Figure 4.03. Soil profile moisture content (cm^3 m^{-3}) in late August (1992) at date 2 alfalfa termination at Carman, Glenlea, and Holland, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels, respectively; ns, nonsignificant).

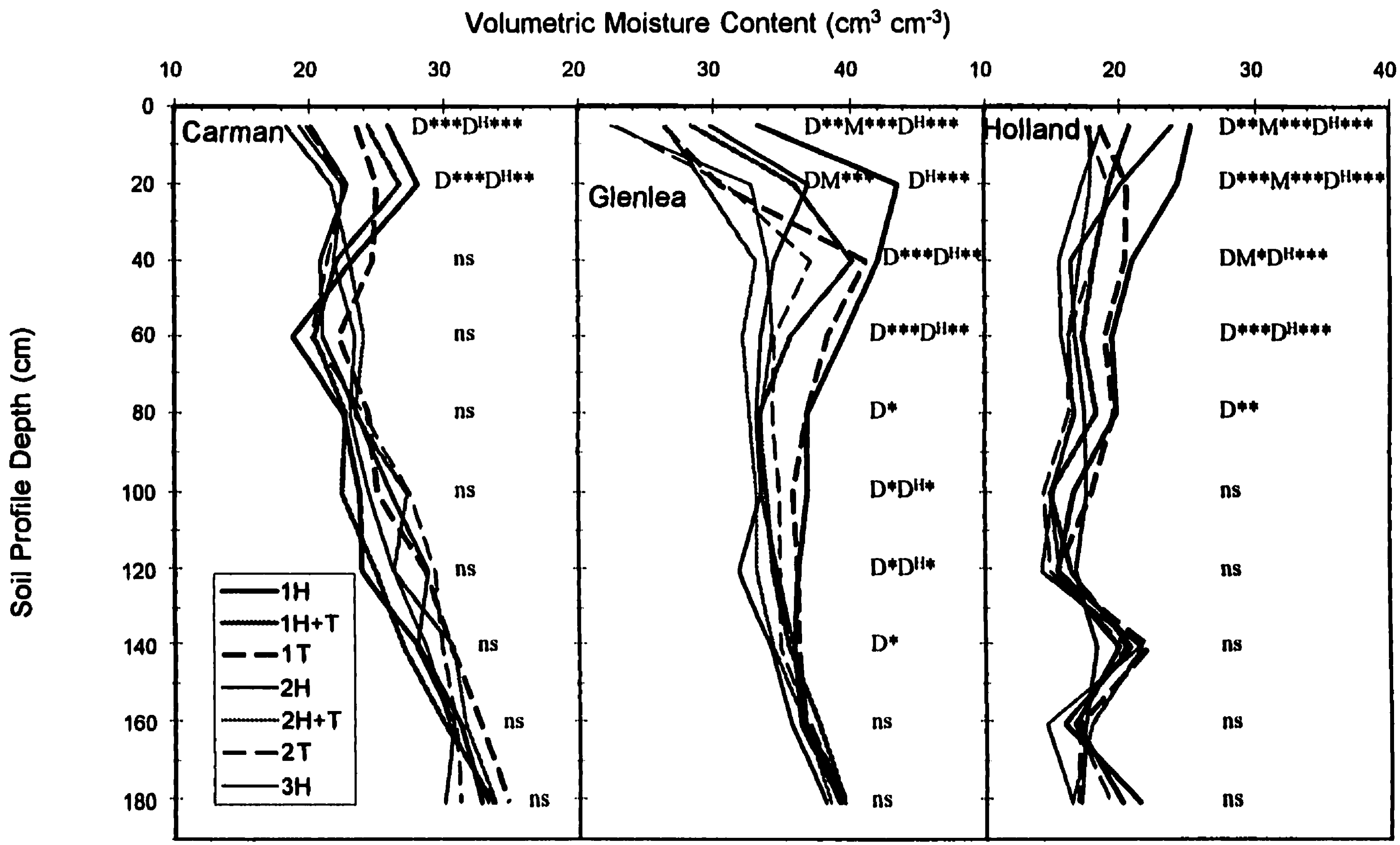

Figure 4.04. Soil profile moisture content ($cm^3\ m^{-3}$) in mid-October (1992) at Carman, Glenlea, and Holland, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels, respectively; ns, nonsignificant).

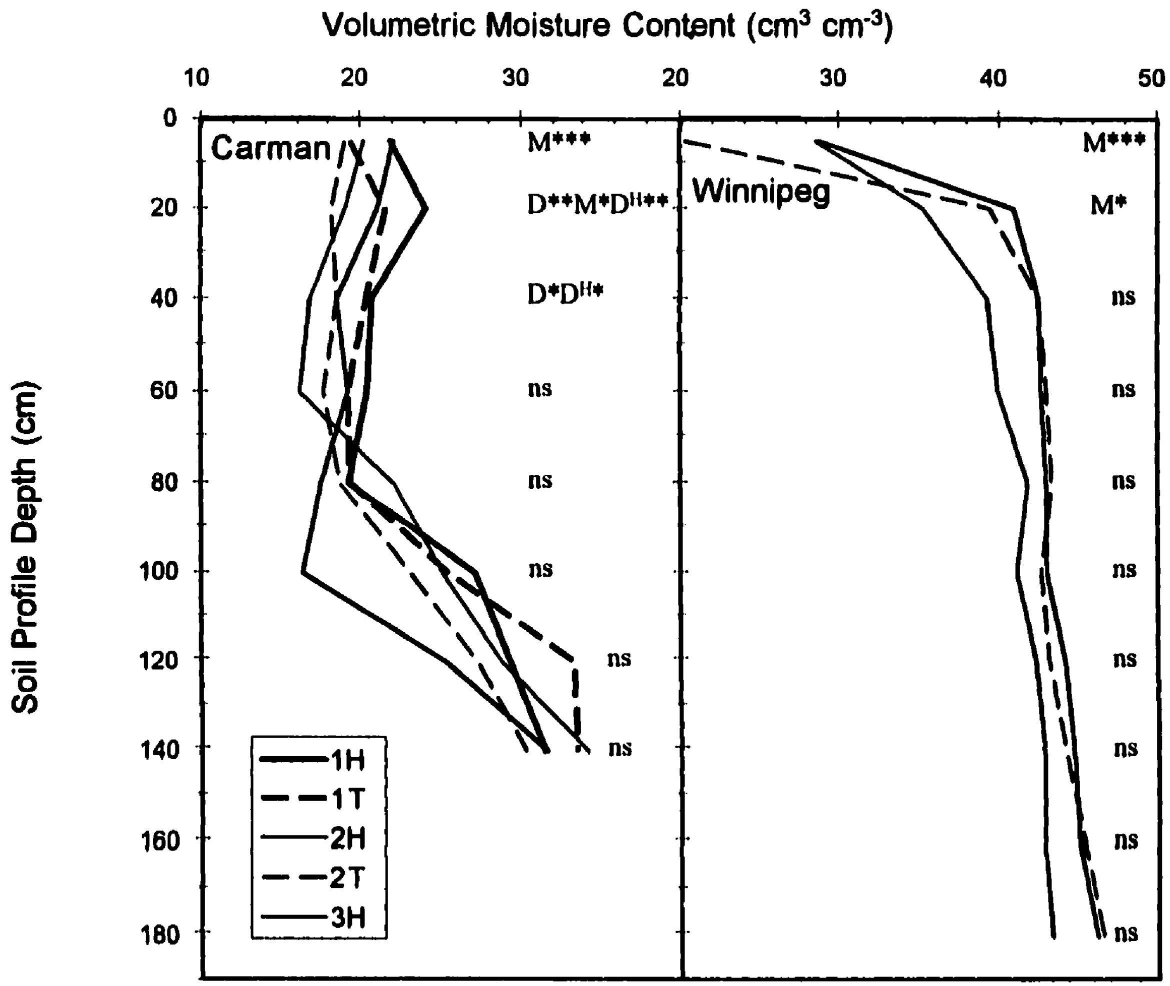

Figure 4.05. Soil profile moisture content (cm³ m⁻³) in mid-October (1993) at Carman and Winnipeg, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

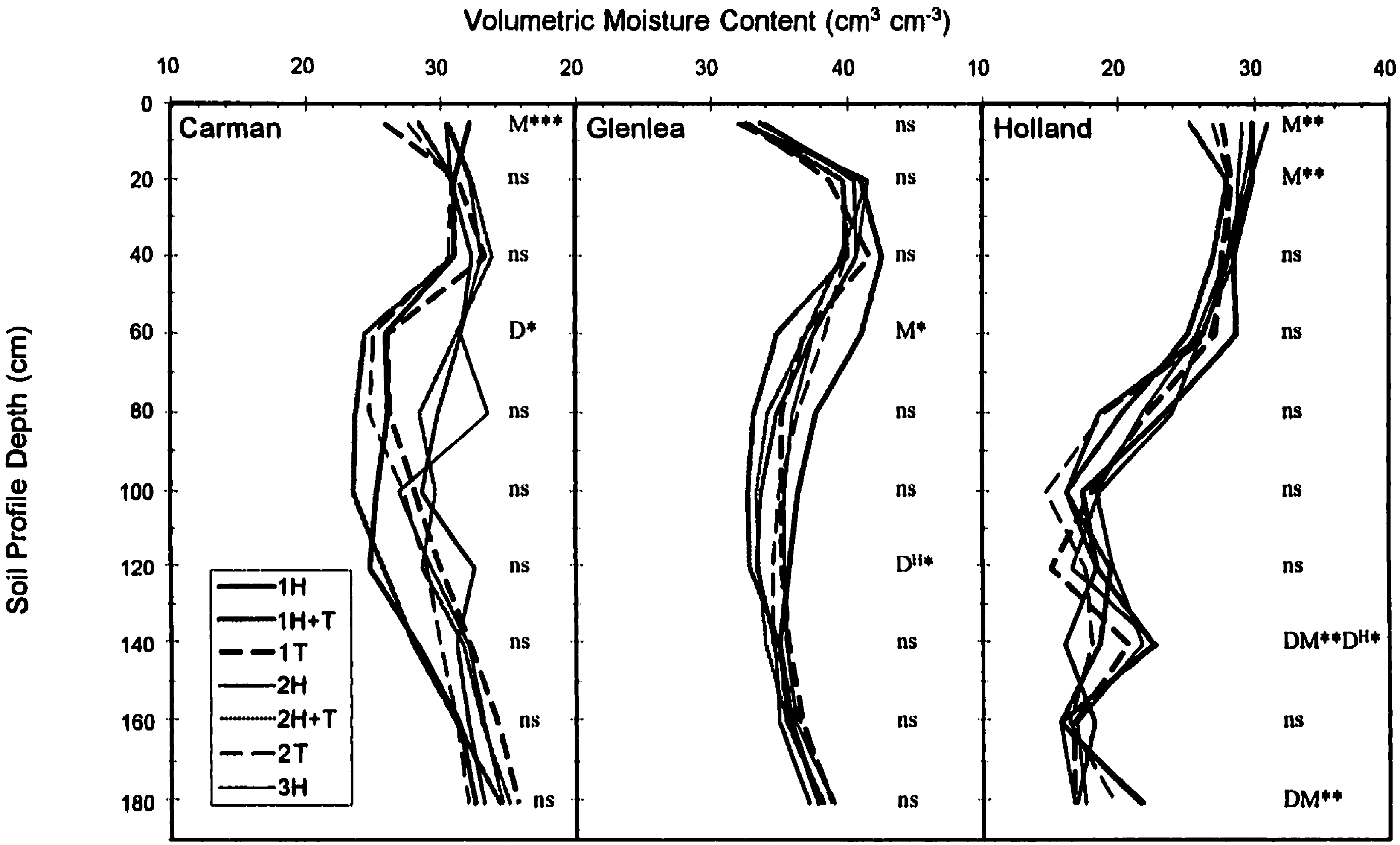

Figure 4.06. Soil profile moisture content ($cm^3 m^{-3}$) during spring (1993) at the time of seeding at Carman, Glenlea, and Holland, MB., as affected by date (1-first temination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels, respectively; ns, nonsignificant).

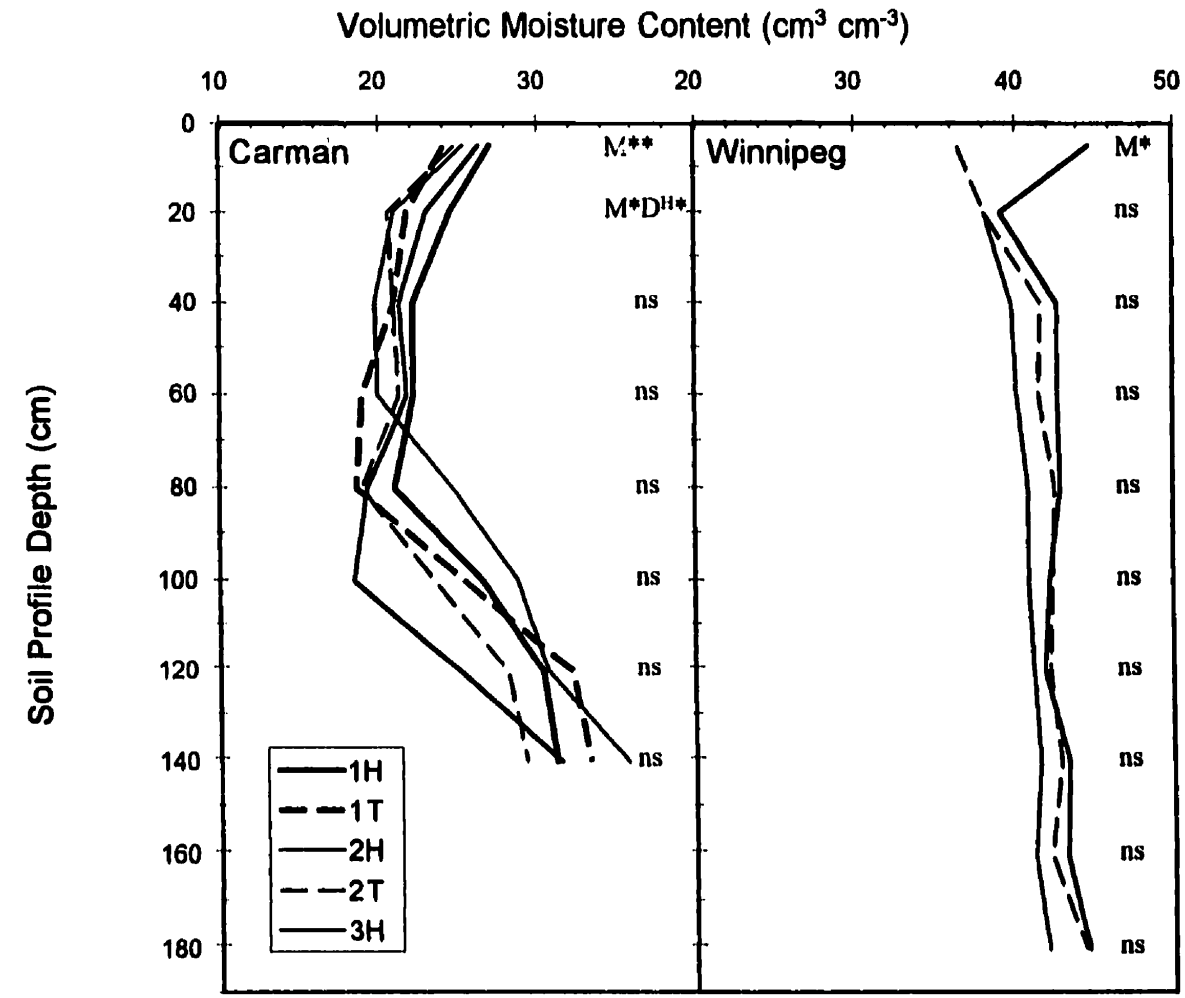

Figure 4.07. Soil profile moisture content (cm³ m⁻³) during spring (1994) at the time of seeding at Carman and Winnipeg, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, significant at 0.05, 0.01 probability levels respectively; ns, nonsignificant).

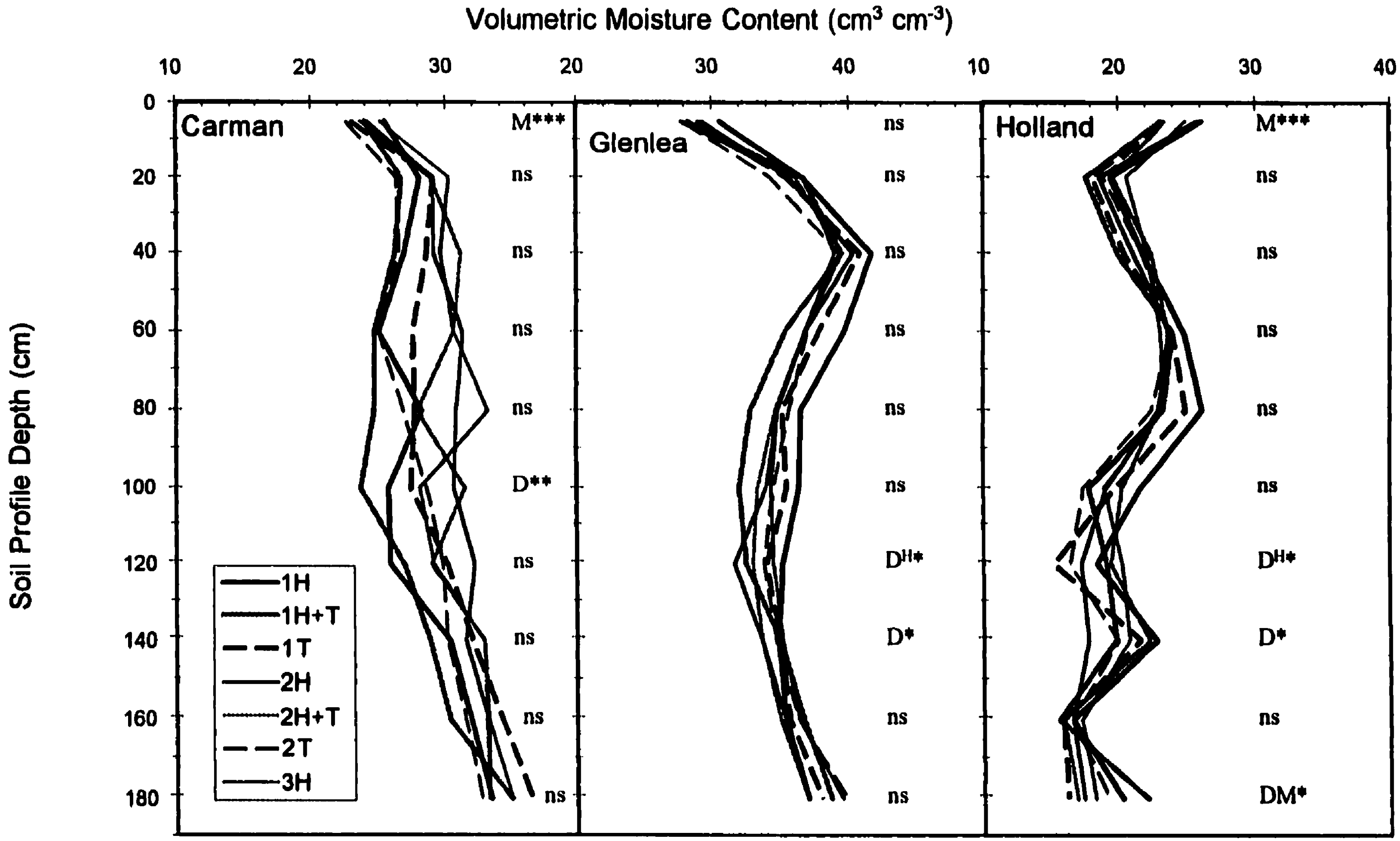

Figure 4.08. Soil profile moisture content (cm³ m⁻³) during late spring (1993) at Carman, Glenlea, and Holland, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels, respectively; ns, nonsignificant).

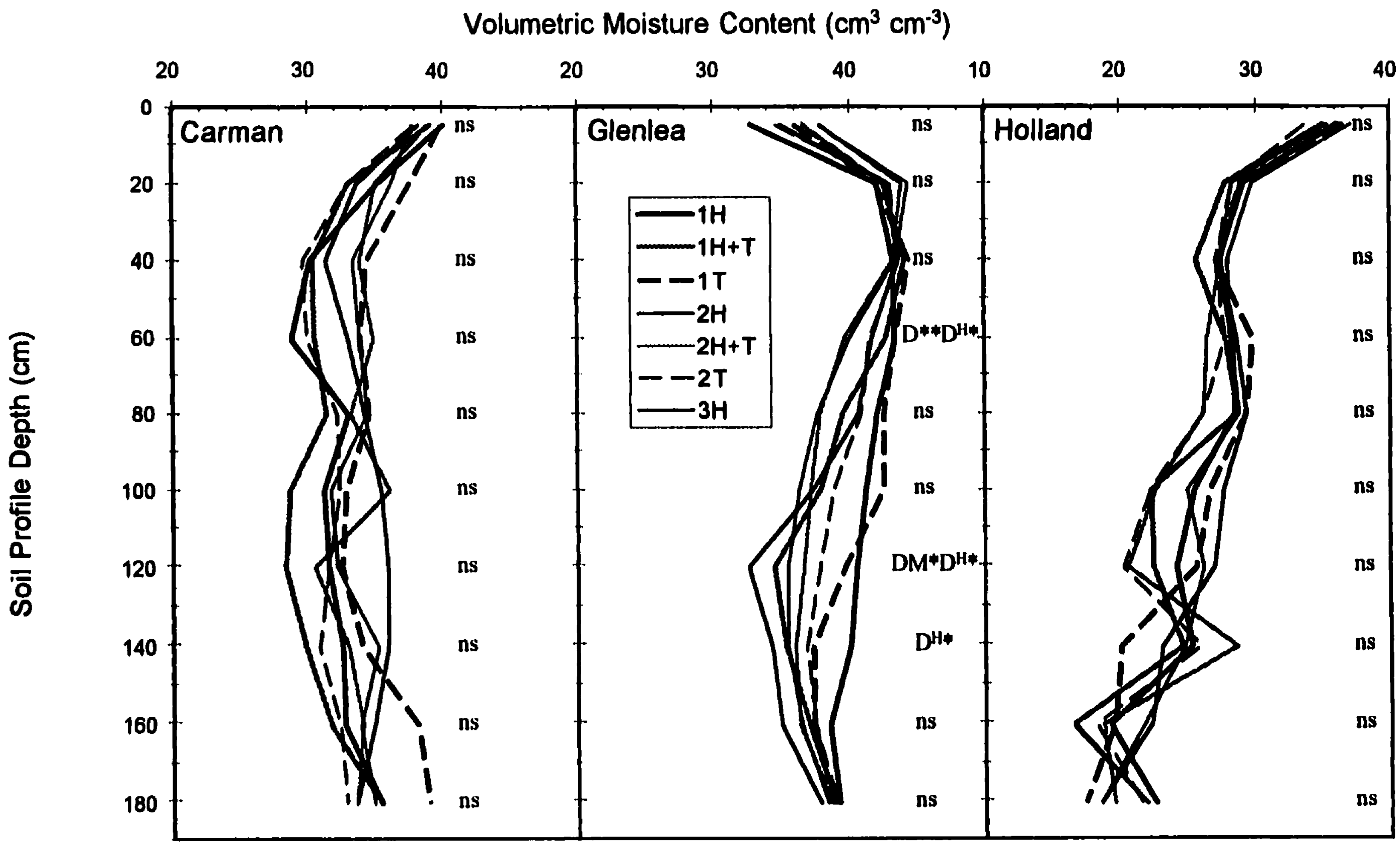

Figure 4.09. Soil profile moisture content ($cm^3\ m^{-3}$) in late August (1993) at the time of harvest at Carman, Glenlea, and Holland, MB., as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). (*, **, significant at 0.05, 0.01 probability levels, respectively; ns, nonsignificant).

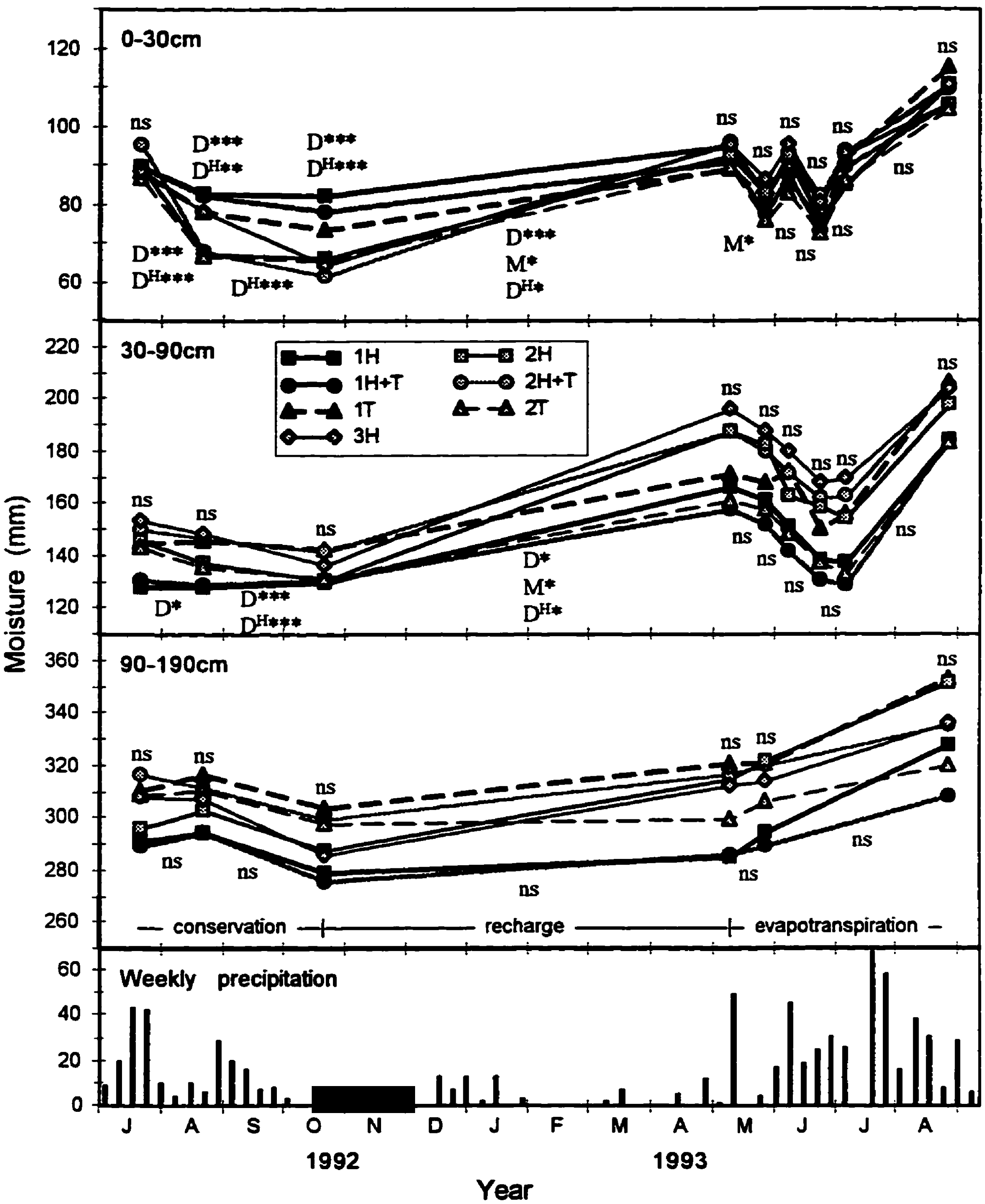

Figure 4.10. Soil moisture content for profile increments of 0-30 cm, 30-90 cm, and 90-190 cm at Carman, MB., from the initial dates of alfalfa termination to the harvest of the successive wheat crop, as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). Upper analysis indicates static soil moisture differences between treatments at a specific time. Lower analysis indicates dynamic soil moisture differences (conservation, recharge, evapotranspiration) between treatments over a duration of time. (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

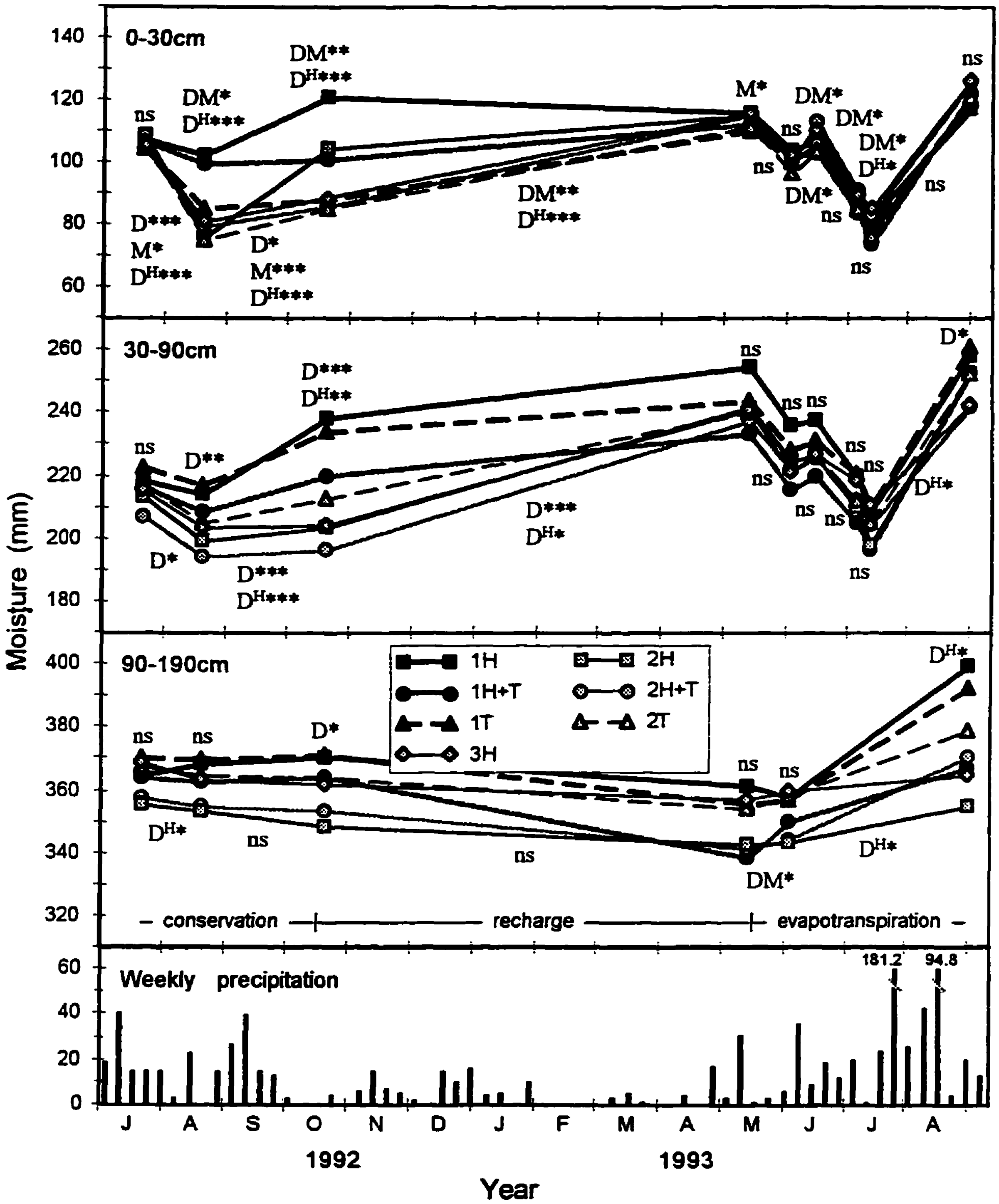

Figure 4.11. Soil moisture content for profile increments of 0-30 cm, 30-90 cm, and 90-190 cm at Glenlea, MB., from the initial dates of alfalfa termination to the harvest of the successive wheat crop, as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). Upper analysis indicates static soil moisture differences between treatments at a specific time. Lower analysis indicates dynamic soil moisture differences (conservation, recharge, evapotranspiration) between treatments over a duration of time. (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

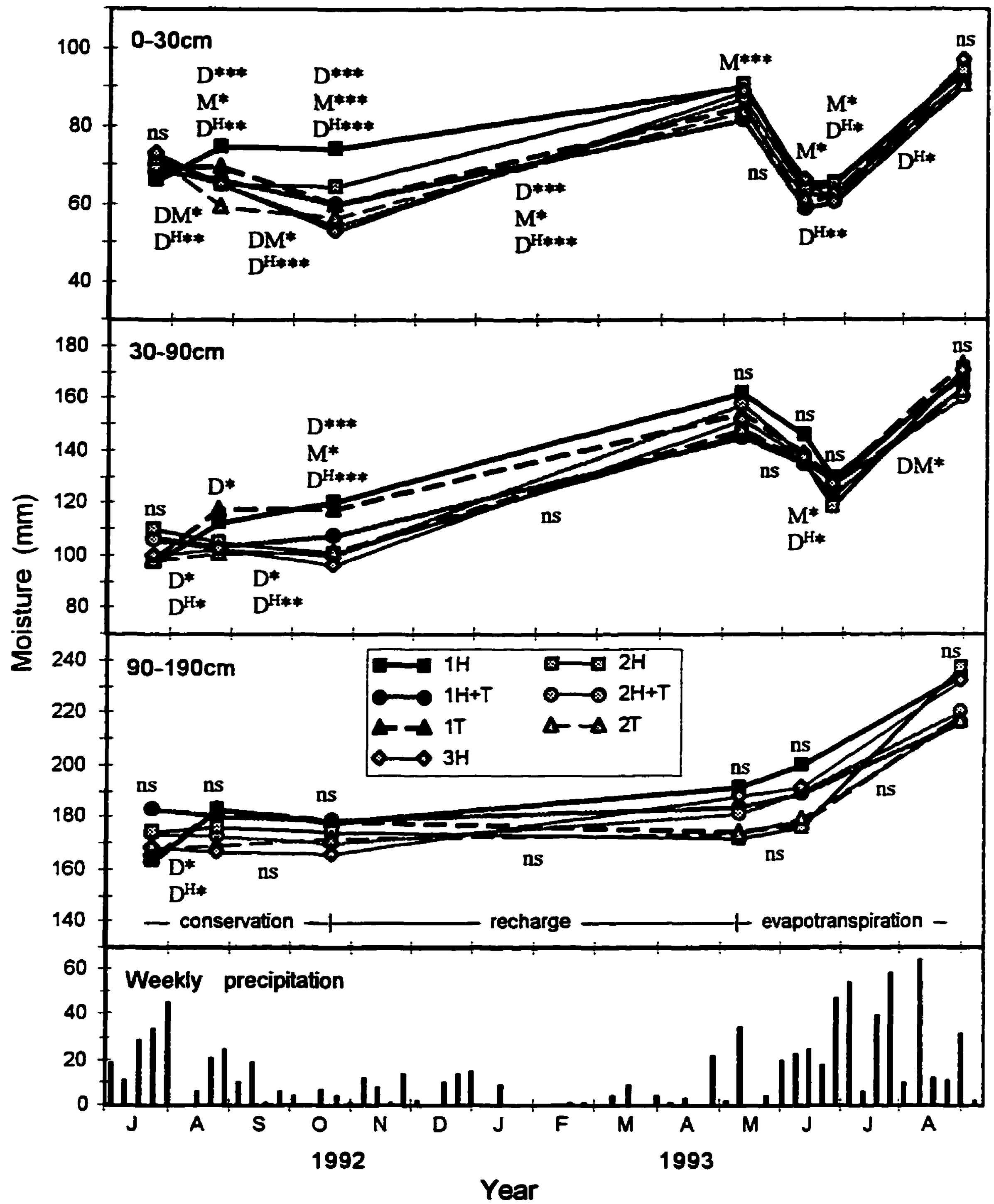

Figure 4.12. Soil moisture content for profile increments of 0-30 cm, 30-90 cm, and 90-190 cm at Holland, MB., from the initial dates of alfalfa termination to the harvest of the successive wheat crop, as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; H+T-herbicide plus delayed tillage; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). Upper analysis indicates static soil moisture differences between treatments at a specific time. Lower analysis indicates dynamic soil moisture differences (conservation, recharge, evapotranspiration) between treatments over a duration of time. (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

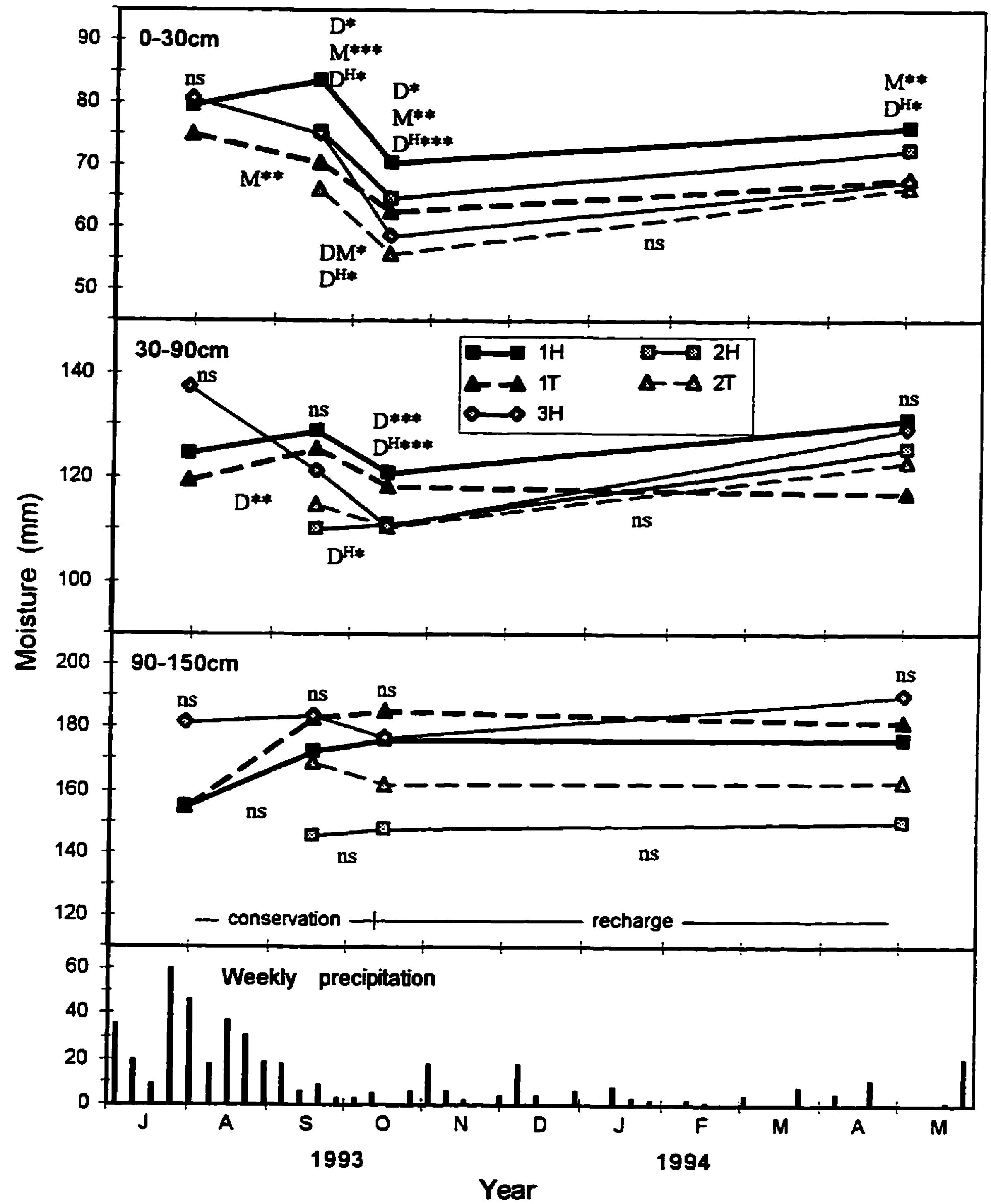

Figure 4.13. Soil moisture content for profile increments of 0-30 cm, 30-90 cm, and 90-150 cm at Carman, MB., from the initial dates of alfalfa termination to the spring of the following year, as affected by date (1-first termination; 2-second termination; 3-spring termination), and method (H-herbicide; T-tillage) of alfalfa removal. (D, date; M, method; DM, date x method interaction; D^H, date of herbicide termination method). Upper analysis indicates static soil moisture differences between treatments at a specific time. Lower analysis indicates dynamic soil moisture differences (conservation, recharge) between treatments over a duration of time. (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

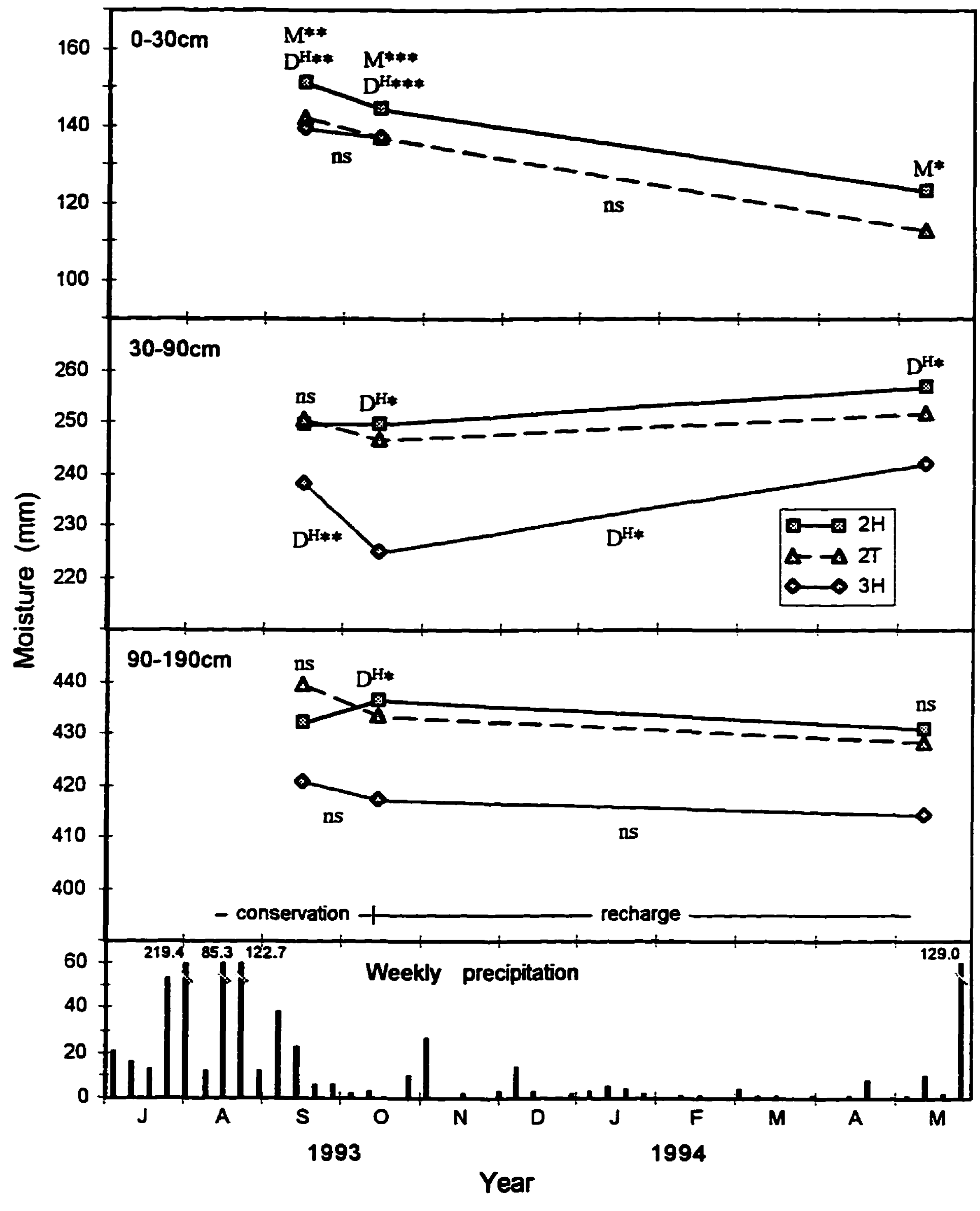

Figure 4.14. Soil moisture content for profile increments of 0-30 cm, 30-90 cm, and 90-190 cm at Winnipeg, MB., from the initial date of alfalfa termination to the spring of the following year, as affected by date (2-second termination; 3-spring termination), and method (H-herbicide; T-tillage) of alfalfa removal. (M, method; D^H, date of herbicide termination method). Upper analysis indicates static soil moisture differences between treatments at a specific time. Lower analysis indicates dynamic soil moisture differences (conservation, recharge) between treatments over a duration of time. (*, **, ***, significant at 0.05, 0.01, 0.001 probability levels respectively; ns, nonsignificant).

Table 4.07. Orthogonal contrasts for soil moisture levels in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) in July at the first alfalfa termination (date 1) as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992), and Carman, MB.(1993).

	1992			1993
Contrasts	Carman	Glenlea	Holland	Carman
	P>F			
0-30 cm				
Herbicide vs. tillage (date 1)	0.840	0.397	0.209	0.160
Herbicide vs. tillage (date 2)	0.490	0.583	0.973	-
Herbicide (date 1 vs. date 2)	0.891	0.776	0.742	0.722
Tillage (date 1 vs. date 2)	0.722	0.558	0.539	-
Herbicide (date 2) vs. tillage (date 1)	0.735	0.262	0.561	0.096
Herbicide (date 2) vs. H+T (date 1)	0.896	0.634	0.294	-
30-90 cm				
Herbicide vs. tillage (date 1)	0.255	0.607	0.831	0.730
Herbicide vs. tillage (date 2)	0.869	0.602	0.194	-
Herbicide (date 1 vs. date 2)	0.250	0.552	0.145	0.424
Tillage (date 1 vs. date 2)	0.879	0.556	0.967	-
Herbicide (date 2) vs. tillage (date 1)	0.989	0.273	0.207	0.268
Herbicide (date 2) vs. H+T (date 1)	0.317	0.728	0.653	-
90-190 cm†				
Herbicide vs. tillage (date 1)	0.357	0.541	0.885	0.998
Herbicide vs. tillage (date 2)	0.534	0.188	0.621	-
Herbicide (date 1 vs. date 2)	0.801	0.301	0.412	0.224
Tillage (date 1 vs. date 2)	0.957	0.753	0.851	-
Herbicide (date 2) vs. tillage (date 1)	0.450	0.109	0.496	0.223
Herbicide (date 2) vs. H+T (date 1)	0.726	0.363	0.504	-

† Soil moisture increment at Carman (1993) was 90-150 cm.

Table 4.08. Orthogonal contrasts for soil moisture levels in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) in August/September at the second alfalfa termination (date 2) as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992), and Carman and Winnipeg, MB.(1993).

	1992			1993	
Contrasts	**Carman**	**Glenlea**	**Holland**	**Carman**	**Winnipeg**
	P>F				
0-30 cm					
Herbicide vs. tillage (date 1)	0.316	<0.001	0.057	<0.001	-
Herbicide vs. tillage (date 2)	0.939	0.825	0.045	0.009	0.004
Herbicide (date 1 vs. date 2)	0.002	<0.001	0.002	0.018	-
Tillage (date 1 vs. date 2)	0.014	0.025	0.001	-	-
Herbicide (date 2) vs. tillage (date 1)	0.017	0.039	0.105	0.103	-
Herbicide (date 2) vs. H+T (date 1)	0.002	<0.001	0.593	-	-
30-90 cm					
Herbicide vs. tillage (date 1)	0.260	0.720	0.467	0.798	-
Herbicide vs. tillage (date 2)	0.914	0.411	0.482	0.729	0.576
Herbicide (date 1 vs. date 2)	0.533	0.037	0.174	0.183	-
Tillage (date 1 vs. date 2)	0.532	0.093	0.010	-	-
Herbicide (date 2) vs. tillage (date 1)	0.604	0.018	0.045	0.272	-
Herbicide (date 2) vs. H+T (date 1)	0.575	0.201	0.804	-	-
90-190 cm†					
Herbicide vs. tillage (date 1)	0.354	0.848	0.996	0.692	-
Herbicide vs. tillage (date 2)	0.760	0.201	0.633	0.382	0.244
Herbicide (date 1 vs. date 2)	0.709	0.096	0.624	0.324	-
Tillage (date 1 vs. date 2)	0.797	0.541	0.341	-	-
Herbicide (date 2) vs. tillage (date 1)	0.574	0.067	0.628	0.177	-
Herbicide (date 2) vs. H+T (date 1)	0.712	0.293	0.748	-	-

† Soil moisture increment at Carman (1993) was 90-150 cm.

Table 4.09. Orthogonal contrasts for dynamic soil moisture differences in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) during the soil moisture conservation period from the first to the second alfalfa termination dates, as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992), and Carman, MB.(1993).

Contrasts	1992 Carman	1992 Glenlea	1992 Holland	1993 Carman
	P>F			
0-30 cm				
Herbicide vs. tillage (date 1)	0.348	0.009	0.004	0.006
Herbicide vs. tillage (date 2)	0.480	0.785	0.054	-
Herbicide (date 1 vs. date 2)	<0.001	<0.001	<0.001	0.003
Tillage (date 1 vs. date 2)	0.013	0.020	<0.001	-
Herbicide (date 2) vs. tillage (date 1)	0.003	0.011	0.039	0.548
Herbicide (date 2) vs. H+T (date 1)	<0.001	<0.001	0.118	-
30-90 cm				
Herbicide vs. tillage (date 1)	0.795	0.736	0.756	0.730
Herbicide vs. tillage (date 2)	0.849	0.794	0.335	-
Herbicide (date 1 vs. date 2)	0.067	0.064	0.012	0.424
Tillage (date 1 vs. date 2)	0.059	0.190	0.048	-
Herbicide (date 2) vs. tillage (date 1)	0.040	0.121	0.006	0.268
Herbicide (date 2) vs. H+T (date 1)	0.127	0.259	0.746	-
90-190 cm†				
Herbicide vs. tillage (date 1)	0.607	0.216	0.798	0.464
Herbicide vs. tillage (date 2)	0.351	0.831	0.966	-
Herbicide (date 1 vs. date 2)	0.539	0.070	0.029	0.307
Tillage (date 1 vs. date 2)	0.403	0.402	0.046	-
Herbicide (date 2) vs. tillage (date 1)	0.920	0.529	0.050	0.106
Herbicide (date 2) vs. H+T (date 1)	0.795	0.714	0.582	-

† Soil moisture increment at Carman (1993) was 90-150 cm.

Table 4.10. Orthogonal contrasts for soil moisture levels in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) in October as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992), and Carman and Winnipeg, MB.(1993).

Contrasts	1992 Carman	1992 Glenlea	1992 Holland	1993 Carman	1993 Winnipeg
	P>F				
0-30 cm					
Herbicide vs. tillage (date 1)	0.018	<0.001	<0.001	0.030	-
Herbicide vs. tillage (date 2)	0.878	<0.001	<0.001	0.017	<0.001
Herbicide (date 1 vs. date 2)	<0.001	<0.001	<0.001	0.096	-
Tillage (date 1 vs. date 2)	0.024	0.406	0.072	-	-
Herbicide (date 2) vs. tillage (date 1)	0.033	<0.001	0.053	0.528	-
Herbicide (date 2) vs. H+T (date 1)	0.002	0.259	0.036	-	-
30-90 cm					
Herbicide vs. tillage (date 1)	0.390	0.674	0.501	0.132	-
Herbicide vs. tillage (date 2)	0.990	0.290	0.920	0.627	0.985
Herbicide (date 1 vs. date 2)	0.920	0.001	<0.001	0.154	-
Tillage (date 1 vs. date 2)	0.454	0.027	<0.001	-	-
Herbicide (date 2) vs. tillage (date 1)	0.446	0.003	<0.001	0.928	-
Herbicide (date 2) vs. H+T (date 1)	0.967	0.078	0.090	-	-
90-190 cm†					
Herbicide vs. tillage (date 1)	0.271	0.990	0.920	0.819	-
Herbicide vs. tillage (date 2)	0.653	0.138	0.795	0.426	0.730
Herbicide (date 1 vs. date 2)	0.699	0.036	0.775	0.192	-
Tillage (date 1 vs. date 2)	0.780	0.476	0.521	-	-
Herbicide (date 2) vs. tillage (date 1)	0.468	0.035	0.700	0.132	-
Herbicide (date 2) vs. H+T (date 1)	0.576	0.138	0.716	-	-

† Soil moisture increment at Carman (1993) was 90-150 cm.

Table 4.11. Orthogonal contrasts for dynamic soil moisture differences in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) during the soil moisture conservation period from the second alfalfa termination date to late fall, as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992), and Carman and Winnipeg, MB.(1993).

	1992			1993	
Contrasts	Carman	Glenlea	Holland	Carman	Winnipeg
	P>F				
0-30 cm					
Herbicide vs. tillage (date 1)	0.175	0.003	<0.001	0.004	-
Herbicide vs. tillage (date 2)	0.950	0.001	0.301	0.720	0.360
Herbicide (date 1 vs. date 2)	0.722	0.058	0.945	0.156	-
Tillage (date 1 vs. date 2)	0.337	0.131	0.008	-	-
Herbicide (date 2) vs. tillage (date 1)	0.307	<0.001	<0.001	0.066	-
Herbicide (date 2) vs. H+T (date 1)	0.356	<0.001	0.012	-	-
30-90 cm					
Herbicide vs. tillage (date 1)	0.043	0.189	0.082	0.248	-
Herbicide vs. tillage (date 2)	0.431	0.380	0.227	0.319	0.220
Herbicide (date 1 vs. date 2)	0.002	<0.001	0.007	0.536	-
Tillage (date 1 vs. date 2)	0.577	0.048	0.941	-	-
Herbicide (date 2) vs. tillage (date 1)	0.186	0.007	0.256	0.089	-
Herbicide (date 2) vs. H+T (date 1)	0.003	0.104	0.051	-	-
90-190 cm†					
Herbicide vs. tillage (date 1)	0.696	0.684	0.769	0.661	-
Herbicide vs. tillage (date 2)	0.611	0.285	0.382	0.703	0.095
Herbicide (date 1 vs. date 2)	0.918	0.057	0.398	0.641	-
Tillage (date 1 vs. date 2)	0.988	0.612	0.161	-	-
Herbicide (date 2) vs. tillage (date 1)	0.622	0.123	0.578	0.978	-
Herbicide (date 2) vs. H+T (date 1)	0.489	0.113	0.944	-	-

† Soil moisture increment at Carman (1993) was 90-150 cm.

Table 4.12. Orthogonal contrasts for dynamic soil moisture differences in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) during the soil moisture recharge period from late fall to spring seeding of the following year, as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992-1993), and Carman and Winnipeg, MB.(1993-1994).

	1992-1993			1993-1994	
Contrasts	Carman	Glenlea	Holland	Carman	Winnipeg
	P>F				
0-30 cm					
Herbicide vs. tillage (date 1)	0.348	<0.001	0.004	0.858	-
Herbicide vs. tillage (date 2)	0.449	<0.001	0.780	0.311	0.609
Herbicide (date 1 vs. date 2)	<0.001	<0.001	<0.001	0.454	-
Tillage (date 1 vs. date 2)	0.021	0.256	0.332	-	-
Herbicide (date 2) vs. tillage (date 1)	0.004	0.001	0.484	0.357	-
Herbicide (date 2) vs. H+T (date 1)	<0.001	0.942	0.088	-	-
30-90 cm					
Herbicide vs. tillage (date 1)	0.355	0.447	0.643	0.998	-
Herbicide vs. tillage (date 2)	0.006	0.250	0.887	0.843	0.439
Herbicide (date 1 vs. date 2)	0.031	0.025	0.733	0.462	-
Tillage (date 1 vs. date 2)	0.865	0.056	0.349	-	-
Herbicide (date 2) vs. tillage (date 1)	0.004	0.005	0.424	0.461	-
Herbicide (date 2) vs. H+T (date 1)	0.003	0.013	0.523	-	-
90-190 cm†					
Herbicide vs. tillage (date 1)	0.288	0.483	0.129	0.976	-
Herbicide vs. tillage (date 2)	0.034	0.601	0.667	0.499	0.286
Herbicide (date 1 vs. date 2)	0.064	0.615	0.158	0.540	-
Tillage (date 1 vs. date 2)	0.174	0.496	0.587	-	-
Herbicide (date 2) vs. tillage (date 1)	0.392	0.236	0.909	0.559	-
Herbicide (date 2) vs. H+T (date 1)	0.145	0.015	0.475	-	-

† Soil moisture increment at Carman (1993-1994) was 90-150 cm.

Table 4.13. Orthogonal contrasts for soil moisture levels in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) in May as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1993), and Carman and Winnipeg, MB.(1994).

	1993			1994	
Contrasts	Carman	Glenlea	Holland	Carman	Winnipeg
	P>F				
0-30 cm					
Herbicide vs. tillage (date 1)	0.084	0.020	0.025	0.018	-
Herbicide vs. tillage (date 2)	0.298	0.133	0.003	0.065	0.029
Herbicide (date 1 vs. date 2)	0.535	0.679	0.655	0.230	-
Tillage (date 1 vs. date 2)	0.901	0.587	0.614	-	-
Herbicide (date 2) vs. tillage (date 1)	0.246	0.048	0.010	0.169	-
Herbicide (date 2) vs. H+T (date 1)	0.551	0.201	<0.001	-	-
30-90 cm					
Herbicide vs. tillage (date 1)	0.737	0.200	0.524	0.356	-
Herbicide vs. tillage (date 2)	0.098	0.907	0.869	0.874	0.343
Herbicide (date 1 vs. date 2)	0.172	0.127	0.203	0.695	-
Tillage (date 1 vs. date 2)	0.514	0.702	0.620	-	-
Herbicide (date 2) vs. tillage (date 1)	0.294	0.790	0.510	0.587	-
Herbicide (date 2) vs. H+T (date 1)	0.066	0.336	0.926	-	-
90-190 cm†					
Herbicide vs. tillage (date 1)	0.140	0.569	0.140	0.818	-
Herbicide vs. tillage (date 2)	0.508	0.213	0.860	0.624	0.608
Herbicide (date 1 vs. date 2)	0.213	0.049	0.084	0.309	-
Tillage (date 1 vs. date 2)	0.365	0.816	0.915	-	-
Herbicide (date 2) vs. tillage (date 1)	0.803	0.144	0.777	0.219	-
Herbicide (date 2) vs. H+T (date 1)	0.231	0.629	0.269	-	-

† Soil moisture increment at Carman (1994) was 90-150 cm.

Table 4.14. Orthogonal contrasts for soil moisture levels in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) in late spring as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1993).

Contrasts	Carman	Glenlea	Holland
		P > F	
0-30 cm			
Herbicide vs. tillage (date 1)	0.912	0.354	0.015
Herbicide vs. tillage (date 2)	0.070	0.333	0.347
Herbicide (date 1 vs. date 2)	0.863	0.436	0.432
Tillage (date 1 vs. date 2)	0.119	0.412	0.372
Herbicide (date 2) vs. tillage (date 1)	0.778	0.878	0.076
Herbicide (date 2) vs. H+T (date 1)	0.196	0.840	0.024
30-90 cm			
Herbicide vs. tillage (date 1)	0.648	0.363	0.434
Herbicide vs. tillage (date 2)	0.124	0.998	0.981
Herbicide (date 1 vs. date 2)	0.183	0.198	0.258
Tillage (date 1 vs. date 2)	0.497	0.688	0.735
Herbicide (date 2) vs. tillage (date 1)	0.370	0.690	0.718
Herbicide (date 2) vs. H+T (date 1)	0.062	0.327	0.895
90-190 cm			
Herbicide vs. tillage (date 1)	0.273	0.907	0.053
Herbicide vs. tillage (date 2)	0.507	0.168	0.781
Herbicide (date 1 vs. date 2)	0.260	0.176	0.043
Tillage (date 1 vs. date 2)	0.527	0.884	0.860
Herbicide (date 2) vs. tillage (date 1)	0.976	0.210	0.919
Herbicide (date 2) vs. H+T (date 1)	0.186	0.675	0.260

Table 4.15. Orthogonal contrasts for dynamic soil moisture differences in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) during the soil moisture evapotranspiration period from spring seeding to late spring, as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1993).

Contrasts	Carman	Glenlea	Holland
		P>F	
0-30 cm			
Herbicide vs. tillage (date 1)	0.064	0.632	0.900
Herbicide vs. tillage (date 2)	0.164	0.911	0.041
Herbicide (date 1 vs. date 2)	0.340	0.576	0.290
Tillage (date 1 vs. date 2)	0.025	0.257	0.232
Herbicide (date 2) vs. tillage (date 1)	0.335	0.304	0.349
Herbicide (date 2) vs. H+T (date 1)	0.255	0.346	0.075
30-90 cm			
Herbicide vs. tillage (date 1)	0.584	0.592	0.904
Herbicide vs. tillage (date 2)	0.746	0.847	0.809
Herbicide (date 1 vs. date 2)	0.979	0.798	0.441
Tillage (date 1 vs. date 2)	0.842	0.929	0.679
Herbicide (date 2) vs. tillage (date 1)	0.602	0.778	0.514
Herbicide (date 2) vs. H+T (date 1)	0.696	0.863	0.997
90-190 cm			
Herbicide vs. tillage (date 1)	0.085	0.278	0.235
Herbicide vs. tillage (date 2)	0.989	0.869	0.806
Herbicide (date 1 vs. date 2)	0.562	0.064	0.478
Tillage (date 1 vs. date 2)	0.227	0.403	0.460
Herbicide (date 2) vs. tillage (date 1)	0.232	0.354	0.620
Herbicide (date 2) vs. H+T (date 1)	0.574	0.129	0.962

Table 4.16. Orthogonal contrasts for soil moisture levels in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) at harvest as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1993).

Contrasts	Carman	Glenlea	Holland
		P>F	
0-30 cm			
Herbicide vs. tillage (date 1)	0.479	0.462	0.855
Herbicide vs. tillage (date 2)	0.803	0.995	0.109
Herbicide (date 1 vs. date 2)	0.432	0.373	0.903
Tillage (date 1 vs. date 2)	0.092	0.870	0.061
Herbicide (date 2) vs. tillage (date 1)	0.144	0.874	0.760
Herbicide (date 2) vs. H+T (date 1)	0.953	0.799	0.117
30-90 cm			
Herbicide vs. tillage (date 1)	0.255	0.652	0.655
Herbicide vs. tillage (date 2)	0.464	0.974	0.363
Herbicide (date 1 vs. date 2)	0.478	0.423	0.792
Tillage (date 1 vs. date 2)	0.246	0.229	0.277
Herbicide (date 2) vs. tillage (date 1)	0.656	0.217	0.853
Herbicide (date 2) vs. H+T (date 1)	0.488	0.950	0.502
90-190 cm			
Herbicide vs. tillage (date 1)	0.288	0.660	0.858
Herbicide vs. tillage (date 2)	0.484	0.147	0.405
Herbicide (date 1 vs. date 2)	0.674	0.013	0.880
Tillage (date 1 vs. date 2)	0.176	0.430	0.653
Herbicide (date 2) vs. tillage (date 1)	0.572	0.032	0.752
Herbicide (date 2) vs. H+T (date 1)	0.255	0.454	0.383

Table 4.17. Orthogonal contrasts for dynamic soil moisture differences in the profile increments (0-30 cm, 30-90 cm, and 90-190 cm) during the soil moisture evapotranspiration period from late spring to harvest, as affected by date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1993).

Contrasts	Carman	Glenlea	Holland
		P>F	
0-30 cm			
Herbicide vs. tillage (date 1)	0.263	0.214	0.025
Herbicide vs. tillage (date 2)	0.227	0.461	0.549
Herbicide (date 1 vs. date 2)	0.201	0.213	0.570
Tillage (date 1 vs. date 2)	0.234	0.458	0.024
Herbicide (date 2) vs. tillage (date 1)	0.023	0.996	0.079
Herbicide (date 2) vs. H+T (date 1)	0.310	0.967	0.496
30-90 cm			
Herbicide vs. tillage (date 1)	0.169	0.163	0.096
Herbicide vs. tillage (date 2)	0.285	0.975	0.167
Herbicide (date 1 vs. date 2)	0.438	0.435	0.065
Tillage (date 1 vs. date 2)	0.276	0.541	0.233
Herbicide (date 2) vs. tillage (date 1)	0.039	0.521	0.838
Herbicide (date 2) vs. H+T (date 1)	0.098	0.248	0.404
90-190 cm			
Herbicide vs. tillage (date 1)	0.962	0.617	0.393
Herbicide vs. tillage (date 2)	0.146	0.180	0.186
Herbicide (date 1 vs. date 2)	0.968	0.010	0.133
Tillage (date 1 vs. date 2)	0.115	0.270	0.499
Herbicide (date 2) vs. tillage (date 1)	0.997	0.026	0.577
Herbicide (date 2) vs. H+T (date 1)	0.264	0.279	0.063

4.4.4 Groundcover

Percent groundcover during late fall differed significantly between treatments at all locations due to the method of alfalfa termination, and to a lesser extent, due to the date of alfalfa termination (Table 4.18). Individual treatment contrasts revealed that groundcover percent for alfalfa termination by herbicide vs. alfalfa termination by tillage was significantly different for both date 1 and date 2 (Table 4.18). The tillage treatment reduced groundcover percentage by incorporating a portion of the alfalfa residue into the soil. Alfalfa termination by herbicide (date 1 vs. date 2) was different at 2 of 4 locations, probably due to a general deterioration of the surface residue during the time between the measurement dates. Alfalfa residue has a low carbon to nitrogen ratio which tends to promote rapid decomposition, compared to that of higher carbon to nitrogen ratio residue such as small cereal straw (Schomberg et al., 1994). Similar groundcover was retained by tillage (date 1 vs. date 2), however, in both treatments there was only a small percent of surface residue present to break down (Table 4.18). Alfalfa termination by herbicide (date 2) retained considerably greater groundcover than that of either tillage (date 1) or herbicide plus delayed tillage (date 1).

Groundcover measurements after spring seeding were lower than fall measurements in virtually all treatments at the measured locations (Table 4.19). This was probably due to deterioration of the alfalfa residue during the time between measurements, and also due to the additional spring tillage on those plots which were tilled. Orthogonal contrasts between treatments for spring groundcover revealed similar responses to that of the fall groundcover measurements (Table 4.19).

Combined site analysis for groundcover percent (Table 4.20) indicated site differences in October. These differences may have been due to soil texture differences between sites. The coarse textured soil at the Holland site retained less groundcover than the loam soil at the Carman site, which retained less groundcover than the clay soil at the Glenlea site. By May, differences in groundcover at the 3 sites were not significant.

Averaged across sites, date 2 of alfalfa termination retained significantly more groundcover than date 1 for the October measurement, however this difference diminished by May of the following spring (Table 4.20). The method of alfalfa termination significantly influenced the amount of surface residue in both October and May. The loss in groundcover from fall to spring was also significantly affected by the method of alfalfa termination, since the herbicide plus delayed tillage treatment reduced groundcover more than the no-till or tilled treatments (Table 4.20). This may have occurred due to the deteriorating effect of the herbicide on the alfalfa biomass, which increased vulnerability of the alfalfa residue to further breakdown by tillage, compared to tillage without an initial herbicide treatment. A significant site x method interaction for both October and May groundcover was attributed to greater burial of residue in the tillage and herbicide plus delayed tillage treatments at the Holland site where the soil was coarser in texture, thus allowing for greater penetration of the tillage implement. Date (herbicide only) was significant for both fall and spring groundcover measurements since live growth in the spring herbicide treatment contributed to greater groundcover than date 1 or date 2 herbicide treatments (Table 4.20). The loss of groundcover for the spring herbicide treatment was due to natural frost killing of the aerial biomass present in the fall, as well as the spring herbicide treatment.

Orthogonal contrasts indicated that the herbicide treatment retained greater groundcover than tillage for both date 1 and date 2, and for both the fall and spring groundcover measurements (Table 4.20). The loss of groundcover from fall to spring was greater for the herbicide treatments (6.7 to 12.3 %) compared to the tillage treatments (0.0 to 0.2 %) since fall groundcover on the herbicide treated plots was considerably greater, therefore greater degradation of groundcover occurred. No difference in groundcover existed between dates of herbicide treatments, or between dates of tillage treatments (Table 4.20). Herbicide (date 2) retained greater groundcover than either tillage (date 1) or herbicide plus delayed tillage (date 1) for both fall and spring measurements, however the herbicide (date 2) treatment also lost a greater percentage of groundcover from fall to spring than either the tillage (Table 4.20) or herbicide plus delayed tillage treatment (date 1) (Table 4.20).

Herbicide treatments retained the greatest groundcover in late fall (Table 4.18; Table 4.20), and also maintained the greatest soil moisture content during the same period (Figure 4.04; Figure 4.05; Figure 4.10 through Figure 4.14). The positive influence of crop residue cover on conserving soil moisture is well documented (Bond and Willis, 1969; Russel, 1939; Smika and Unger, 1986). A progressive increase in soil moisture storage during fallow from increasing amounts of crop residue on the soil surface was shown by Unger (1978b) and Greb et al. (1967).

Herbicide treatments maintained the highest amount of soil residue cover in the spring (Table 4.18; Table 4.20), as well as the highest soil moisture reserves in the upper soil profile (Figure 4.06; Figure 4.07; Figure 4.10 through Figure 4.14). Willis and Carlson (1962) suggested that the retention of crop residue on the soil surface will reduce runoff loses from overwinter water accumulation during spring melt. Unger et al. (1988) implied that residue cover on the field will reduce evaporative loss by allowing moisture additional time to move deeper into the soil. Triplett et al. (1968) found that moisture infiltration was significantly greater with 80 % surface cover than treatments with less cover.

Table 4.18. Groundcover† percent response during late fall to date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992), and Carman and Winnipeg, MB.(1993).

	1992			1993	
	Carman	Glenlea	Holland	Carman	Winnipeg
	%				
Means					
Herbicide (date 1)	75.0	77.0	83.8	71.5	-
Herbicide + delayed tillage (date 1)	21.8	28.3	12.5	-	-
Tillage (date 1)	4.6	7.0	3.4	3.5	-
Herbicide (date 2)	74.4	82.8	84.5	85.3	76.8
Herbicide + delayed tillage (date 2)	37.5	25.2	12.4	-	-
Tillage (date 2)	6.3	11.3	4.8	15.0	4.9
Herbicide (date 3)	93.2	90.3	96.8	90.7	80.5
	ANOVA (P > F)				
Source of variation					
Date	0.001	0.096	0.572	<0.001	-
Method	<0.001	<0.001	<0.001	<0.001	<0.001
Date x Method	<0.001	0.033	0.859	0.430	-
Date (herbicide only)	<0.001	<0.001	<0.001	<0.001	0.175
	P > F				
Contrasts					
Herbicide vs. tillage (date 1)	<0.001	<0.001	<0.001	<0.001	-
Herbicide vs. tillage (date 2)	<0.001	<0.001	<0.001	<0.001	<0.001
Herbicide (date 1 vs. date 2)	0.808	0.022	0.715	<0.001	-
Tillage (date 1 vs. date 2)	0.493	0.082	0.491	-	-
Herbicide (date 2) vs. tillage (date 1)	<0.001	<0.001	<0.001	<0.001	-
Herbicide (date 2) vs. H+T (date 1)	<0.001	<0.001	<0.001	-	-
	%				
CV	8.3	7.1	6.5	5.1	6.2

† Groundcover includes live alfalfa regrowth.

Table 4.19. Groundcover† percent response during spring after seeding to date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1993).

	Carman	Glenlea	Holland
		%	
Means			
Herbicide (date 1)	66.6	65.3	83.9
Herbicide + delayed tillage (date 1)	15.4	19.0	7.0
Tillage (date 1)	4.9	7.4	4.3
Herbicide (date 2)	66.6	54.4	83.9
Herbicide + delayed tillage (date 2)	20.8	17.9	6.1
Tillage (date 2)	6.3	10.8	4.7
Herbicide (date 3)	87.4	78.0	91.7
		ANOVA (P > F)	
Source of variation			
Date	0.341	0.169	0.873
Method	<0.001	<0.001	<0.001
Date x Method	0.616	0.029	0.872
Date (herbicide only)	<0.001	<0.001	<0.001
		P > F	
Contrasts			
Herbicide vs. tillage (date 1)	<0.001	<0.001	<0.001
Herbicide vs. tillage (date 2)	<0.001	<0.001	<0.001
Herbicide (date 1 vs. date 2)	0.995	0.006	1.000
Tillage (date 1 vs. date 2)	0.730	0.348	0.827
Herbicide (date 2) vs. tillage (date 1)	<0.001	<0.001	<0.001
Herbicide (date 2) vs. H+T (date 1)	<0.001	<0.001	<0.001
		%	
CV	14.9	13.6	5.9

† Groundcover includes live alfalfa regrowth.

Table 4.20. Combined site response of groundcover† percent during mid-October and mid-May and loss of groundcover from mid-October to mid-May to date and method of alfalfa termination at Carman, Glenlea and Holland, MB.(1992-1993).

	mid-October	mid-May	loss (fall to spring)
Means		%	
Site			
Carman	44.7	38.3	6.4
Glenlea	46.0	36.1	9.9
Holland	42.6	40.2	2.4
Treatment			
Herbicide (date 1)	78.6	71.9	6.7
Herbicide + delayed tillage (date 1)	20.9	13.8	7.1
Tillage (date 1)	5.0	5.5	0.0
Herbicide (date 2)	80.6	68.3	12.3
Herbicide + delayed tillage (date 2)	25.0	14.9	10.1
Tillage (date 2)	7.5	7.3	0.2
Herbicide (date 3)	93.4†	85.7	7.7
		ANOVA (P > F)	
Source of variation			
Site	0.019	0.518	0.092
Date	<0.001	0.784	0.007
Method	<0.001	<0.001	<0.001
Site x Date	0.035	0.083	0.107
Site x Method	<0.001	<0.001	<0.001
Date x Method	0.472	0.043	0.210
Site x Date x Method	<0.001	0.071	<0.001
Date (herbicide only)	<0.001	<0.001	0.023
		P > F	
Contrasts			
Herbicide vs. tillage (date 1)	<0.001	<0.001	<0.001
Herbicide vs. tillage (date 2)	<0.001	<0.001	<0.001
Herbicide (date 1 vs. date 2)	0.141	0.057	0.212
Tillage (date 1 vs. date 2)	0.066	0.362	0.831
Herbicide (date 2) vs. tillage (date 1)	<0.001	<0.001	<0.001
Herbicide (date 2) vs. H+T (date 1)	<0.001	<0.001	0.005
		%	
CV	7.3	11.9	59.9

† Groundcover includes live alfalfa regrowth.

4.4.5 Crop Parameters

4.4.5.1 Crop Emergence

Wheat emergence was affected by the method of alfalfa termination at the Glenlea site only (Table 4.21). No differences for crop emergence density were evident due to the date of alfalfa termination. Orthogonal contrasts indicated differences in wheat emergence density between alfalfa termination by herbicide (date 1) and alfalfa termination by tillage (date 1) at the Glenlea site only. Differences in emergence density were also shown by orthogonal contrasts for alfalfa termination by herbicide (date 2) vs. alfalfa termination by tillage (date 1) at the Glenlea and Holland sites (Table 4.21).

Combined site analysis for wheat emergence density (Table 4.22) indicated differences due to site and method of alfalfa termination. Mean crop density at the Glenlea site was lower than that of the other two sites (Table 4.22). All herbicide termination treatments had lower mean crop emergence densities than either herbicide plus delayed tillage or tillage treatments (Table 4.22). Clayton (1982) also observed lower wheat populations under no-tillage in alfalfa sod compared to minimum and conventional tillage, which he attributed to variable seeding depth, poor seed-soil contact, and seed desiccation, especially on clay soils under dry conditions. Orthogonal contrasts for the combined analysis did not indicate any differences between individual treatments for crop emergence density. Lafond et al. (1992) found the rate of plant establishment of spring wheat to be similar with zero-tillage, minimum tillage, and conventional tillage. Krall et al. (1989) showed corn populations in plowed alfalfa treatments to be significantly lower than that in no-till treatments. Carefoot et al. (1990) concluded that increased soil water reserves and improved seedbed moisture with a no-till practice resulted in greater seed imbibition of water and plant emergence compared to a conventional tillage system. However, Knake et al. (1986a) experienced higher corn populations and taller corn height with moldboard plowed alfalfa, compared to no-tillage terminated alfalfa.

4.4.5.2 Grain Yield

Grain yield was influenced by the method of alfalfa termination at all three locations (Table 4.23). The date of alfalfa termination affected grain yield at the Holland site only, where date 2 treatments outyielded date 1 treatments. The date of alfalfa termination (herbicide only) affected grain yield at the Carman site only (Table 4.23). Orthogonal contrasts for alfalfa termination treatments showed grain yield to be greater at 2 of 3 sites when alfalfa was terminated on date 1 with herbicide rather than tillage (Table 4.23). On date 2, grain yield of herbicide vs. tillage terminated alfalfa was greater only at the Carman site. Alfalfa termination by tillage (date 2) at the Holland site resulted in a higher grain yield than alfalfa termination by tillage on date 1. Grain yield was higher for herbicide (date 2) than tillage (date 1) at the Carman and Holland sites (Table 4.23).

Combined site analysis for grain yield indicated that the highest grain yields were achieved in the herbicide treatment (date 1), whereas the lowest yields were observed in the tillage treatment (date 1) (Table 4.22). This is supported by Jones et al. (1969) who observed that grain yield of corn was increased 1,932 kg ha^{-1} due to conserved soil moisture from killed sod mulch on the soil surface. Adams et al. (1970) emphasized that the success of a no-till corn crop seeded into a killed grass sod was dependent on soil water availability. Spring seeding moisture levels at Glenlea and Holland, but not Carman, were different in the 0-30 cm soil profile due to the method of alfalfa termination. However growing season precipitation was high (Figure 4.10; Figure 4.11; Figure 412) and may have masked earlier soil moisture differences between treatments. The greatest yield response to surface mulch during the growing season was found to occur when soil water at seeding was low (Steiner, 1994). No-till corn yields in Wyoming were also found to be higher (1,479 kg ha^{-1}) than plowed treatments (Krall et al., 1989). Barnett (1990) concluded that no-till corn planted after herbicide terminated alfalfa/grass sod in Wisconsin produced yields equal to that planted after conventionally tilled sod. Moomaw and Martin (1976) also measured corn grain yield from no-till treatments that were similar to that of spring plow treatment.

Grain yield was influenced by site, with Carman having the highest yield, and Glenlea having the lowest yield. Grain yield was also influenced by date and method of alfalfa termination. Orthogonal contrasts for the combined analysis of grain yield indicated alfalfa termination by herbicide (date 1) to significantly achieve higher grain yields than termination by tillage (date 1) (Table 4.22). Alfalfa termination by tillage (date 2) resulted in higher grain yields than termination by tillage (date 1). Alfalfa termination by herbicide (date 2) resulted in higher grain yields than termination by either tillage (date 1), or termination by herbicide plus delayed tillage (date 1) (Table 4.22). Currently, the majority of producers terminate their alfalfa stands by tillage, or herbicide plus delayed tillage on date 1, indicating that an expected increase in grain yield can occur by changing their termination strategy to date 2 with herbicide. Site x date interactions affected grain yield (Table 4.22), since the tillage treatment on date 2 outyielded tillage on date 1 at the Holland site only (Table 4.23). Significant site x method interactions also influenced grain yield primarily because the herbicide treatment outyielded the tillage treatment for both date 1 and date 2 at the Carman site, only date 1 at Holland, and not at all at Glenlea (Table 4.23). Date (herbicide only) was significant since grain yield decreased, as alfalfa termination progressed from date 1 to date 3.

4.4.5.3 Aerial Biomass Yield

Biomass production is an important measure of the ability of a system to grow plants. Total above ground wheat biomass yield at harvest was affected by the date of alfalfa termination at the Glenlea site only (Table 4.24). However, date (herbicide only) termination influenced aerial biomass yield at all 3 sites. The method of alfalfa termination affected aerial biomass yield at the Carman and Holland sites. Orthogonal contrasts for the alfalfa termination treatments indicated that alfalfa termination on date 1 by herbicide produced a higher aerial biomass yield than termination by tillage at the Carman and Holland sites (Table 4.24). On date 2, aerial biomass yield was greater for alfalfa termination with herbicide than with tillage at the Holland site only. Alfalfa termination (date 1) produced greater aerial biomass yield than alfalfa termination with herbicide (date 2) at the Glenlea site only. No differences in aerial biomass were noted between dates of termination with tillage. Alfalfa termination by herbicide (date 2) produced higher aerial biomass yield than termination by tillage (date 1) at the Holland site, however the opposite occurred at the Glenlea site. No differences were found in aerial biomass yield when alfalfa termination by herbicide (date 2) and termination by herbicide plus delayed tillage were contrasted (Table 4.24).

Combined site analysis of aerial biomass indicated yield differences among the three sites (Table 4.22). Yield differences in aerial biomass were also due to the date and method of alfalfa termination (Table 4.22). Site x date and site x method interactions of alfalfa termination influenced aerial biomass yield due to date and method differences among the sites (Table 4.24). Date (herbicide only) of alfalfa termination had a significant impact on aerial biomass yield, which decreased with each successive date of termination. Alfalfa termination by herbicide (date 1) had a higher aerial biomass yield than termination by tillage (date 1), as indicated by orthogonal contrast (Table 4.22). Alfalfa termination by herbicide (date 1) also resulted in higher aerial biomass yield than termination by herbicide (date 2).

4.4.5.4 Water Use Efficiency

Grain yield water use efficiency (WUE) was influenced by the date and method of alfalfa termination at the Holland site only (Table 4.25). The date (herbicide only) affected grain yield WUE at the Glenlea site. Grain yield WUE was 1.1 kg ha^{-1} mm^{-1} greater when the alfalfa was terminated with herbicides (date 1) rather than with tillage at the Holland site (Table 4.25). No affect on WUE at any location was evident between alfalfa termination by herbicide and tillage on date 2. Grain yield WUE was found to be higher at the Holland location when alfalfa was terminated by herbicide (date 2) than by either tillage (date 1) or herbicide plus delayed tillage (date 1). Deibert et al. (1986) reported grain WUE of continuous spring wheat under no-till averaging 5.3 kg ha^{-1} mm^{-1} soil water, and WUE of wheat with spring plow only marginally higher. Clayton (1982) observed higher grain WUE with conventional tillage compared to no-tillage, due to higher grain yields on the conventional treatments.

Combined site analysis indicated that Glenlea had significantly lower grain yield WUE due to excess rainfall, than either the Carman or Holland sites (Table 4.22). The method of alfalfa termination significantly influenced grain yield WUE, with herbicide termination being greater. Steiner (1994) concluded that wheat residue on the soil surface during the growing season enhanced WUE of both aerial biomass and grain for dryland sorghum. Site x date and site x method also affected grain yield WUE. The date (herbicide only) of alfalfa termination influenced grain yield WUE, primarily due to lower grain yield of the spring terminated treatment (Table 4.22). Grain yield WUE was significantly greater when alfalfa was terminated by herbicide rather than by either tillage or herbicide plus delayed tillage on date 1 (Table 4.22).

Aerial biomass WUE was influenced by the date of alfalfa termination at the Glenlea site, and the method of alfalfa termination at the Holland site (Table 4.26). Above ground biomass WUE was affected by the date (herbicide only) of alfalfa termination at all 3 sites (Table 4.26). Alfalfa termination by herbicide (date 1) produced greater aerial biomass WUE at Carman than that by tillage (date 1). Shanholtz and Lillard (1969) measured greater aerial dry matter in no-till killed grass sod plots, which they attributed to the ability of the no-till system to use soil moisture more efficiently than the conventional system.

Alfalfa termination on date 2 by herbicide produced higher aerial biomass WUE at Holland than did the tillage treatment. Greater aerial biomass WUE was achieved on date

1 with alfalfa termination by herbicide treatment than with date 2 at the Glenlea location, however the opposite was observed at the Holland site. The tillage treatment on date 1 produced greater aerial biomass WUE than with date 2 at the Glenlea site. By terminating alfalfa on date 2 with herbicide rather than on date 1 with tillage or herbicide plus delayed tillage, higher aerial biomass WUE was attained at the Holland location. However, greater aerial biomass WUE was achieved at Glenlea when alfalfa was terminated by tillage (date 1) rather than with herbicide on date 2 (Table 4.26).

Aerial biomass WUE for the combined site analysis was lower at the Glenlea site than either the Carman or Holland locations (Table 4.22). Aerial biomass WUE was greater when alfalfa was terminated on date 1 rather than date 2. Site x date and site x method interactions also influenced above ground biomass WUE. Date (herbicide only) of alfalfa termination also significantly affected aerial biomass WUE (Table 4.22). Orthogonal contrasts indicated aerial biomass WUE to be greater when alfalfa was terminated by herbicide rather than by tillage on date 1, as well as on date 2 (Table 4.22).

Table 4.21. Wheat emergence response to date and method of alfalfa termination in 1992 at Carman, Glenlea and Holland, MB.(1993).

	Carman	Glenlea	Holland
		$no.\ m^{-2}$	
Means			
Herbicide (date 1)	343.6	214.4	336.6
Herbicide + delayed tillage (date 1)	344.0	238.2	343.2
Tillage (date 1)	338.3	250.1	346.5
Herbicide (date 2)	350.6	215.7	323.5
Herbicide + delayed tillage (date 2)	357.5	248.9	344.8
Tillage (date 2)	350.6	242.3	335.0
Herbicide (date 3)	318.2	241.1	334.2
		ANOVA (P > F)	
Source of variation			
Date	0.256	0.880	0.195
Method	0.857	0.019	0.141
Date x Method	0.955	0.706	0.522
Date (herbicide only)	0.136	0.181	0.387
		P > F	
Contrasts			
Herbicide vs. tillage (date 1)	0.746	0.034	0.332
Herbicide vs. tillage (date 2)	0.671	0.103	0.259
Herbicide (date 1 vs. date 2)	0.670	0.937	0.199
Tillage (date 1 vs. date 2)	0.456	0.621	0.259
Herbicide (date 2) vs. tillage (date 1)	0.457	0.040	0.032
Herbicide (date 2) vs. H+T (date 1)	0.689	0.163	0.061
		%	
CV	6.6	9.3	4.1

Table 4.22. Combined site response of crop parameters to date and method of alfalfa termination in 1992 at Carman, Glenlea and Holland, MB.(1993).

	Emergence	Grain yield	Aerial biomass yield	WUE (grain)	WUE (biomass†)
Means	no m^{-2}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1} mm^{-1} ET	kg ha^{-1} mm^{-1} ET
Site					
Carman	343.2	2,679	8,518	7.3	23.0
Glenlea	235.8	1,782	5,333	4.0	11.9
Holland	337.7	2,384	7,811	6.2	20.3
Treatment					
Herbicide (date 1)	298.2	2,414	8,118	6.2	20.8
Herbicide + delayed tillage (date 1)	308.5	2,227	7,328	5.7	18.7
Tillage (date 1)	311.6	2,094	7,038	5.6	18.8
Herbicide (date 2)	296.6	2,395	7,447	6.2	19.5
Herbicide + delayed tillage (date 2)	317.1	2,324	7,200	5.7	17.8
Tillage (date 2)	309.3	2,286	6,924	5.8	17.5
Herbicide (date 3)	297.8	2,232	6,488	5.5	16.2
			ANOVA (P > F)		
Source of variation					
Site	<0.001	<0.001	<0.001	<0.001	<0.001
Date	0.712	0.014	0.044	0.511	0.017
Method	0.009	<0.001	<0.001	0.002	0.002
Site x Date	0.205	0.002	0.010	<0.001	0.012
Site x Method	0.115	0.004	0.002	0.038	0.013
Date x Method	0.494	0.058	0.221	0.853	0.930
Site x Date x Method	0.958	0.057	0.506	0.166	0.088
Date (herbicide only)	0.978	0.010	<0.001	0.007	<0.001
			P > F		
Contrasts					
Herbicide vs. tillage (date 1)	0.106	<0.001	<0.001	0.013	0.029
Herbicide vs. tillage (date 2)	0.125	0.091	0.074	0.057	0.027
Herbicide (date 1 vs. date 2)	0.842	0.763	0.023	0.858	0.145
Tillage (date 1 vs. date 2)	0.776	0.004	0.693	0.432	0.137
Herbicide (date 2) vs. tillage (date 1)	0.706	<0.001	0.159	0.008	0.446
Herbicide (date 2) vs. H+T (date 1)	0.151	0.011	0.680	0.032	0.371
			%		
CV	5.8	6.5	8.5	9.1	10.6

Table 4.23. Grain yield response of wheat to date and method of alfalfa termination in 1992 at Carman, Glenlea and Holland, MB.(1993).

	Carman	Glenlea	Holland
		$kg\ ha^{-1}$	
Means			
Herbicide (date 1)	2,925	1,828	2,488
Herbicide + delayed tillage (date 1)	2,625	1,751	2,306
Tillage (date 1)	2,481	1,861	1,940
Herbicide (date 2)	2,779	1,853	2,552
Herbicide + delayed tillage (date 2)	2,782	1,668	2,523
Tillage (date 2)	2,535	1,835	2,488
Herbicide (date 3)	2,625	1,679	2,394
		ANOVA (P > F)	
Source of variation			
Date	0.731	0.531	0.003
Method	0.001	0.031	0.017
Date x Method	0.153	0.603	0.061
Date (herbicide only)	0.037	0.069	0.524
		P > F	
Contrasts			
Herbicide vs. tillage (date 1)	<0.001	0.671	<0.001
Herbicide vs. tillage (date 2)	0.035	0.812	0.649
Herbicide (date 1 vs. date 2)	0.188	0.740	0.648
Tillage (date 1 vs. date 2)	0.623	0.740	<0.001
Herbicide (date 2) vs. tillage (date 1)	0.012	0.925	<0.001
Herbicide (date 2) vs. H+T (date 1)	0.165	0.195	0.089
		%	
CV	5.6	6.0	8.1

Table 4.24. Wheat aerial biomass yield response to date and method of alfalfa termination in 1992 at Carman, Glenlea and Holland, MB.(1993).

	Carman	Glenlea	Holland
		$kg\ ha^{-1}$	
Means			
Herbicide (date 1)	9,806	6,206	8,343
Herbicide + delayed tillage (date 1)	8,390	5,458	8,136
Tillage (date 1)	7,770	6,167	7,176
Herbicide (date 2)	8,925	4,885	8,532
Herbicide + delayed tillage (date 2)	8,769	4,812	8,019
Tillage (date 2)	7,854	5,311	7,607
Herbicide (date 3)	8,111	4,492	6,861
		ANOVA (P > F)	
Source of variation			
Date	0.697	0.001	0.505
Method	0.008	0.154	0.009
Date x Method	0.335	0.533	0.669
Date (herbicide only)	0.041	0.002	0.002
		P > F	
Contrasts			
Herbicide vs. tillage (date 1)	0.004	0.927	0.014
Herbicide vs. tillage (date 2)	0.097	0.332	0.044
Herbicide (date 1 vs. date 2)	0.166	0.006	0.662
Tillage (date 1 vs. date 2)	0.893	0.061	0.328
Herbicide (date 2) vs. tillage (date 1)	0.075	0.008	0.005
Herbicide (date 2) vs. H+T (date 1)	0.393	0.196	0.367
		%	
CV	10.2	11.3	7.7

Table 4.25. Grain yield water use efficiency response of wheat to date and method of alfalfa termination in 1992 at Carman, Glenlea and Holland, MB.(1993).

	Carman	Glenlea	Holland
		kg ha^{-1} mm^{-1} ET	
Means			
Herbicide (date 1)	8.2	4.1	6.2
Herbicide + delayed tillage (date 1)	7.1	4.1	5.9
Tillage (date 1)	7.3	4.4	5.1
Herbicide (date 2)	7.5	4.0	7.2
Herbicide + delayed tillage (date 2)	7.2	3.7	6.3
Tillage (date 2)	6.7	4.1	6.4
Herbicide (date 3)	6.8	3.6	6.3
		ANOVA (P > F)	
Source of variation			
Date	0.318	0.114	0.004
Method	0.132	0.080	0.032
Date x Method	0.515	0.701	0.386
Date (herbicide only)	0.059	0.046	0.072
		P > F	
Contrasts			
Herbicide vs. tillage (date 1)	0.110	0.205	0.045
Herbicide vs. tillage (date 2)	0.215	0.581	0.094
Herbicide (date 1 vs. date 2)	0.256	0.759	0.039
Tillage (date 1 vs. date 2)	0.330	0.301	0.019
Herbicide (date 2) vs. tillage (date 1)	0.715	0.121	<0.001
Herbicide (date 2) vs. H+T (date 1)	0.520	0.890	0.008
		%	
CV	10.8	7.3	9.3

Table 4.26. Aerial biomass yield water use efficiency response of wheat to date and method of alfalfa termination in 1992 at Carman, Glenlea and Holland, MB.(1993).

	Carman	Glenlea	Holland
		$kg\ ha^{-1}\ mm^{-1}$ ET	
Means			
Herbicide (date 1)	27.5	13.9	20.9
Herbicide + delayed tillage (date 1)	22.5	12.6	21.0
Tillage (date 1)	22.9	14.5	19.0
Herbicide (date 2)	23.9	10.6	24.0
Herbicide + delayed tillage (date 2)	22.7	10.8	19.8
Tillage (date 2)	20.8	12.0	19.7
Herbicide (date 3)	20.9	9.6	18.0
		P>F	
Source of variation			
Date	0.228	<0.001	0.381
Method	0.066	0.102	0.020
Date x Method	0.460	0.562	0.084
Date (herbicide only)	0.023	<0.001	0.006
		P>F	
Contrasts			
Herbicide vs. tillage (date 1)	0.047	0.539	0.347
Herbicide vs. tillage (date 2)	0.186	0.158	0.004
Herbicide (date 1 vs. date 2)	0.156	0.003	0.027
Tillage (date 1 vs. date 2)	0.338	0.020	0.942
Herbicide (date 2) vs. tillage (date 1)	0.638	<0.001	0.006
Herbicide (date 2) vs. H+T (date 1)	0.503	0.051	0.030
		%	
CV	13.0	11.5	8.7

4.5 Summary and Conclusions

Soil moisture content following alfalfa is influenced by both the date and method of alfalfa termination. The extent to which soil water is conserved for the following crop is also dependent on initial moisture levels in the soil and accumulated precipitation. Sufficient moisture in the soil profile of the seedbed is necessary for successful establishment of fall and spring seeded crops. Greater soil moisture levels were attained in the 0-30 cm and 30-90 cm soil increments in October at the end of the first season by terminating alfalfa on date 1 compared to date 2, primarily because the growing alfalfa continued to extract soil moisture until the date 2 termination treatments were applied. Soil moisture was also conserved in the 0-30 cm soil increment at fall by utilizing herbicides instead of tillage to terminate alfalfa, which was likely due to either the ability of the alfalfa residue to reduce evaporative moisture loss, as well as the additional moisture loss incurred by each tillage event, or both. Termination with herbicides increased soil moisture levels in the 0-30 cm soil increment by 52 mm to 81 mm more than the tillage at date 1, and 32 mm to 72 mm more than tillage at date 2. Producers wanting to obtain a second alfalfa cut prior to termination are able to also conserve soil moisture in the upper 30 cm soil profile increment by utilizing herbicide termination on date 2 in lieu of tillage or herbicide plus delayed tillage on date 1.

The method of alfalfa termination influenced grain yield at all three sites, whereas the date of termination affected grain yield at only one site. Grain yield was 15.3 % and 14.4 % higher by utilizing herbicide on date 1 or date 2 respectively, instead of tillage on date 1. Also, by using herbicide to terminate alfalfa at date 2, increased grain and biomass yields can be achieved in the crop following alfalfa, and as well, a second cutting of alfalfa can be harvested in the alfalfa year.

Greater WUE of grain yield (10.7 %) and crop aerial biomass (10.6 %) was achieved by terminating alfalfa on date 1 with herbicide compared to using tillage on date 1. Greater WUE for crop aerial biomass (11.4 %) was also attained on date 2 by using herbicides to terminate alfalfa. Termination of alfalfa on date 2 with herbicide was able to promote 3.8 % and 1.8 % greater WUE of grain yield than using tillage or herbicide plus delayed tillage respectively, on date 1. In conditions of moisture shortage for crop production, herbicide termination of alfalfa coupled with no-till seeding of the following crop appears to make the best use of available soil moisture. Terminating alfalfa with herbicides combined with a no-till cropping system also include soil conservation benefits through additional retention of residue on the soil surface.

5.0 General Summary and Conclusions

5.1 Conclusions

Successful termination of alfalfa in a crop rotation involves a systems approach including initial termination, soil moisture conservation, crop competition, and post-emergence herbicide management strategies. Conclusions from this study indicate that alfalfa can be successfully terminated with 1.78 kg a.i. ha^{-1} glyphosate. Results also show that 1.78 kg a.i. ha^{-1} glyphosate can suppress alfalfa as well as tillage for both fall and spring termination.

Increased soil moisture in the upper soil profile can be conserved by using herbicide instead of tillage for alfalfa termination. Soil moisture content in the upper soil profile at fall of the year of termination was influenced by both the date and method of termination, however, only the method of termination influenced soil moisture at spring seeding.

Grain yields of the crop following alfalfa termination were similar or greater for the 1.78 kg a.i. ha^{-1} glyphosate treatment than tillage when alfalfa was terminated in the fall, however, the tillage treatment resulted in higher crop yields for spring termination. Problems associated with spring termination by herbicide include soil moisture loss, late crop seeding, slow die back of alfalfa causing excess competition to the emerging crop, and interference with the ability of the post-emergence herbicide application. The post-emergence herbicide application is an important component of the termination strategy to suppress alfalfa escapes which cause competition to the emerging grain crop.

5.2 Recommendations

Producers rotating out of alfalfa with tillage who experience inadequate suppression of the alfalfa stand or excessive moisture loss from the soil profile, should consider using the herbicide approach in combination with no-till seeding. The use of herbicides will promote successful termination of perennial alfalfa in a cropping system which may encourage producers to rotate alfalfa stands more frequently, thus enabling alfalfa's beneficial attributes to the rotation to be better realized. Herbicide termination of alfalfa coupled with no-till seeding of spring crops will retain alfalfa residue on the soil surface, resulting in reduced soil erosion potential, and reduced soil moisture loss.

Fall termination of alfalfa with herbicides enables the following grain crop to be seeded earlier in the spring, thus taking advantage of early spring moisture, as well as the full duration of the growing season. Spring terminated alfalfa, on the other hand, delays crop seeding, and often results in soil moisture loss prior to seeding. Also, reduced effectiveness of the post-emergence herbicide on in-crop alfalfa escapes may occur for spring herbicide terminated alfalfa compared to fall terminated alfalfa.

The selection of herbicide used to terminate alfalfa depends on the presence of weeds in the stand in addition to the alfalfa. If perennial grass weeds are present, a glyphosate mixture must be used. Glyphosate mixed with 2,4-D or dicamba will suppress alfalfa better than glyphosate alone.

The crop in rotation following alfalfa should be relatively competitive, such as wheat or barley, and be able to withstand a post-emergence herbicide application to suppress alfalfa escapes.

5.3 Future Research

Additional research is required to support the results of the current study, since alfalfa is grown across a wider range of soil, crop, and environmental conditions, than that supported by the current project. Further investigation into the timing of alfalfa termination, to find the stage of alfalfa development for optimum herbicide efficacy, and further investigate the time of year for alfalfa termination, such as pre-harvest alfalfa termination which may better suit crop management objectives. Further research is required to develop cost effective herbicide mixtures for optimum control of alfalfa across a broad range of environmental conditions, and also develop herbicide mixtures for alfalfa stands with unique weed infestations. Consideration must also be given to subsequent crop susceptibility to herbicide residue from the termination treatments. Additional research is also required to better understand the physiological aspects of herbicide efficacy within the alfalfa plant, and interactions of herbicide efficacy with other herbicides, either in mixtures or split applications (i.e. pre-plant and post-emergence), soil and environmental conditions, alfalfa growth and development, and the date of alfalfa termination.

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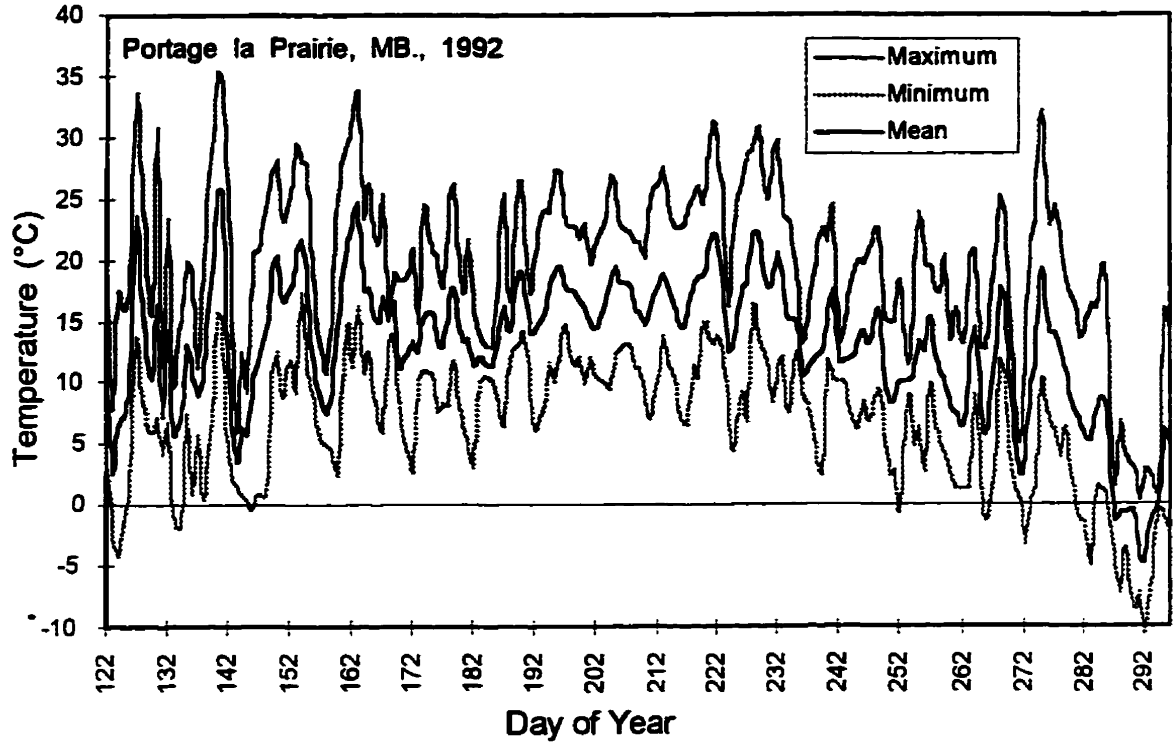
7.1 Appendix A



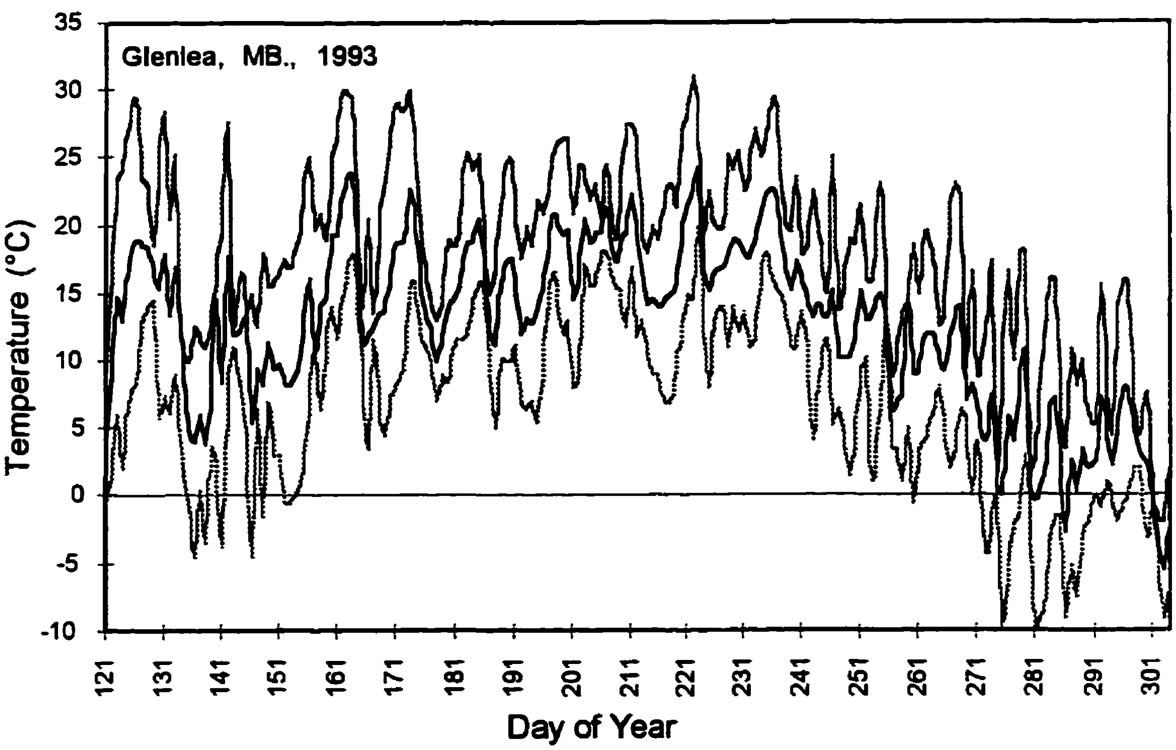


Figure A.01. Daily maximum, minimum, and mean air temperature at Portage la Prairie, MB. (1992), and Glenlea, MB. (1993).

Table A.01 F-test significance (P > F) for fall termination of alfalfa treatment effects on soil moisture at 0-10 cm and 10-30 cm depths at Portage la Prairie, MB. (1992).

	Day of Year											
	129†		134		141		148		155		162	
Source of variation	0-10 (28.2)‡	10-30 (74.6)	0-10 (36.2)	10-30 (82.0)	0-10 (32.5)	10-30 (77.9)	0-10 (26.9)	10-30 (73.9)	0-10 (14.5)	10-30 (60.9)	0-10 (26.7)	10-30 (75.6)
Termination (T)	0.012	0.768	0.096	0.531	<0.001	0.240	0.018	0.284	0.501	0.830	0.252	0.248
Crop (C)	0.512	0.315	0.298	0.418	0.354	0.601	0.721	0.601	0.379	0.415	0.311	0.219
Post herbicide (P)	-	-	-	-	-	-	-	-	0.482	0.739	0.614	0.315
T x C	0.654	0.797	0.513	0.509	0.368	0.930	0.546	0.421	0.084	0.358	0.490	0.217
T x P	-	-	-	-	-	-	-	-	0.728	0.514	0.429	0.616
C x P	-	-	-	-	-	-	-	-	0.847	0.691	0.514	0.409
T x C x P	-	-	-	-	-	-	-	-	0.527	0.459	0.610	0.569

† Planting date DOY 129 (May 8).
‡ Mean soil moisture (mm).

Table A.02 F-test significance (P > F) for spring termination of alfalfa treatment effects on soil moisture at 0-10 cm and 10-30 cm depths at Portage la Prairie, MB. (1992).

	Day of Year											
	148†		155		162		170		178		188	
Source of variation	0-10 (23.4)‡	10-30 (66.2)	0-10 (23.3)	10-30 (68.4)	0-10 (18.9)	10-30 (55.4)	0-10 (31.5)	10-30 (72.6)	0-10 (37.1)	10-30 (77.1)	0-10 (37.8)	10-30 (77.6)
Termination (T)	0.004	<0.001	0.004	0.003	0.817	0.260	0.002	0.038	<0.001	0.331	0.038	0.942
Crop (C)	0.460	0.455	0.988	0.359	0.980	0.291	0.482	0.273	0.179	0.707	0.201	0.139
Post herbicide (P)	-	-	-	-	-	-	-	-	-	-	0.340	0.663
T x C	0.864	0.213	0.316	0.224	0.398	0.281	0.440	0.306	0.233	0.155	0.662	0.210
T x P	-	-	-	-	-	-	-	-	-	-	0.306	0.253
C x P	-	-	-	-	-	-	-	-	-	-	0.339	0.486
T x C x P	-	-	-	-	-	-	-	-	-	-	0.344	0.204

† Planting date DOY 129 (May 8).
‡ Mean soil moisture (mm).

Table A.03 F-test significance (P > F) for fall termination of alfalfa treatment effects on soil moisture at 0-10 cm depth at Glenlea, MB. (1993).

	Day of Year							
Source of variation	133† (26.9) ‡	139 (25.2)	146 (26.9)	153 (28.9)	158 (27.2)	162 (35.8)	168 (33.3)	173 (23.7)
Termination (T)	0.026	0.002	0.005	<0.001	0.001	0.090	<0.001	0.003
Crop (C)	0.237	0.865	0.926	0.046	0.241	0.758	0.272	0.425
Post herbicide (P)	-	-	-	-	-	-	-	0.328
T x C	0.358	0.685	0.576	0.752	0.838	0.396	0.316	0.540
T x P	-	-	-	-	-	-	-	0.578
C x P	-	-	-	-	-	-	-	0.467
T x C x P	-	-	-	-	-	-	-	0.227

† Planting date DOY 133 (May 13).
‡ Mean soil moisture (mm).

Table A.04 F-test significance (P > F) for spring termination of alfalfa treatment effects on soil moisture at 0-10 cm depth at Glenlea, MB. (1993).

	Day of Year								
Source of variation	146† (24.6) ‡	153 (26.2)	158 (25.9)	162 (33.3)	168 (32.7)	173 (21.6)	182 (32.0)	188 (35.2)	195 (25.1)
Termination (T)	0.004	<0.001	0.011	0.002	0.004	0.010	0.003	0.198	0.582
Crop (C)	0.835	0.308	0.805	0.798	0.553	0.262	0.660	0.511	0.864
Post herbicide (P)	-	-	-	-	-	-	0.324	0.633	0.076
T x C	0.217	0.217	0.660	0.782	0.752	0.028	0.889	0.710	0.650
T x P	-	-	-	-	-	-	0.034	0.495	0.426
C x P	-	-	-	-	-	-	0.852	0.294	0.146
T x C x P	-	-	-	-	-	-	0.498	0.707	0.177

† Planting date DOY 146 (May 26).
‡ Mean soil moisture (mm).

7.2 Appendix B

Efficacy of Herbicides and Herbicide Combinations to Terminate Perennial Alfalfa Stands

B.1 Abstract

Herbicides currently available are often inadequate to terminate perennial alfalfa sufficiently for crop production the following year. In addition, few studies are available for herbicide termination of alfalfa stands in Canadian Prairie conditions. An alfalfa termination study was initiated at Glenlea, Manitoba on a six year alfalfa (cv. Beaver) stand to investigate the ability of glyphosate, dicamba, 2,4-D, clopyralid, and combinations of these herbicides to effect termination of alfalfa.

Visual and aerial biomass assessments of alfalfa suppression indicated that herbicides applied in combination with one another generally controlled alfalfa to a greater extent than herbicides applied alone. Clopyralid at 0.30 kg a.i. ha^{-1} applied alone, however, was the only treatment to terminate alfalfa as effectively as the herbicide combination treatments. Weed growth was also assessed, indicating the importance of attending to weeds, which often invade alfalfa stands. Winter annuals including shepherd's purse (*Capsella bursa-pastoris* [L.] Medic.) and stinkweed (*Thlaspi arvense* L.), and perennial grasses including quackgrass (*Agropyron repens* [L.] Beauv.), and foxtail barley (*Hordeum jubatum* L.) were not controlled with the clopyralid treatment. As well, 0.50 kg a.i. ha^{-1} 2,4-D and 0.60 kg a.i. ha^{-1} dicamba treatments were ineffective for dandelion (*Taraxacum officinale* Weber) control. Overall weed control was generally adequate with glyphosate combinations with dicamba or 2,4-D, however for total control including summer annual weeds, and complete control of alfalfa, post-emergence herbicide applications are recommended in addition to the initial termination treatment.

B.2 Introduction

Complete control of perennial alfalfa is required for successful annual crop production in the year following alfalfa termination. The inability of many herbicides to control alfalfa adequately suggests that additional studies need to be performed, in order to find herbicides or herbicide combinations to effect increased suppression of alfalfa. Many herbicides, including glyphosate, dicamba, and 2,4-D applied alone or at sublethal rates, are not sufficient for adequate alfalfa control (Button, 1991; Clayton, 1982; Knake et al., 1985b). Individual treatment of clopyralid however, can control alfalfa adequately for crop production (Koethe, 1987). Treatments of the preceding herbicides used in combination with one another have been successful for adequate alfalfa termination (Button, 1991; Knake et al., 1985b; Moomaw and Martin, 1976).

Weed control is also an important aspect to be considered when terminating alfalfa with herbicides, since at the time of termination, many alfalfa fields are infested with quackgrass, dandelion, and other perennial weeds (Buhler and Proost, 1990). In situations where alfalfa is terminated successfully, and the herbicide has no efficacy on a weed population, that weed population will often flourish from lack of competition by the alfalfa. Knake et al. (1984b) experienced vigorous quackgrass growth when alfalfa was terminated with 2,4-D. Treatments of glyphosate have often been utilized to control a wide diversity of weed species, including alfalfa (Buhler and Proost, 1990; Knake, 1984b).

B.3 Materials and Methods

The study was located at Glenlea, Manitoba on an Osborne clay soil with the surface texture consisting of 9% sand, 26% silt, 66% clay. The experiment was conducted on a six year alfalfa (cv. Beaver) stand, and was designed as a randomized complete block experiment with four replications. Fourteen treatments were applied to the alfalfa stand including 0.50 kg a.i. ha^{-1} 2,4-D, 0.60 kg a.i. ha^{-1} dicamba, 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.30 kg a.i. ha^{-1} clopyralid, 0.30 kg a.i. ha^{-1} clopyralid plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.44 kg a.i. ha^{-1} glyphosate, 0.66 kg a.i. ha^{-1} glyphosate, 0.66 kg a.i. ha^{-1} glyphosate plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.66 kg a.i. ha^{-1} glyphosate plus 0.60 kg a.i. ha^{-1} dicamba, 0.66 kg a.i. ha^{-1} glyphosate plus 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.66 kg a.i. ha^{-1} glyphosate plus 0.08 kg a.i. ha^{-1} clopyralid, 0.89 kg a.i. ha^{-1} glyphosate, 1.78 kg a.i. ha^{-1} glyphosate, and an untreated check. The treatments were applied at 7:00 pm on September 22, 1992. The wind was calm, temperature was 9.8°C, and relative humidity was 49%. The herbicide treatments were applied in 107L water ha^{-1} with a CO_2 equipped bicycle sprayer.

Visual ratings of alfalfa suppression were recorded on October 15 and May 8, by averaging three observations per plot. A rating scale of zero to five was utilized with five representing the untreated check, and zero representing the complete absence of green regrowth. Alfalfa aerial regrowth was also assessed May 25 and June 22, by removing two 0.5 m^2 quadrats of biomass per plot, and hand sorting the alfalfa from other plant species. Alfalfa biomass was dried at 8°C for 48h, and weighed. Each treatment was expressed as a percentage of the untreated check.

Weed control was also assessed on May 25, by removing two 0.5 m^2 quadrats of biomass per plot, and hand sorting the weeds into groups of similar growth characteristics (i.e. summer annuals including lamb's quarters (*Chenopodium album* L.), winter annuals including shepherd's purse (*Capsella bursa-pastoris* [L.] Medic.) and stinkweed (*Thlaspi arvense* L.), perennial broadleaf weeds including dandelions (*Taraxacum officinale* Weber), and perennial grasses including quackgrass (*Agropyron repens* [L.] Beauv.), and foxtail barley (*Hordeum jubatum* L.).

Statistical analysis of the data was performed using analysis of variance (Statistical Analysis Systems, 1990). Fischer's Least Significant Difference test was used to determine mean separation of treatments.

B.4 Results and Discussion

B.4.1 Alfalfa Termination

Visual ratings of alfalfa suppression on October 15, three weeks after herbicide termination of alfalfa indicated that combinations of herbicide were more effective for suppressing alfalfa than that of individual herbicide mixtures (Table B.01). The most effective treatments were 0.66 kg a.i. ha^{-1} glyphosate plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.66 kg a.i. ha^{-1} glyphosate plus 0.60 kg a.i. ha^{-1} dicamba, 0.66 kg a.i. ha^{-1} glyphosate plus 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D, and 0.66 kg a.i. ha^{-1} glyphosate plus 0.08 kg a.i. ha^{-1} clopyralid, which suppressed alfalfa to a greater extent than the other treatments. The 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D treatment was almost as effective in suppressing alfalfa growth as the preceding treatments, however it was not different than the 0.30 kg a.i. ha^{-1} clopyralid, 0.30 kg a.i. ha^{-1} clopyralid plus 0.50 kg a.i. ha^{-1} 2,4-D, and 1.78 kg a.i. ha^{-1} glyphosate treatments. The remaining treatments were considerably less effective in terminating alfalfa. The visual assessment on May 8 showed a similar pattern of treatment comparisons as that on October 15 (Table B.01), however differences between treatments were not as obvious, probably because alfalfa regrowth was only beginning in early May. The May visual rating assessed regrowth of alfalfa, whereas alfalfa die back, which was more prominent, was assessed in the October rating. Button (1991) conducted visual assessments of chemically suppressed alfalfa in the fall and spring, and determined herbicide combinations to be generally more effective than individual herbicides to control alfalfa regrowth.

Aerial regrowth of alfalfa biomass measured on May 25 indicated few differences between treatments, except for the 0.66 kg a.i. ha^{-1} glyphosate, 0.44 kg a.i. ha^{-1} glyphosate, and 0.50 kg a.i. ha^{-1} 2,4-D treatments, which did not terminate alfalfa as well as the other treatments (Figure B.01a). Reassessment of alfalfa aerial regrowth on June 22 clearly indicated the superior termination treatments (Figure B.01b), and ranking of treatments was similar to that of the October 15 visual assessment. The herbicide treatments which obtained greater than 85% suppression of alfalfa according to the June 22 assessment of alfalfa aerial regrowth were 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.30 kg a.i. ha^{-1} clopyralid plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.66 kg a.i. ha^{-1} glyphosate plus 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.66 kg a.i. ha^{-1} glyphosate plus 0.60 kg a.i. ha^{-1} dicamba, and 0.30 kg a.i. ha^{-1} clopyralid (Figure B.01b). Button (1991) found that 0.89 kg a.i. ha^{-1} glyphosate plus 0.825 kg a.i. ha^{-1} 2,4-D, 0.89 kg a.i. ha^{-1} glyphosate plus 0.14 kg a.i. ha^{-1} dicamba, and 0.076 kg a.i. ha^{-1} clopyralid plus 0.588 kg a.i. ha^{-1} 2,4-D provided adequate suppression of alfalfa, as indicated by spring, post-1st alfalfa cut, and early fall spraying. Koethe et al. (1987) obtained 94% control of alfalfa with clopyralid at 0.28 kg ha^{-1} with spring termination.

The herbicide treatments, which provided between 55% and 75% suppression of alfalfa, were 0.66 kg a.i. ha^{-1} glyphosate plus 0.50 kg a.i. ha^{-1} 2,4-D, 0.60 kg a.i. ha^{-1} dicamba, and 1.78 kg a.i. ha^{-1} glyphosate. The remaining treatments (0.89 kg a.i. ha^{-1} glyphosate, 0.66 kg a.i. ha^{-1} glyphosate plus 0.08 kg a.i. ha^{-1} clopyralid, 0.50 kg a.i. ha^{-1} 2,4-D, 0.66 kg a.i. ha^{-1} glyphosate, and 0.44 kg a.i. ha^{-1} glyphosate) provided less than 40% control of alfalfa and were not considered feasible in a field situation (Figure B.01b). Generally, the herbicide combinations provided better control of alfalfa than the individual herbicide treatments. Button (1991) cited 0.89 kg a.i. ha^{-1} glyphosate and 0.14 kg a.i. ha^{-1} dicamba treatments as being inadequate for alfalfa control. Buhler and Proost (1990) however, achieved 78% control of alfalfa with fall applied glyphosate at 1.1 kg a.e. ha^{-1} prior to post-emergence herbicide application. Moomaw and Martin (1976) achieved greater suppression of alfalfa in spring or fall with 1.12 kg ha^{-1} 2,4-D plus 0.28 kg ha^{-1} dicamba combined than with either herbicide applied alone. Clayton (1982) also observed that herbicides in combination with each other were able to terminate alfalfa more effectively than herbicides applied alone. He found that herbicide combinations of 1.12 kg a.i. ha^{-1} 2,4-D plus 0.42 kg a.i. ha^{-1} dicamba, and 2.25 kg a.i. ha^{-1} 2,4-D plus 0.42 kg a.i.

ha^{-1} dicamba effectively suppressed alfalfa to 75% of the untreated control when sprayed August 30, but were not significantly different than combinations of 1.12 kg a.i. ha^{-1} 2,4-D or 2.25 kg a.i. ha^{-1} 2,4-D plus 1.12 kg a.i. ha^{-1} glyphosate or 1.75 kg a.i. ha^{-1} glyphosate. Clayton (1982) noted that all of the preceding herbicide combinations gave unacceptable levels of alfalfa suppression for crop production. Knake et al. (1985b) found inadequate alfalfa control with 0.56 kg ha^{-1} 2,4-D, or 0.56 kg ha^{-1} dicamba, but obtained greatly increased alfalfa control with combinations of 0.56 kg ha^{-1} 2,4-D plus 0.56 kg ha^{-1} dicamba.

Table B.01. Visual rating assessment of alfalfa termination treatments at Glenlea, MB (1993).

Main effect	Visual rating October 15, 1992	 May 8, 1993
Termination treatment		
2,4-D 0.50‡	3.3b†	3.3b
D 0.60	2.0cd	0.3e
D 0.60 + 2,4-D 0.50	0.9ef	0.0e
C 0.30	1.5de	0.3e
C 0.30 + 2,4-D 0.50	1.6de	0.0e
G 0.44	3.6b	1.5c
G 0.66	3.2b	1.0d
G 0.66 + 2,4-D 0.50	0.3fg	1.0d
G 0.66 + D 0.60	0.0g	0.3e
G 0.66 + D 0.60 + 2,4-D 0.50	0.0g	0.0e
G 0.66 + C 0.08	0.7fg	1.0d
G 0.89	2.3c	1.0d
G 1.78	1.4de	0.3e
Untreated Check	5.0a	5.0a
LSD (0.05)	0.7	0.5
Source of variation	ANOVA (P > F)	
Termination	<0.001	<0.001

† Mean visual ratings followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).
‡ kg a.i. ha^{-1}.

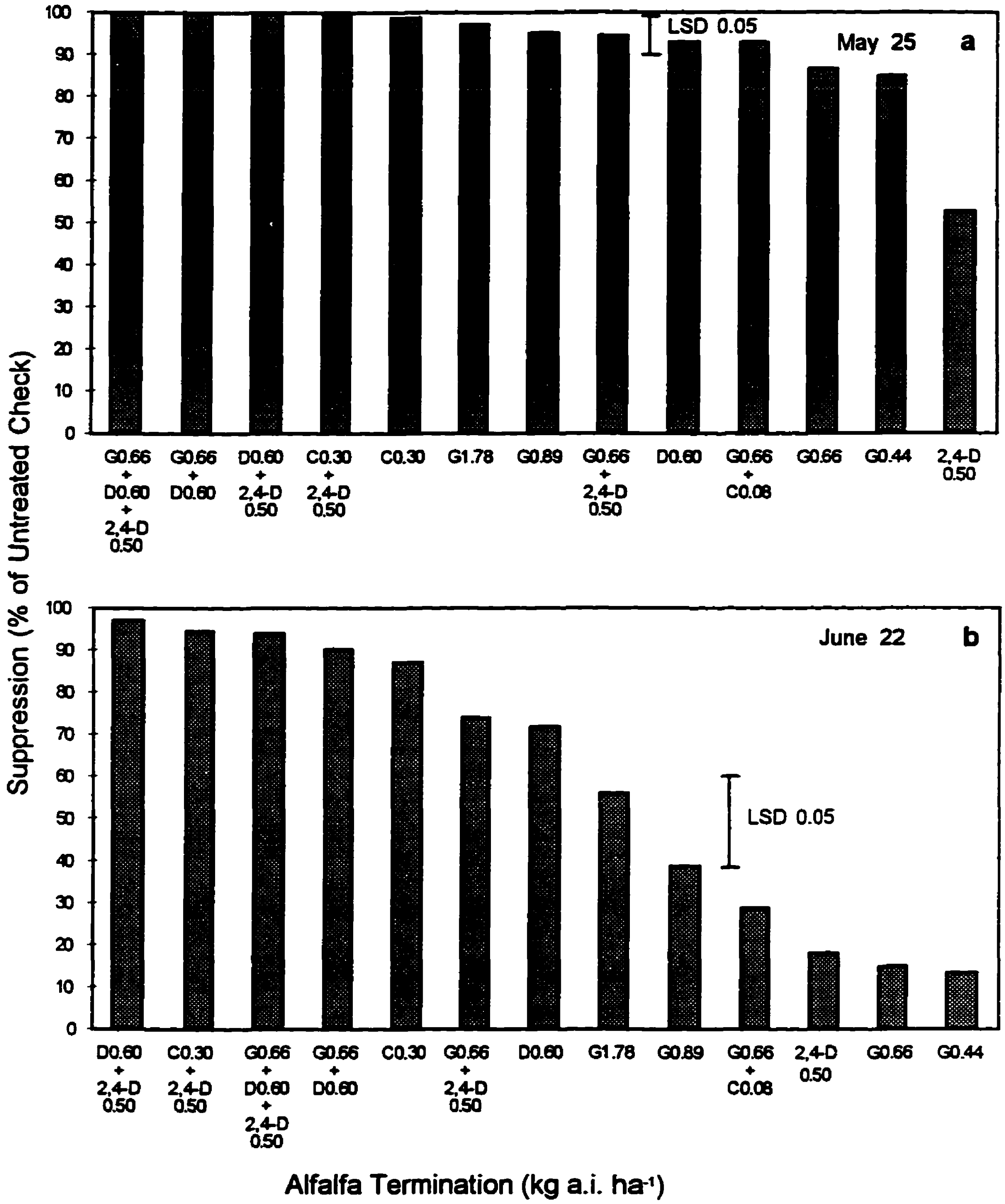


Figure B.01. Fall alfalfa suppression treatments, glyphosate (G), clopyralid (C), dicamba (D), 2,4-D, and combinations of herbicides rated as % of untreated check at Glenlea, MB. on May 25 (a), and June 22 (b). Error bar represents LSD (0.05).

B.4.2 Weed Suppression

Successful termination of an alfalfa stand also includes control of weed species growing with the alfalfa. Control of weed types in the alfalfa stand differed among the termination treatments (Table B.02). Generally, annual weeds were less abundant in treatments where alfalfa was not adequately controlled, and competed with emerging weeds. Knake et al. (1984d) also indicated that competition from uncontrolled alfalfa and sweetclover provided some suppression of annual broadleaf weeds. Moomaw and Martin (1976) achieved good alfalfa control with spring applied 1.12 kg ha^{-1} 2,4-D plus 0.28 kg ha^{-1} dicamba, however they found that the dicamba did not provide enough residual activity to control annual weeds in the absence of the alfalfa. Generally, post-emergence herbicide applications are required to provide adequate control of annual broadleaf weeds (Knake et al., 1992; Smith et al., 1992b).

Winter annual weeds including stinkweed and shepherd's purse were not controlled by the 0.30 kg a.i. ha^{-1} clopyralid treatment (Table B.02), which has no suppressive activity for these weeds (Manitoba Agriculture, 1997). The winter annual weeds were controlled to a similar extent by the other termination treatments.

Dandelions were not controlled with the 0.50 kg a.i. ha^{-1} 2,4-D, or 0.60 kg a.i. ha^{-1} dicamba treatments relative to the other treatments, excluding the untreated control, which had the greatest dandelion biomass (Table B.02). Glyphosate (Buhler and Proost, 1990), dicamba (Smith et al., 1992b), 2,4-D, and clopyralid (Hall and Sagan, 1993; Smith and Zollinger, 1993) have been utilized to suppress dandelion growth. Buhler and Proost (1990) achieved 96% control of dandelions with fall applied glyphosate at 1.1 kg a.e. ha^{-1} treatment in alfalfa. Smith et al. (1992b) used a post-emergence application of 0.56 kg a.e. ha^{-1} dicamba to control both alfalfa and dandelion regrowth, in addition to an initial alfalfa termination treatment of 2.24 kg a.i ha^{-1} glyphosate.

Perennial grasses were best controlled by treatments containing glyphosate either alone or in combinations with other herbicides. (Table B.02). The 0.30 kg a.i.ha^{-1}

clopyralid, 0.30 kg a.i. ha^{-1} clopyralid plus 0.50 kg a.i. ha^{-1} 2,4-D, and 0.60 kg a.i. ha^{-1} dicamba plus 0.50 kg a.i. ha^{-1} 2,4-D treatments contained the greatest amount of perennial grass biomass probably because these treatments were very effective for alfalfa control, but not for grass control, and in the absence of the alfalfa competition, the grasses achieved greater growth. The 0.50 kg a.i. ha^{-1} 2,4-D, or 0.60 kg a.i. ha^{-1} dicamba treatments were ineffective for both grass and alfalfa control, and have the alfalfa regrowth which provided competition to the grass weeds. Knake et al. (1984b) experienced similar results with invading quackgrass when alfalfa was 80% controlled with 1.12 kg. ha^{-1} 2,4-D. Knake et al. (1984b) however, achieved good quackgrass control in an alfalfa stand with a treatment of 2.24 kg ha^{-1} glyphosate.

Table B.02. Weed aerial biomass response to alfalfa termination treatments at Glenlea, MB. (1993).

	Weed type			
Main effect	Summer annuals	Winter annuals	Dandelions	Perennial Grasses
	kg ha^{-1}			
Termination treatment				
2,4-D 0.50‡	1.5bc†	0.0b	236.0b	15.0b
D 0.60	1.5bc	5.0b	139.8bc	16.0b
D 0.60 + 2,4-D 0.50	1.8bc	0.0b	4.5c	26.0ab
C 0.30	0.0c	202.5a	20.5c	52.5a
C 0.30 + 2,4-D 0.50	2.0bc	0.0b	12.3c	49.8a
G 0.44	7.0abc	7.0b	30.5c	7.0b
G 0.66	7.3abc	1.8b	10.8c	7.3b
G 0.66 + 2,4-D 0.50	8.3ab	2.3b	12.8c	8.8b
G 0.66 + D 0.60	0.0c	0.3b	7.3c	0.0b
G 0.66 + D 0.60 + 2,4-D 0.50	0.5c	0.5b	9.0c	3.3b
G 0.66 + C 0.08	10.3a	10.3b	23.3c	10.3b
G 0.89	6.0abc	14.5b	8.8c	6.0b
G 1.78	7.3abc	6.0b	2.5c	7.3b
Untreated Check	0.0c	5.8b	840.5a	5.0b
LSD (0.05)	7.6	30.9	192.6	28.0
Source of variation		ANOVA (P > F)		
Termination	0.060	<0.001	<0.001	0.006

† Mean aerial biomass followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).
‡ kg a.i. ha^{-1}.

B.5 Summary and Conclusions

This study has highlighted two important aspects of perennial alfalfa termination. First, increased suppression of alfalfa was achieved by application of herbicides in combination with one another, rather than by individual applications of herbicides. Second, weed species growing in the alfalfa stand must also be adequately controlled for successful crop production in the following year. Herbicide combinations including glyphosate are generally required to control perennial grass weeds and dandelions.

To achieve successful alfalfa termination, especially in situations with diverse perennial weed populations, it is recommended that herbicide combinations including glyphosate be utilized in order to address adequate weed and alfalfa control. Since no treatment achieved total alfalfa or weed control, it is recommended that in addition to the initial alfalfa termination treatment, a post-emergence herbicide application is also applied to control alfalfa and weed escapes, as well as annual in-crop weeds.

7.3 Appendix C

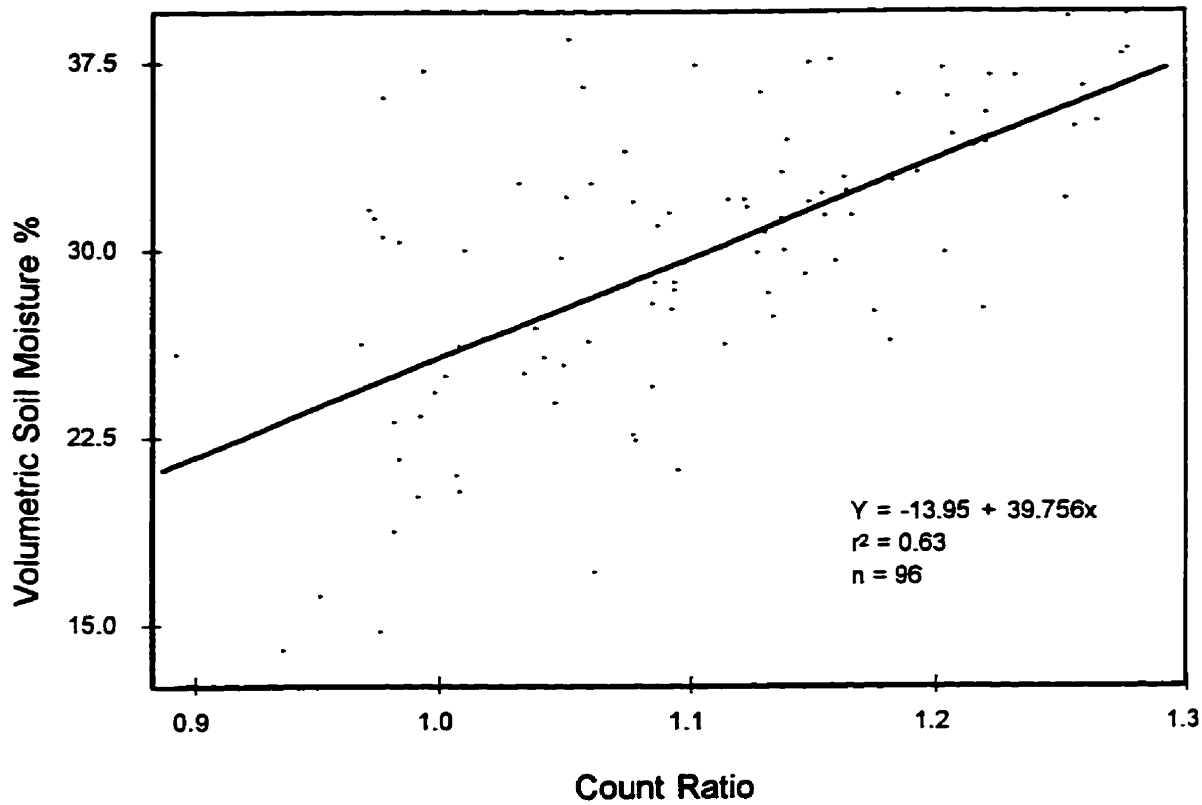


Figure C.01. Neutron probe standard calibration curve derived from volumetric soil moisture measurements with a surface shield (Troxler model 4300 moisture gauge, Troxler Electronic Laboratories, Inc., Triangle Park, NC.) at the 0-10 cm soil depth at Holland, Carman, and Glenlea, MB.