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Immediate Effects of Time and Method of Alfalfa Termination on Soil Mineral Nitrogen, Moisture, Weed Control, and Seed Yield, Quality, and Nitrogen Uptake

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ABSTRACT

Three field experiments were conducted on Gray Luvisol (Typic Cryoboralf) soils in northeastern Saskatchewan to compare the effects of alfalfa (*Medicago sativa* Leyss) stand termination with tillage and herbicides at different times on mineral nitrogen (N) (ammonium-N and nitrate-N) and moisture content of soil in spring (experiments 1 and 2), soil moisture, volunteer alfalfa and dandelion control, plant density, seed yield, protein concentration and N uptake for wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L), canola (*Brassica rapa* L.), and pea (*Pisum sativum* L.) crops (experiment 3). Termination treatments included combinations of times (in mid-June after cut 1, in mid-August after cut 2 and in mid-May during spring) and methods [tillage alone, herbicides alone (glyphosate + 2,4-D amine and also clopyralid + 2,4-D ester in experiment 3) and these herbicides + tillage]. Tillage alone significantly increased spring soil nitrate-N levels over herbicides alone or herbicides + tillage. Termination after cut 1 had the highest levels of soil nitrate-N. There was little effect of time and method of termination on soil ammonium-N and moisture content in spring. Herbicides + tillage generally provided better control of both volunteer alfalfa and dandelion in the four crops than tillage or herbicides alone. In general, alfalfa termination with herbicides alone significantly reduced plant density, seed yield, and N uptake of all crops and

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protein concentration of cereals only due to effects on levels of soil nitrate-N, dandelion control, and crop injury by clopyralid or 2,4-D residues in soil. Plant density, seed yield, N uptake and protein concentration of crops tended to decline with delay in termination time. The results of this study support the use of some tillage in alfalfa stand termination in helping to control volunteer alfalfa and dandelion and optimize annual crop yields and quality.

Keywords: alfalfa termination, N uptake, protein concentration, seed yield, soil mineral N, soil moisture, weed control

INTRODUCTION

Perennial forages play a vital role in the farm economy and in diversifying the cropping systems of the Parkland region for the Canadian prairies (Entz et al., 1997, 2002). Production of alfalfa (*Medicago sativa* Leyss) forage, seed, and various products (e.g., dehydrated alfalfa, alfalfa pellets, and sun-cure hay) also provide an opportunity to tap into international markets. Legumes such as alfalfa reduce fertilizer nitrogen (N) input by symbiotic nitrogen fixation (Henry and Tomasiewicz, 1980; Zentner et al., 1990, 2001; Entz et al., 1995; Mohr et al., 1999). In addition, the year-round crop stand of these perennial crops may prevent the development of soil salinity (Agriculture Canada, 1991), suppress weeds (Dryden et al, 1983; Harvey and McNevin, 1990), and create favorable soil moisture conditions by snow trapping (Cutforth et al., 2002). Moreover, one of the most important benefits of forage for farmers is higher yield of grain crops following forages in the rotation (Hoyt and Hennig, 1971; Badaruddin and Meyer, 1990). Forages also improve the physical properties (Blackwell et al., 1990) and organic matter of soil (Campbell et al., 1990), and reduce soil erosion (Stinner and House, 1989). This is particularly important on Gray Luvisol soils in the Parkland region, which are inherently low in organic matter, and have surface and sub-surface soil structure problems (e.g., crusting and weak aggregates) that pose unique challenges for crop production.

In the prairie provinces of Canada, alfalfa fields are terminated after 3–5 years, primarily due to low production and infestation with weeds (dandelion-*Taraxacum officinale* G. H. Weber ex 'Wiggers' and 'quackgrass' - *Elytrigia repens* (L.) Desv. ex 'B. D. Jacks') that reduces its value to the pellet processors. Traditionally, tillage has been used to terminate the forage stands and to prepare the seedbed for the following crop. A survey of forage producers on the Canadian prairies showed that 77% of forage stands were terminated using tillage alone, 1% by herbicides alone, and 22% by a combination of tillage and herbicides (Entz et al., 1995). Where tillage is used alone, an average of five to seven tillage operations are used to terminate the forage and establish a seedbed. These conventional stand termination and seedbed preparation techniques dry the soil, increase the risk of soil erosion, and decrease organic matter and productivity of soil (Entz et al., 1995). Intensive tillage can also lead to deterioration of soil structure and crusting, which result in poor seedling emergence and crop stands (Bullied et al., 1999) and loss of nitrate-N through leaching and denitrification (Robbins and Carter, 1980; Firestone, 1982; Campbell et al., 1984; 1994).

Wide adoption of direct seeding (zero-till) production systems in the region and an attempt to preserve some of the soil benefits provided by the perennial forage have prompted interest amongst producers into finding alternatives to tillage for alfalfa stand termination. Zero tillage (ZT) has been demonstrated as a feasible alternative to conventional tillage (CT) for seedbed preparation and crop establishment (Allen and Entz, 1994). Studies have shown ZT to result in plant populations similar to CT (Wolf et al., 1985). Direct seeding of crops into stubble is also beneficial in terms of soil moisture conservation (Allen and Entz, 1994; Bullied and Entz, 1999; Cutforth et al., 2002) and alleviating other problems associated with CT. Herbicides have been identified that can control alfalfa (Button, 1991). However, seeding into alfalfa stubble has led to questions regarding weed control (particularly dandelion), crop selection and rates of mineral N release from alfalfa residues and availability to subsequent crops (Westerman and Crothers, 1993).

Northeastern Saskatchewan is one of the major forage-producing areas of the Parkland region in western Canada. However, few field studies have examined stand termination of forage crops and subsequent annual crop establishment under a ZT regime in this area (Bullied et al., 1999; Mohr et al., 1999). The objective of this study was to evaluate the effects of time and method of alfalfa termination on (1) soil mineral N and moisture content in spring, (2) volunteer alfalfa and dandelion control, and (3) plant density, seed yield, protein concentration, and N uptake for annual cereal, oilseed, and pulse crops.

MATERIALS AND METHODS

Three field experiments were conducted on Gray Luvisol (Typic Cryoboralf) soils at Star City (experiments 1 and 2) and Gronlid (experiment 3) in northeastern Saskatchewan. High level of dandelion infestation, which is typical for alfalfa stands at the time of termination, was used to select the experimental sites. In experiments 1 and 2, alfalfa stands were terminated in 1993 and 1994, respectively; and soil properties were determined in the following spring. In experiment 3, alfalfa stand was terminated in 1996 and soil cropped in 1997. Treatments were combinations of various termination times and methods. Three termination times were after cut 1 (mid-June), after cut 2 (mid-August) and spring (mid-May), except for tillage alone in experiment 3, which was performed in the previous autumn in mid-October for all the termination times. Termination methods were three for experiments 1 and 2 [tillage alone; herbicide mixture: 1 (glyphosate at 879 g ai ha^{-1} + 2,4-D amine at 815 g ai ha^{-1})

and herbicide mixture 1 + tillage] and five for experiment 3 [tillage alone; herbicide mixture 1, herbicide mixture 1 + tillage, herbicide mixture 2 (clopyralid at 133 g ai ha^{-1} + 2,4-D ester at 500 g ai ha^{-1}), and herbicide mixture 2 + tillage]. Treatment plots (6 m × 15 m) were arranged in a randomized complete block design with four replications.

All herbicide treatments were applied when the alfalfa foliage regrowth was approximately 10 cm in high. Tillage treatments were performed immediately after forage harvest, or two weeks after herbicide application in the herbicide + tillage treatments. Tillage involved two tandem disc operations for cut 1 termination (i.e., one after cut 1 and one after cut 2) and one tandem disc operation for cut 2 termination (i.e., after cut 2), followed by a cultivation in autumn and in spring, and harrowing before seeding. When forage was terminated in the spring, the tillage and herbicides were applied to regrowth of 10 cm, followed by tillage seven days later on the tillage and herbicide + tillage treatments and harrowing prior to seeding. For the herbicide alone treatments, plots received an additional application of glyphosate (440 g ai ha^{-1}) two days after seeding.

Wheat (*Triticum aestivum* L. cv. Katepwa), barley (*Hordeum vulgare* L. cv. Harrington), canola (*Brassica rapa* L. cv. Parkland), and pea (*Pisum sativum* L. cv. Princess) were seeded in May with a ConservaPack air seeder drill equipped with knives in 22.5 cm row spacing. Seed rate was 134, 108, 7, and 202 kg ha^{-1} and seeding depth was 4.4, 3.8, 1.9, and 4.5 cm for wheat, barley, canola, and pea, respectively. For wheat, barley, and canola, a fertilizer blend (50 kg N, 9 kg phosphorus (P), 8 kg potassium (K), and 10 kg sulfur (S) ha^{-1}) was side banded (2.5 cm to the side and 5 cm below the seed). Pea received a side banded fertilizer blend (15 kg N, 9 kg P, 8 kg K, and 10 kg S ha^{-1}) and granular inoculant in the seedrow. Weeds during the growing season were controlled by appropriate herbicides.

Plant data collection included assessment of volunteer alfalfa and dandelion control; and plant density, seed yield, protein concentration, and N uptake for wheat, barley, canola, and pea. Volunteer alfalfa and dandelion control was assessed in June of the annual cropping year by visual rating. Crop plant density was measured three weeks after seedling emergence by counting plants in 1-m length of two rows in each plot. At maturity, crops were harvested using a small plot combine. Representative seed samples were analyzed for total N (AOAC, 1995). Total N uptake (kg N ha^{-1}) was calculated as: seed yield (kg ha^{-1}) × total N concentration (g N kg^{-1}) × 0.001. Protein concentration was calculated by multiplying total N by 5.70 for wheat and by 6.25 for barley, canola, and pea (Williams et al., 1998).

Soil samples were collected immediately prior to seeding for moisture content and mineral N at the 0–15, 15–30, 30–60 depths (experiments 1 and 2) and also at the 60–90 cm depth (experiment 3 only). Soil moisture samples were dried at 105°C for 48 h to determine gravimetric moisture content. Soil samples for mineral N were air dried and finely ground for nitrate-N and ammonium-N determination using 2.0 M potassium chloride (KCl) (Keeney and Nelson, 1982).

Data were subjected to analysis of variance (ANOVA) using the GLM procedure in SAS (SAS Institute Inc., 1993). Least significant difference (LSD at $P \leq 0.05$) was used to assess treatment differences.

RESULTS AND DISCUSSION

Spring Soil Mineral Nitrogen and Moisture Content

Soil nitrate-N was influenced by time and method of alfalfa termination in both 1994 and 1995 (Tables 1 and 2). In 1995, highest nitrate-N levels were recorded for termination after cut 1, while little difference was found between the after cut 2 and in the following spring termination times. This effect was observed throughout the soil profile sampled (0–60 cm). Of the termination methods, tillage had a far greater accumulation of soil nitrate-N than herbicides alone, in both years. Herbicide + tillage tended to result in higher soil nitrate-N values over the herbicide alone treatment. Almost all of this nitrate-N accumulated in the surface soil (0–15 cm soil depth) where the tillage was performed, but in 1995 this effect was also observed in the 15–30 cm soil depth. A significant interaction was recorded between time and method of alfalfa termination for soil nitrate-N in 1995 (Table 2). While termination after cut 1 with tillage resulted in higher soil nitrate-N levels than termination after cut 2 or in the following spring, few differences were observed between termination times when herbicides alone or herbicides + tillage were used. The narrow window (seven days between termination and sampling) available for legume decomposition with spring herbicide application was likely responsible for little N accumulation.

The levels of ammonium-N in soil were low and much less influenced by the times and methods of alfalfa termination than nitrate-N (Tables 1 and 2). In 1995, a significant response to method of termination revealed the opposite response than that of nitrate-N, with tillage alone being lower than the herbicide alone or combination of herbicide followed by tillage (30–60 and 0–60 cm). With only one exception in 1994, time of alfalfa termination had no effect on the levels of spring soil ammonium-N.

Similar to the present study, earlier studies showed that accumulation of nitrate-N in soil was lower when green manure crops were terminated by herbicides than tillage (Biederbeck and Slinkard, 1988; Sarrantonio and Scott, 1988). Other researchers have also reported greater release of nitrate-N from soil when alfalfa residues were incorporated into soil compared to those left on the soil surface in greenhouse/growth chamber (Mohr et al., 1998a, 1998c) and field conditions (Biederbeck and Slinkard, 1988; Mohr et al., 1999). Greater accumulation of nitrate-N in tilled soils may be due to a greater release of N from incorporation of residues into the soil (Wilson and Hargrove, 1986; Varco et al.,

Table 1
Amount of nitrate-N (NO_3-N), ammonium-N (NH_4-N) and water in soil in spring of 1994 as influenced by time and method of alfalfa termination at Star City, Saskatchewan (experiment 1)

Treatment	NO_3-N (kg N ha^{-1}) in soil depths (cm)				NH_4-N (kg N ha^{-1}) in soil depths (cm)				Water (mm) in 0–90 cm
	0–15	15–30	30–60	0–60	0–15	15–30	30–60	0–60	
Termination time									
After cut 1	43.5	8.0	5.3	56.8	8.9	8.4 a	14.9	32.2	19.5
After cut 2	28.1	3.6	5.1	36.8	9.2	6.9 ab	12.6	28.7	17.8
Spring	26.8	2.3	5.0	34.0	10.0	6.6 b	13.7	30.4	19.4
$LSD_{0.05}$	NS	$5.0^{\bullet}$	NS	NS	NS	1.6^{*}	NS	NS	NS
Termination method									
Tillage	61.0 a	7.7	4.8	73.5 a	9.5	7.1	12.6	29.2	19.6
Glyphosate + 2,4-D Amine	13.3 b	3.4	4.4	21.0 b	9.5	7.5	15.0	32.0	17.8
Glyphosate + 2,4-D Amine + Tillage	24.1 b	2.8	6.2	33.0 b	9.1	7.4	13.6	30.1	19.5
$LSD_{0.05}$	27.2^{**}	$8.6^{\bullet}$	NS	31.6^{**}	NS	NS	NS	NS	NS

Time × method									
After cut 1									
Tillage	96.5	15.3	5.4	117.2	8.8	7.7	13.3	29.9	19.7
Glyphosate + 2,4-D Amine	2.5	5.4	5.0	12.8	9.4	9.2	19.9	38.4	16.2
Glyphosate + 2,4-D Amine + Tillage	31.7	3.3	5.5	40.5	8.4	8.5	11.4	28.2	22.5
After cut 2									
Tillage	30.4	4.5	4.5	39.4	8.8	6.4	11.1	26.3	17.4
Glyphosate + 2,4-D Amine	18.6	3.4	5.8	27.8	9.3	8.0	13.9	31.3	18.4
Glyphosate + 2,4-D Amine + Tillage	35.2	3.1	5.0	43.2	9.5	6.2	12.9	28.6	18.1
Spring									
Tillage	56.2	3.4	4.5	64.1	10.9	7.1	13.4	31.4	21.5
Glyphosate + 2,4-D Amine	18.9	1.4	2.4	22.7	9.7	5.4	11.2	26.2	18.7
Glyphosate + 2,4-D Amine + Tillage	5.3	2.0	8.0	15.3	9.5	7.4	16.5	33.5	17.9
$LSD_{0.05}$	46.3$^{•}$	NS	NS	NS	NS	NS	NS	NS	3.9*

$^{•,*,**}$ and NS refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

Table 2
Amount of nitrate-N (NO_3-N), ammonium-N (NH_4-N) and water in soil in spring of 1995 as influenced by time and method of alfalfa termination at Star City, Saskatchewan (experiment 2)

Treatment	NO_3-N (kg N ha^{-1}) in soil depths (cm)				NH_4-N (kg N ha^{-1}) in soil depths (cm)				Water (mm) in 0–90 cm
	0–15	15–30	30–60	0–60	0–15	15–30	30–60	0–60	
Termination time									
After cut 1	27.4 a	6.0 a	5.3 a	38.7 a	10.0	8.3	12.9	31.2	13.8
After cut 2	15.0 b	2.6 b	2.5 b	20.0 b	9.8	8.2	15.2	33.2	11.9
Spring	7.1 b	1.6 b	2.3 b	11.0 b	9.3	9.0	14.9	33.1	12.3
$LSD_{0.05}$	9.8***	2.5**	1.6***	12.5***	NS	NS	NS	NS	NS
Termination method									
Tillage	36.1 a	6.9 a	4.3	47.3 a	8.8 b	7.2	10.7 b	26.7 b	14.1 a
Glyphosate + 2,4-D Amine	3.0 b	1.3 b	3.0	7.1 b	9.2 b	9.0	15.7 a	33.8 a	11.0 b
Glyphosate + 2,4-D Amine + Tillage	10.4 b	2.0 b	2.9	15.3 b	11.2 a	9.3	16.6 a	37.0 a	12.8 a
$LSD_{0.05}$	9.8***	2.5***	NS	12.5***	1.9*	NS	4.3*	6.9*	1.7*

Time × method									
After cut 1									
Tillage	68.8	15.4	8.2	92.4	7.5	5.3	7.6	20.4	15.4
Glyphosate + 2,4-D Amine	1.5	0.7	4.1	6.3	9.7	9.3	15.7	34.8	10.9
Glyphosate + 2,4-D Amine + Tillage	11.8	1.8	3.8	17.4	12.8	10.2	15.5	38.4	15.1
After cut 2									
Tillage	23.7	2.8	2.1	28.6	8.8	7.2	9.9	25.9	12.6
Glyphosate + 2,4-D Amine	4.3	2.2	2.5	8.9	8.6	9.2	17.8	35.6	11.7
Glyphosate + 2,4-D Amine + Tillage	17.2	2.7	2.8	22.7	12.0	8.2	18.1	38.2	11.5
Spring									
Tillage	16.0	2.4	2.5	20.9	9.9	9.2	14.7	33.9	14.5
Glyphosate + 2,4-D Amine	3.1	0.9	2.3	6.3	9.2	8.3	13.6	31.1	10.5
Glyphosate + 2,4-D Amine + Tillage	2.3	1.5	2.0	5.7	8.7	9.5	16.2	34.5	12.0
$LSD_{0.05}$	16.6***	4.3***	5.5•	4.0***	3.2•	NS	NS	NS	NS

•,*,**,*** and NS refer to significant treatment effects in ANOVA at $P \leq 0.10$, $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

1993; Mohr et al., 1998a, 1998c). This process is facilitated by better aeration and higher temperature (Mitchell and Teel, 1977), which promote residue decomposition and N mineralization when soil moisture is adequate. In addition, incorporation of alfalfa residues may reduce gaseous N losses and consequently result in a greater supply of mineral N (Janzen and McGinn, 1991; Mohr et al., 1998b). For termination after cut 1, tillage alone also resulted in greater accumulation of nitrate-N in soil than other times of termination in the 15–30 and 30–60 cm layers in 1995. This suggests downward movement of nitrate-N in the soil profile, most likely due to increased duration for N mineralization and greater moisture in autumn after cut 1 (Bullied and Entz, 1999).

In 1994 (experiment 1), the effect of termination time and method on spring soil moisture content was not significant but the interaction was significant (Table 1). Highest soil water contents were obtained by herbicide + tillage when used after cut 1. In 1995 (experiment 2), spring soil moisture was significantly affected by termination method, and soil moisture content was lowest with herbicide termination (Table 2). In 1997 (experiment 3), spring soil moisture in the 15–30 and 30–60 cm soil depths was not affected by termination method, but it was significantly affected by termination time (Table 3). In these two soil depths, moisture content was higher for termination after cut 1 and cut 2 than that for spring termination. Termination time by termination method interaction on soil moisture was significant for the 30–60 and 60–90 cm depths, but termination method for different termination times did not show any consistent trends. Contrary to these findings, Bullied and Entz (1999) observed higher soil moisture content with delaying termination using herbicide. Other researchers in the Parkland region have reported higher soil moisture content under ZT than CT (Malhi and O'Sullivan, 1990; Lafond et al., 1992; Malhi et al., 1992), but this effect was not detected in this study.

Weed Control

Time of termination significantly affected the control of volunteer alfalfa and dandelion in all crops (Table 4). Volunteer alfalfa control was >80% in wheat, barley and canola for all termination times, but in pea only when alfalfa was terminated after cut 1. Dandelion was similarly controlled in wheat, barley, and canola for all termination times, but in pea only when alfalfa was terminated in spring. Mean effect of termination method and termination time by method interaction was significant for dandelion control in all crops, but in pea only for the control of alfalfa regrowth.

All the termination methods provided effective control of alfalfa regrowth in the subsequent pea crop, when alfalfa was terminated after cut 1. However, they were less effective on the alfalfa regrowth control at later termination times. For termination after cut 2 or in spring, best control of alfalfa regrowth was obtained when tillage was combined with herbicide application (glyphosate

Table 3
Effect of alfalfa stand termination method and time on soil moisture content in spring of 1997 at Gronlid, Saskatchewan (experiment 3)

	Moisture content (%) in soil layers (cm)			
Treatment	0–15	15–30	30–60	69–90
Termination time				
After cut 1	20.0	17.8 a	16.5 a	17.6
After cut 2	26.1	18.1 a	16.8 a	16.6
Spring	19.6	16.3 b	14.5 b	15.9
$LSD_{0.05}$	NS	1.3**	1.8*	NS
Termination method				
Tillage	20.2	17.5	16.7	16.1
Glyphosate + 2,4-D Amine	20.5	17.4	15.4	17.9
Glyphosate + 2,4-D Amine + Tillage	24.5	17.3	15.8	16.1
$LSD_{0.05}$	NS	NS	NS	NS
Time × method				
Termination after cut 1				
Tillage	18.4	17.8	17.5	15.3
Glyphosate + 2,4-D Amine	21.0	18.5	16.6	22.3
Glyphosate + 2,4-D Amine + Tillage	20.7	17.1	15.5	15.1
Termination after cut 2				
Tillage	21.5	17.4	15.5	15.8
Glyphosate + 2,4-D Amine	23.0	18.3	16.5	16.8
Glyphosate + 2,4-D Amine + Tillage	33.7	18.6	18.5	17.1
Termination in spring				
Tillage[z]	20.8	17.3	17.2	17.2
Glyphosate + 2,4-D Amine	17.6	15.4	13.0	14.4
Glyphosate + 2,4-D Amine + Tillage	20.5	16.1	13.4	16.1
$LSD_{0.05}$	NS	NS	3.1*	5.0*

[z]This termination method was applied in autumn.
*, ** and and NS refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively.

+ 2,4-D amine or clopyralid + 2,4-D ester). The use of either herbicide mixture alone did not provide good control. Because pea was the least competitive test crop, early season alfalfa stand termination by any method or use of herbicides + tillage to terminate stands closer to time of seeding is required for effective

Table 4
Effect of alfalfa stand termination method and time on control of volunteer alfalfa and dandelion in wheat, barley, canola and pea crops in 1997 at Gronlid, Saskatchewan (experiment 3)

	Alfalfa control (%)				Dandelion control (%)			
Treatment	Wheat	Barley	Canola	Peas	Wheat	Barley	Canola	Peas
Termination time								
After cut 1	99 a	99 a	100 a	96 a	92 b	91 b	84 b	68 b
After cut 2	90 b	92 b	87 b	67 b	92 b	92 b	90 ab	77 ab
Spring	96 a	97 a	95 ab	60 b	99 a	99 a	98 a	85 a
$LSD_{0.05}$	6**	6*	9*	11***	6*	7*	9**	11**
Termination method								
Tillage	97	97	95	68 b	100 a	100 a	99 a	92 a
Glyphosate + 2,4-D Amine	92	93	85	56 b	80 c	79 c	73 c	51 c
Glyphosate + 2,4-D Amine + Tillage	99	99	99	91 a	100 a	100 a	99 a	79 ab
Clopyralid + 2,4-D Ester	90	91	92	67 b	92 b	92 b	81 b	67 b
Clopyralid + 2,4-D Ester + Tillage	98	100	99	88 a	100 a	100 a	100 a	93 a
$LSD_{0.05}$	NS	NS	NS	14***	8***	9***	12***	14***

Time × method								
Termination after cut 1								
Tillage	100	100	99	95	100	100	100	97
Glyphosate + 2,4-D Amine	95	98	100	90	60	54	35	15
Glyphosate + 2,4-D Amine + Tillage	100	100	100	98	100	100	98	65
Clopyralid + 2,4-D Ester	100	100	100	98	100	100	87	65
Clopyralid + 2,4-D Ester + Tillage	100	100	100	98	100	100	100	98
Termination after cut 2								
Tillage	97	96	93	68	100	100	100	90
Glyphosate + 2,4-D Amine	84	86	64	39	83	84	96	64
Glyphosate + 2,4-D Amine + Tillage	96	99	96	80	100	100	100	85
Clopyralid + 2,4-D Ester	78	78	84	62	78	78	63	58
Clopyralid + 2,4-D Ester + Tillage	98	100	99	86	100	100	100	89
Termination in spring								
Tillage[z]	95	95	93	41	100	100	96	90
Glyphosate + 2,4-D Amine	96	96	91	48	99	99	99	75
Glyphosate + 2,4-D Amine + Tillage	100	100	100	94	100	100	100	88
Clopyralid + 2,4-D Ester	94	96	93	40	98	98	93	78
Clopyralid + 2,4-D Ester + Tillage	98	99	98	79	100	100	100	93
$LSD_{0.05}$	NS	NS	NS	24*	14***	16***	20***	24**

[z]This termination method was applied in autumn.

*, **, *** and NS refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

in-crop control of volunteer alfalfa. Incomplete stand kill and regrowth of alfalfa after herbicide application have been observed by other researchers (Clayton, 1982; Button, 1991). This can result in competition between crop and weeds for moisture, nutrients, and light, producing reduced seed yield (Moomaw and Martin, 1976; Smith et al., 1992; Krall et al., 1995). This suggests the need for additional herbicide application (Davies, 1976).

Tillage alone or tillage combined with clopyralid + 2,4-D ester resulted in good control of dandelion in all crops for all termination times. Dandelion, in contrast to volunteer alfalfa was not controlled in any crop when glyphosate + 2,4-D amine was used to terminate the stand early. Both these herbicides have no (glyphosate) or short (2,4-D) soil residual activity, in contrast to that of clopyralid. In addition, control of alfalfa likely allowed dandelion to increase in abundance. In the more weakly competitive pea crop, dandelion, similar to volunteer alfalfa, was poorly controlled by herbicide alone treatments for all termination times.

Crop Establishment

Alfalfa stand termination timing significantly affected seedling emergence of barley and pea, with termination in spring resulting in lowest emergence (Table 5). Termination method had significant effects on emergence of all crops. In general, termination without tillage reduced plant density of all crops. Interaction of termination time and termination method was significant only for pea, and trends were not consistent. These findings contradict those of other researchers, who found improved crop emergence with herbicide termination compared to tilled treatment (Bullied et al., 1999).

Seed Yield, Nitrogen Uptake, and Protein Concentration

The effect of termination time on seed yield was significant only for canola and pea (Table 6). Seed yields were highest when alfalfa stand was terminated after cut 1. Lowest pea seed yield was obtained when alfalfa stand was terminated in the spring. The effect of termination method on seed yield was significant for all crops, while the termination time by termination method interaction was significant for wheat, canola, and pea. In general, best seed yields were obtained when alfalfa stands were terminated using tillage or tillage in combination with herbicides, rather than with herbicides alone. The wheat, barley, canola and pea plots treated with glyphosate or clopyralid + 2,4-D alone, respectively, yielded only 59 and 66%, 63 and 62%, 32 and 51%, and 26 and 47% of the plots treated with the same herbicide plus tillage. The drastic decline of canola and pea seed yield with herbicides alone compared to the same herbicides plus tillage treatments was more evident when the alfalfa stand was terminated after cut

Table 5
Effect of alfalfa stand termination method and time on seedling emergence of wheat, barley, canola and pea crops in 1997 at Gronlid, Saskatchewan (experiment 3)

	Seedling emergence (plants m^{-2})			
Treatment	Wheat	Barley	Canola	Pea
Termination time				
After cut 1	274.6	212.7 a	85.0	64.1 a
After cut 2	247.2	196.7 ab	86.5	64.6 a
Spring	240.9	189.0 b	80.5	53.5 b
$LSD_{0.05}$	NS	17.3*	NS	6.7**
Termination method				
Tillage	275 .3 a	217.3 a	99.7 a	62.8 a
Glyphosate + 2,4-D Amine	222.8 c	189.8 b	53.0 c	50.7 b
Glyphosate + 2,4-D Amine + Tillage	270.2 ab	203.8 ab	87.8 ab	65.5 a
Clopyralid + 2,4-D Ester	234.2 bc	182.7 b	77.7 b	59.5 a
Clopyralid + 2,4-D Ester + Tillage	268.7 ab	203.7 ab	101.8 a	65.2 a
$LSD_{0.05}$	40.7*	22.4***	19.0***	8.6**
Time × method				
Termination after cut 1				
Tillage	329.5	235.5	105.0	51.5
Glyphosate + 2,4-D Amine	213.5	195.0	57.5	43.5
Glyphosate + 2,4-D Amine + Tillage	300.5	225.0	89.5	77.0
Clopyralid + 2,4-D Ester	242.5	180.5	70.5	68.5
Clopyralid + 2,4-D Ester + Tillage	287.0	227.5	102.5	80.0
Termination after cut 2				
Tillage	256.5	208.5	100.5	64.0
Glyphosate + 2,4-D Amine	213.0	177.0	56.0	55.0
Glyphosate + 2,4-D Amine + Tillage	265.5	219.0	99.0	72.0
Clopyralid + 2,4-D Ester	212.5	179.0	79.5	64.5
Clopyralid + 2,4-D Ester + Tillage	288.5	200.0	97.5	67.5
Termination in spring				
Tillage[z]	240.0	208.0	93.5	73.0
Glyphosate + 2,4-D Amine	242.0	197.5	45.5	53.5
Glyphosate + 2,4-D Amine + Tillage	244.5	167.5	75.0	47.5
Clopyralid + 2,4-D Ester	247.5	188.5	83.0	45.5
Clopyralid + 2,4-D Ester + Tillage	230.5	183.5	105.5	48.0
$LSD_{0.05}$	NS	NS	NS	15.0***

[z]This termination method was applied in autumn.
*, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 6
Effect of alfalfa stand termination method and time on seed yield of wheat, barley, canola and pea crops in 1997 at Gronlid, Saskatchewan (experiment 3)

	Seed yield (kg ha $^{-1}$)			
Treatment	Wheat	Barley	Canola	Pea
Termination time				
After cut 1	2597	2253	908 a	1293 a
After cut 2	2479	2154	688 b	1136 b
Spring	2497	2345	742 b	822 c
$LSD_{0.05}$	NS	NS	136**	149***
Termination method				
Tillage	2685 b	2512 a	1002 a	1412 a
Glyphosate + 2,4-D Amine	1818 c	1701 b	331 c	399 c
Glyphosate + 2,4-D Amine + Tillage	3082 a	2711 a	1023 a	1506 a
Clopyralid + 2,4-D Ester	2003 c	1661 b	522 b	674 b
Clopyralid + 2,4-D Ester + Tillage	3033 ab	2658 a	1019 a	1427 a
$LSD_{0.05}$	388***	388***	176**	192***
Time × method				
Termination after cut 1				
Tillage	3238	2766	1257	1881
Glyphosate + 2,4-D Amine	1075	1566	242	119
Glyphosate + 2,4-D Amine + Tillage	3282	2812	1096	1549
Clopyralid + 2,4-D Ester	2153	1472	799	1240
Clopyralid + 2,4-D Ester + Tillage	3235	2649	1144	1745
Termination after cut 2				
Tillage	2495	2468	924	1247
Glyphosate + 2,4-D Amine	1949	1676	210	495
Glyphosate + 2,4-D Amine + Tillage	3063	2541	1017	1682
Clopyralid + 2,4-D Ester	1836	1622	302	601
Clopyralid + 2,4-D Ester + Tillage	3056	2463	988	1654
Termination in spring				
Tillage[z]	2321	2301	824	1176
Glyphosate + 2,4-D Amine	2430	1862	539	582
Glyphosate + 2,4-D Amine + Tillage	2902	2814	956	1287
Clopyralid + 2,4-D Ester	2020	1887	463	182
Clopyralid + 2,4-D Ester + Tillage	2810	2861	925	882
$LSD_{0.05}$	673**	NS	305*	334***

[z]This termination method was applied in autumn.

*, **, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

1, especially with the herbicide mixture glyphosate + 2,4-D amine, and seed yield canola and pea was as low as 19 and 6% of that obtained when tillage followed this herbicide mixture, respectively. Pea seed yield was also markedly reduced when clopyralid + 2,4-D ester was used to terminate alfalfa stand in the spring, in comparison with the herbicide + tillage treatment.

Termination with glyphosate + 2,4-D resulted in relatively poor control of dandelion after cut 1 in all crops; and volunteer alfalfa in canola and pea, and dandelion in pea after cut 2 termination (Table 4). The increasing dandelion population during this period may explain why canola and pea establishment and seed yields were low following termination with glyphosate + 2,4-D after cut 1. Similarly, in earlier studies in Saskatchewan seed yield of wheat was lower when a green manure crop or alfalfa was terminated using herbicides rather than tillage (Biederbeck and Slinkard, 1988; Bullied et al., 1999). Crop injury by clopyralid or 2,4-D may have contributed to reduced yields. Clopyralid residues in soil may injure pea in the following season. In addition, spring-applied preplant 2,4-D can injure canola or pea. Tillage may alleviate crop injury by herbicides by mixing residues throughout the tilled soil layer and thus effectively diluting the bioactive herbicide concentration.

The effect of termination time and method, and their interaction on N uptake in seed were usually similar to seed yield (Table 7). The effect of termination time on N uptake in seed was significant for canola and pea. Seed N uptake was greater with termination after cut 1 compared to the termination after cut 2 or in spring. Previous research in Manitoba (Mohr et al., 1999) has shown reduced N uptake of wheat by delaying termination until the following spring. The effect of termination method on N uptake in seed was significant for all crops. Herbicide alone treatments resulted in markedly lower N uptake in seed than tillage alone or tillage + herbicide. Sarrantonio and Scott (1988) also observed much lower N uptake for corn (*Zea mays* L.) under ZT than CT. Interaction of termination time and termination method on N uptake in seed was significant for wheat, canola, and pea. For all termination times, herbicide alone had much lower N uptake than with tillage alone or tillage + herbicide.

The effect of termination time on protein concentration was significant for canola and pea (Table 8). Protein concentration was lower for the termination in spring than after cut 1 or cut 2. This was most likely associated with the higher amount of soil nitrate-N in spring with earlier termination dates, as shown in experiments 1 and 2 of this study (Tables 1 and 2). In an earlier study in Manitoba, Mohr et al. (1999) also observed higher total N concentration of wheat seed for the early compared to delayed termination. The effect of termination method on protein concentration was significant for wheat, barley, and pea. For wheat and barley, in spite of greater seed yield, protein concentration was higher with the tillage alone or herbicides + tillage treatments compared to the herbicide alone treatments. This was probably due to usually greater amounts of mineralized N in soil with tillage or herbicide + tillage treatments than in herbicide alone treatments, as indicated in experiments 1 and 2 of this study (Tables 1 and 2).

Table 7
Effect of alfalfa stand termination method and time on N uptake in seed of wheat, barley, canola and pea crops in 1997 at Gronlid, Saskatchewan (experiment 3)

Treatment	N uptake (kg N ha^{-1})			
	Wheat	Barley	Canola	Pea
Termination time				
After cut 1	69.4	51.5	44.9 a	65.4 a
After cut 2	64.8	48.7	30.0 b	48.0 b
Spring	64.8	51.3	30.0 b	38.2 c
$LSD_{0.05}$	NS	NS	3.5***	6.8***
Termination method				
Tillage	72.8 a	58.5 a	40.2 a	56.0 a
Glyphosate + 2,4-D Amine	46.2 b	37.0 b	20.0 b	26.5 c
Glyphosate + 2,4-D Amine + Tillage	81.7 a	61.3 a	40.3 a	59.8 a
Clopyralid + 2,4-D Ester	50.8 b	35.7 b	23.9 b	36.3 b
Clopyralid + 2,4-D Ester + Tillage	80.0 a	60.1 a	40.2 a	57.9 a
$LSD_{0.05}$	10.0***	8.4***	4.6***	9.0***
Time × method				
Termination after cut 1				
Tillage	89.1	65.9	51.3	74.8
Glyphosate + 2,4-D Amine	27.1	33.3	32.7	–
Glyphosate + 2,4-D Amine + Tillage	89.2	64.0	44.0	62.1
Clopyralid + 2,4-D Ester	55.8	31.6	40.6	52.6
Clopyralid + 2,4-D Ester + Tillage	86.0	62.8	45.7	72.2
Termination after cut 2				
Tillage	66.6	56.6	36.5	49.1
Glyphosate + 2,4-D Amine	48.5	36.6	9.7	24.7
Glyphosate + 2,4-D Amine + Tillage	81.6	58.2	40.3	67.7
Clopyralid + 2,4-D Ester	45.4	34.9	15.3	25.1
Clopyralid + 2,4-D Ester + Tillage	82.0	57.1	39.5	67.5
Termination in spring				
Tillage[z]	62.8	52.9	32.7	44.2
Glyphosate + 2,4-D Amine	63.1	41.0	26.1	28.3
Glyphosate + 2,4-D Amine + Tillage	74.5	61.7	36.8	49.5
Clopyralid + 2,4-D Ester	51.2	40.7	17.9	16.2
Clopyralid + 2,4-D Ester + Tillage	72.2	60.4	35.4	33.9
$LSD_{0.05}$	17.3***	NS	26.6**	13.8**

[z]This termination method was applied in autumn.
, * and NS refer to significant treatment effects in ANOVA at $P \leq 0.01$, $P \leq 0.001$ and not significant, respectively.

Table 8
Effect of alfalfa stand termination method and time on seed protein concentration of wheat, barley, canola and pea in 1997 at Gronlid, Saskatchewan (experiment 3)

	Protein concentration (g kg^{-1})			
Treatment	Wheat	Barley	Canola	Pea
Termination time				
After cut 1	151	141	251 a	258 a
After cut 2	148	140	248 a	254 b
Spring	148	137	242 b	241 c
$LSD_{0.05}$	NS	NS	3***	4***
Termination method				
Tillage	155 a	146 a	250	246 d
Glyphosate + 2,4-D Amine	144 c	135 c	245	253 b
Glyphosate + 2,4-D Amine + Tillage	151 ab	141 b	246	247 cd
Clopyralid + 2,4-D Ester	144 c	134 c	245	261 a
Clopyralid + 2,4-D Ester + Tillage	150 b	142 ab	246	251 bc
$LSD_{0.05}$	4***	4***	NS	5***
Time × method				
Termination after cut 1				
Tillage	158	149	255	258
Glyphosate + 2,4-D Amine	143	132	243	–
Glyphosate + 2,4-D Amine + Tillage	155	142	251	251
Clopyralid + 2,4-D Ester	147	134	249	264
Clopyralid + 2,4-D Ester + Tillage	152	148	250	259
Termination after cut 2				
Tillage	152	144	248	245
Glyphosate + 2,4-D Amine	141	135	247	259
Glyphosate + 2,4-D Amine + Tillage	152	143	248	252
Clopyralid + 2,4-D Ester	140	134	246	262
Clopyralid + 2,4-D Ester + Tillage	153	145	250	254
Termination in spring				
Tillage[z]	154	144	248	235
Glyphosate + 2,4-D Amine	148	138	243	248
Glyphosate + 2,4-D Amine + Tillage	147	138	240	240
Clopyralid + 2,4-D Ester	144	134	242	245
Clopyralid + 2,4-D Ester + Tillage	147	133	240	241
$LSD_{0.05}$	6*	8*	NS	NS

[z]This termination method was applied in autumn.
*, *** and ns refer to significant treatment effects in ANOVA at $P \leq 0.05$, $P \leq 0.001$ and not significant, respectively.

Similarly, Mohr et al. (1999) obtained higher total N concentration in wheat seed in tillage treatments than in herbicide treatments. In contrast, pea grown in herbicide alone treatments tended to have higher protein concentration than other termination methods. Contrasting results from the cereal crops may be due to N fixation by pea, which can be greater under ZT than CT. Interaction of termination time and termination method for protein concentration was significant for wheat and barley. For termination after cut 1 and cut 2, herbicide alone resulted in lower protein concentration than when tillage alone or tillage + herbicide were used for termination. For the termination in spring, there was no consistent effect of termination method on protein concentration.

In summary, termination of alfalfa stands in the Parkland region of the prairies by a combination of herbicides and judicious tillage in the year before annual cropping is recommended for optimum yield and quality through release of alfalfa residue N, weed management, and crop establishment. Growing cereals (e.g., wheat, feed barley) rather than broadleaf crops in the year following alfalfa stand termination also is recommended to reduce the risk of herbicide carryover injury and enhance productivity and grain protein content.

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