THE ROLE OF SHORT-TERM ALFALFA STANDS IN CEREAL-BASED CROP ROTATIONS

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Summary

A four-year study to investigate the role of alfalfa in cereal-based crop rotations was started at the University of Manitoba in 1990. The objective of this study was to further assess the agronomic and environmental implications of short-term alfalfa stands and to determine the economic optimum stand length of alfalfa for farmers to use. Rotations under consideration were annual crop rotations and rotations that included different stand lengths of alfalfa. Field sites were established at two Manitoba locations. Parameters measured included crop yield and quality, wheat root activity, extraction of soil N and P, overall N budget of one, two and three year alfalfa stands, soil physical properties, and economic performance.

Including alfalfa in cereal-based rotations enhanced growth, root activity and grain yield of subsequent wheat crops. Surprisingly, even a one-year alfalfa stand provided significant long-term benefits. Improvements in root activity of wheat following alfalfa vs. wheat in the annual crop rotation was attributed to significant improvements in soil hydraulic conductivity, however, reduction in root and leaf diseases may also have played a role.

A four year alfalfa stand effectively extracted deep-leached nitrates to a depth of 240 cm. While extraction of available P was also observed, no significant differences could be detected. Intensive nutrient profile analysis will be conducted again in 1995.

A N budget was determined for short-term (one to three years) alfalfa stands. Results suggest that from a N perspective, there appears to be little advantage to extending the alfalfa stand past two production years.

Economic analysis indicated that while the optimum stand length was five years, three and four year alfalfa stands were also profitable compared with a wheat-barley-pea rotation. Improved technologies for establishing and removing alfalfa from the crop rotation (these are currently being developed) should reduce the cost of including alfalfa in crop rotations. Also, the economic analysis did not consider the fact that rotations containing alfalfa require fewer herbicides (due to residual weed control from the alfalfa stand).

The rotation studies will continue for at least eight more years.

Introduction

A research project to investigate the role of short-term alfalfa stands in cereal-based crop rotations was initiated at the University of Manitoba in 1990. Funding from the Potash and Phosphate Institute and The Foundation for Agronomic Research was critical to getting the research started, and as research leader, I would like extend my gratitude to your organization.

PPI and FAR research funds were used mainly to support graduate and summer students, to purchase ^{15}N, and to assist with lab analysis costs.

This research project is by no means over. The Winnipeg rotation trial will be maintained for at least another eight years. Also, a second crop rotation trial will be established at the U of M's new field research station located near Carman, MB. Nor is this the final project report. The PPI and FAR funds were matched by NSERC, and a final report to NSERC (which will include 1994 research data) must be completed by Dec., 1994. A copy of this report will be sent to Dr. Terry Roberts of PPI Canada.

Methodology

Crop Rotations and Management

Field research trials were conducted on a Black Lake clay at Winnipeg and on a Dugas clay at Portage la Prairie, MB. The Winnipeg site had high levels of subsoil nitrates while the Portage site did not. The experimental design at each location was a split plot with crop rotation as the mainplot and nitrogen fertility as the subplot.

The crop rotations under investigation were:

1. annual crops only (wheat-barley-pea) - a total of three treatments per replicate (each phase of the rotation represented each year)
2. annual cereal crops only (wheat-wheat-barley)
3. alfalfa (from 1 to 4 years) followed by annual crops
4. continuous summerfallow
5. restored native tallgrass prairie

The nitrogen fertility treatments consisted of:

1. Fertilized to soil test recommendations.
2. No N fertilizer added.

P (triple super phosphate) and K were added each year to soil test recommendations. No sulfur deficiencies were observed the first three years of the study, however, soil test levels of sulfur were low in fall of 1994.

All crops were managed according to provincial recommendations. The alfalfa crops were cut three times per year, except in the establishment year when one cut was taken at Winnipeg and two cuts were taken at Portage.

Measurements:

Soil nitrate and phosphorous levels were determined on late-season (Oct.) soil samples taken in 1990, 1991, 1992 and 1993. Soil was sampled to a depth of 240 cm in 1990 and 1991, and to a depth of 300 cm in 1992 and 1993. Two samples where taken in each plot, and each was analyzed seperately. Nitrate-N and available P were extracted and measured using standard lab methods (Norwest labs, Winnipeg). The accuracy of nitrate values from the commercial lab was verified in the lab of Dr. Kevin Vessey. Soil available phosphorous was determined in 1990 and 1993 only. All soil nitrate and phosphorous levels are expressed in ppm.

Nitrogen fixation was measured using the ^{15}N isotope dilution technique. ^{15}N labelled $(NH_4)_2SO_4$ (60-85% enrichment) was applied in 1 L of water with a pressurized garden sprayer to 0.60 m by 1.5 m alfalfa subplots at a rate of 2.8 kg ha^{-1} at both sites in 1991. In 1992, 15.9% enriched product was applied to 0.75 by 1.4 m alfalfa subplots at a rate of 9.5 kg ha^{-1}. Wheat served as the reference crop. Applications of ^{15}N were made in mid-May each year. Seedling alfalfa established in 1991 at Winnipeg received ^{15}N labelled fertilizer on June 7, when the majority of the plants were in the cotyledon stage. Herbage from these alfalfa subplots were removed immediately prior to hay harvest or soil incorporation, while the wheat was harvested at the soft dough stage (whole shoot).

N concentration of the material analyzed for ^{15}N:^{14}N ratios in 1991 was determined using the micro-kjeldahl procedure. ^{15}N:^{14}N analysis was performed on a Finnigan Mat 250 mass spectrometer at the laboratory of Dr. A. Blackmer, Iowa State University in 1991, and on an ANCA-MS nitrogen determinator/mass spectrometer (Europa Scientific, Crewe, UK) at the laboratory of Dr. C. van Kessel, University of Saskatchewan in 1992.

Nitrogen concentration in alfalfa roots. Alfalfa roots were not harvested in this study, and root yields were therefore determined using shoot:root ratios in the literature. Using the data of Petterson et al. (1986), ratios were derived by combining the first and second harvest yields with the amount of herbage remaining at the end of the year, and relating this figure to end of season root yield (0.5 m) depth. The ratio was averaged for two and three year old alfalfa stands, giving a shoot:root ratio of 1.59:1. Average root N concentrations of 25.7% were determined from root samples taken at the end of the season.

Volumetric Soil water content between 0 and 240 cm was determined at the beginning and end of the growing season, and at intervals during the season, using a Troxler Model 4330 neutron probe.

Soil hydraulic conductivity was measured at the Winnipeg site only in 1993. This work was conducted by MSc student Curtis Cavers of the U of M Soil Science Department using a Guelph permeameter.

Crop Yield was assessed using traditional small plot techniques.

Economic Analysis. The economic viability of introducing alfalfa into a cereal/legume crop rotation was assessed using a combination of enterprise budgets and basic present value accounting measures. Data from our rotation trials was supplemented with data from other forage and crop rotation research in the Black soil zone of prairie Canada. The economic analysis was conducted to i) determine if it is profitable to include alfalfa in the rotation, and ii) to determine the economically optimum length of alfalfa stand. This analysis was conducted by Dr. Scott Jeffrey of the University of Alberta.

Results and Discussion

1. Influence of Crop Rotation and Nitrogen Fertilization on Grain Yield

i) What happened When N Fertilization was Stopped in the Cereals Only Rotation?

The yield performance of wheat in the minus N fertilization plots was greatly influenced by crop rotation. In the annual crop rotation, grain yields at both the Winnipeg and Portage la Prairie sites decreased dramatically in the fourth year (Table 1). It was interesting to note that the wheat yield in the non-N fertilized treatments in year four of this study (ie. 1993) was similar to unfertilized N yields (approx. 1000 kg ha^{-1}) reported in other long-term research field trials in the Black soil zone of western Canada (eg. Zentner et al. 1987).

ii) Wheat yields after alfalfa

As expected, wheat yields following alfalfa were higher in the minus N treatments compared with the minus N treatments in the annual crop rotation. The difference between these two treatments in year four of the study (ie. 1993) was between 1100 and 1500 kg ha^{-1} at both sites (Table 1). Assuming the maximum N use efficiency for wheat of 25 kg grain kg N^{-1} (Henry et al. 1986), the fertilizer replacement value of the alfalfa stand would be from 44 to 60 kg ha^{-1}. This estimate is surprisingly close to the difference in amount of N uptake into whole shoots of wheat the year after alfalfa-breaking vs. wheat after barley (69 kg ha^{-1} at Portage la Prairie and 67 kg ha^{-1} at Winnipeg - Appendix 1).

iii) "Rotation Effect" of a Single Year Alfalfa Stand

While the yield enhancing effects of a single year of alfalfa on one subsequent grain crop (Badarrudin and Meyer 1990) and the residual effects of a multiyear alfalfa stand (Hoyt and Leitch 1983) are well documented, the long-term residual effect of a single year of alfalfa is not. In the present study, we compared the yield of spring wheat three years after a single year of alfalfa with wheat the year after a three year alfalfa stand and wheat in an annual rotation (crop rotation 1). Surprisingly, the yield enhancing effect of a single year of alfalfa three years hence, was as great as a three year alfalfa stand that had been terminated the previous year (Table 2). This trend was observed at both the Winnipeg and Portage la Prairie sites.

One explanation for this "rotation effect" is that the single year alfalfa stand improved the soil physical structure, and that the residual effect of the soil structure improvement resulted in increased wheat productivity three year later. Because the test year (ie. 1993) was extremely wet, any improvement in soil water infiltration capacity or soil O_2 concentration would have greatly enhanced wheat productivity.

Others have attributed superior wheat yields on alfalfa breaking to fewer cereal root diseases (Cook, unpublished data, in Cook and Veseth 1991, p. 93).

2. Root Activity of Wheat as Influenced by Crop Rotation

Soil water extraction is an indirect measure of root density and root activity in wheat (Entz et al. 1992). In the present study (Winnipeg rotation trial only), soil water extraction between spring seeding and anthesis (early July) was measured for wheat grown on barley stubble, and wheat sown on alfalfa breaking. Results from the 1993 field season indicated that wheat following a three-year alfalfa stand extracted significantly more soil water between 10 and 70 cm compared with wheat in the annual crop rotation (Table 3). The additional root activity of wheat following alfalfa did not appear to be related to nitrogen, as the fertilized wheat in the annual rotation still extracted significantly less water than unfertilized wheat after alfalfa (Table 3).

Greater soil water extraction by wheat after alfalfa compared to wheat in the annual crop rotation may be due to changes in soil physical properties with alfalfa. For example, the hydraulic conductivity of soil after three years of alfalfa was two to three orders of magnitude greater than in the annual crop rotation (Figure 1). Similar observations of "biological tillage" have been made by Blackwell et al. (1990). Others have suggested that superior root activity of wheat following "break" crops is due to fewer cereal root diseases (Cook 1992). Whatever the reason, enhanced root activity of annual crops is important for maximizing efficiency of soil nutrient and water use.

Investigations to determine the extent to which wheat roots actually "colonize" the macropores left by the alfalfa roots, and to compare the soil "cleansing" effect of crop rotation vs. soil fumigation in a cereal-based rotation will begin in 1995 (PhD student project).

3. Extraction of Deep-Leached Nitrates With Alfalfa

Soil nitrogen profiles for the Winnipeg site are shown in Figures 2 and 3. It is clear from this data that initial soil nitrate-N levels were very high (resulting from a high frequency of summerfallow over past 50 years).

Nitrate-N was determined from two samples per plot taken in October of 1990, 1991, 1992, and 1993. Results indicate that alfalfa effectively extracted nitrate to depths of 90, 160, 200, and 260 cm after one, two, three and four years, respectively (Figure 3), while the annual crop rotation (rotation 1) did not extract any nitrate below 120 cm (Figure 2). (Note: Crop yields of the rotations under investigation are given in Appendix 2).

Nitrate extraction patterns in this study were similar to late-season soil water extraction patterns (Appendix 3), indicating that nitrate was removed from the same depths that water was utilized (Mathers et al. 1975).

Results of this study indicate that alfalfa can play an important role in soil remediation in the Black soil zone of prairie Canada. However, because soil temperatures are lower, the time (number of years) required to extract deep-leached nitrates in western Canada will likely be greater than in warmer climates (Mathers et al. 1975).

While alfalfa can clean-up nitrate contaminated soils, "recontamination" of subsoil with N can occur if land is fallowed after alfalfa-breaking (Campbell et al. 1993). We are presently investigating N release patterns from alfalfa stands as influenced by termination method (herbicide vs. tillage) and time (after first vs. after second cut vs. spring) (PhD student project).

4. Nitrogen Contributions from Alfalfa: Partitioning

Nitrogen budgets were developed for both the Winnipeg and Portage la Prairie crop rotation trials by Mr. David Kelner (MSc. student - supervisor: Dr. J. Kevin Vessey).

The partitioning of biologically fixed and soil N into herbage removed for hay, or incorporated herbage and roots, for the varying stand lengths is illustrated for the two sites in Figures 4 and 5 (First year stand available for Winnipeg site only). The total amount of N (fixed plus soil) in the herbage (removed with hay plus incorporated) was similar between years of established alfalfa, with 407.3 and 404.3 kg ha^{-1} present in the herbage of alfalfa at Winnipeg, and 391.2 and 390.9 kg N ha^{-1} in the herbage at Portage la Prairie, for second and third year alfalfa, respectively. The total N herbage of first year alfalfa at Winnipeg was 166.4 kg ha^{-1} (Figure 4), a substantially smaller amount when compared with older stands. Wivstad et al. (1987) and Heichel et al. (1984) noted substantial increases in the herbage and N yields of established alfalfa relative to the seedling year.

In general, more N (fixed plus soil) was removed with the herbage at the first cut relative to the second, which corresponds to normal alfalfa yield patterns in Manitoba, as first cut hay generally yields better than second cut. The amount of N incorporated into the soil in fall (herbage) was less than that removed for individual hay cuts, due to the relatively immature state of the incorporated alfalfa (30 cm regrowth, prior to bud).

There was a trend for increasing biological N_2 fixation activity as the season progressed (measured as the percentage of N derived from the atmosphere (%ndfa) in the herbage). %Ndfa for the first and second hay cuts and the herbage incorporated into the soil (equivalent to third cut) was 47.9, 81.9 and 90.7%, respectively, when averaged for the second and third years of alfalfa over both sites. Wivstad et al. (1987) reported similar %ndfa levels of 67, 82 and 76% for measurements taken at the first and second harvests and at the season's end, respectively, when averaged for the second and third years of alfalfa. Increased mineral N availability caused by the turnover of organic N from dead, overwintered plant material could cause a reduction in N_2 fixation in the spring. As mineral N availability decreases, the alfalfa might respond by increasing N_2 fixation later in the season.

The mean level of N_2 fixed (averaged for hay and incorporated materials) for the two and three year old alfalfa stands was 70.1 and 76.8% ndfa, respectively, when averaged over both sites. The average %ndfa in the herbage of first year alfalfa at Winnipeg was 64.6%. In general, the percent N derived from symbiosis increases with increasing stand age, particularly after the establishment year (Peterson and Ruselle 1991). Increases in %ndfa from 59 to 78% from the first to the fourth year of alfalfa (Heichel et al. 1984) and 70 to 80% from the second to third year of alfalfa growth (Wivstad et al. 1987) have been observed.

The contribution of nitrate extraction from depth to the N budgets is presented for the Winnipeg site only, as there was little nitrate accumulated at depth at Portage la Prairie, and therefore no discernable extraction (Figure 4). Despite the increase in extracted nitrate over time, there was still an increasing trend in N_2 fixation with each year of alfalfa growth. In fact, the amount of symbiotically fixed nitrogen in the herbage increased by 30.2 kg N ha^{-1} from the second to the third year, while the total amount of N in the herbage remained the same between years.

The estimated amount of N (fixed plus soil-derived N) returned to the soil with the crowns and roots ranged from 207.5 to 259.0 kg ha^{-1} for established alfalfa (Figures 1 and 2). The crown and root total nitrogen addition of first year alfalfa was notably smaller (106.4 kg ha^{-1}) than that added by the two or three year old alfalfa stands. Most of the previous studies on crown and root N contributions of alfalfa have been conducted on seeding year stands. N additions of 36.5 to 98.8 kg ha^{-1} have been reported (Bruulsema and Christie 1987; Griffin and Hesterman 1991). Little research has been conducted on older stands, but it is reasonable that crown and root N contributions of established alfalfa would be substantially greater than those of seedling stands. In the present study, the amount of N added by the crowns and roots for the second and third year alfalfa was an average 2.3 times the N added to the soil with the incorporated herbage, stressing the importance of below ground biomass in alfalfa soil N contributions.

5. Soil Available Phosphorous

Levels of soil available phosphorous at the beginning of the study were quite high at the Winnipeg site (Table 4). One explanation for the very high indigenous levels of subsoil available P is leaching, since this land was in a crop-summerfallow rotation for approximately 50 years prior to 1990. Although P is much less mobile than N, it has been established through long-term research that P may leach in the more humid regions of prairie Canada (Campbell et al. 1994). At any rate, this situation has provided us with the opportunity to determine the influence of a four year alfalfa stand on pattern of soil available phosphorous.

The change in soil available phosphorous was determined by subtracting soil phosphorous levels in 1993 from those in 1990 for each crop. Although differences between soil available phosphorous were not significant for the different crops, alfalfa clearly extracted more P below 120 cm than the annual rotation (Table 4). It should be noted that all plots in this experiment received 30 kg P_2O_5 ha^{-1} each year of the study.

While the differences in soil P use between alfalfa-containing and straight annual rotations were not significant, the fact that alfalfa used more P (even though it was fertilized), underscores the need for attention to P fertility with alfalfa crops and alfalfa-containing rotations.

The rotation will be sampled for available P again in 1995. At that time, differences between rotations will likely be greater.

6. Economically Optimum Stand Length for Alfalfa in Cereal/Legume Rotations (Full Report in Appendix 4).

The economic viability of introducing alfalfa into grain crop rotations was assessed using a combination of enterprise budgets and basic present day value measurements. A 1000 acre farm was chosen as the representative farm for this study. In both scenarios tested (1. equipment for handling forages already owned by farmer; 2. equipment had to be purchased), the five year alfalfa stand (A-A-A-A-A-Wheat-Barley-Pea) generated the greatest annual income per acre. Ranking of the rotations was found to be stable across alfalfa yields (ranging from 3.3 to 5.0 t/ha) and alfalfa prices ($55.60 to $36.50 per tonne).

While the optimum stand length was 5 years, 3 and 4 year alfalfa stands were almost as profitable. It is important to note that the profitability of shorter stands (2 to 4 years) would increase if more reliable methods for forage establishment and removal were adopted. (Note: These are currently being developed; see Appendix 5 and 6). It is also important to note that weed suppressing benefits of including forages in cereal-based crop rotations (which reduces weed control costs by approximately $15/acre for two years after forage-breaking; Ominski and Entz 1994) were not considered in the analysis.

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Table 1. Grain yield of N fertilized and unfertilized wheat following barley vs. after one (1991), two (1992) or three (1993) years of alfalfa. Average of field trials at Winnipeg and Portage la Prairie, MB.

Previous Crop	Nitrogen Fertilizer	1991	1992	1993
		---------- grain yield (kg ha^{-1}) ----------		
Barley	yes	3036	3695	1995
	no	2474	3141	884
Yield difference (fertilizer minus unfertilized)		562 (19%)	554 (15%)	1111 (56%)
Alfalfa	yes	2969	3541	2222
	no	3105	3741	2403
Yield difference (fertilizer minus unfertilized)		69 (-4%)	46 (-6%)	343 (-8%)
Unfertilized wheat after alfalfa minus unfertilized wheat after barley		631 (20%)	600 (16%)	1519 (63%)

Table 2. Wheat yield as influenced by crop rotation and nitrogen fertilizer at two locations in Manitoba, 1993.

Crop Rotation 1990-1993	Fertilizer Nitrogen (kg ha^{-1})	
	0	80
	----- grain yield (kg ha^{-1}) -----	
Winnipeg		
1. B-W-P-W[1]	1974	2021
2. A-W-P-W	2245	-
3. A-A-A-W	2338	-
Portage la Prairie		
1. B-W-P-W	1723	1973
2. A-W-P-W	2438	-
3. A-A-A-W	2468	-

[1] W = wheat in 1993

Results of combined site analysis indicate yields in rotations 2 and 3 both significantly higher than the two N treatments in rotation 1.

Table 3. Influence of crop rotation on soil water extraction between seeding and anthesis by spring wheat at Winnipeg, 1993.

Soil Depth	A-A-A-*Wheat*[1]	W-P-B-*Wheat*[2]		LSD
	0[3]	80	0	(0.05)
-------cm-------	-----------cm water extracted-----------			
0-10	4.2	3.4	3.9	ns
10-30	1.8a	0.8b	0.1c	(0.54)
30-50	1.5a	0.5b	0.3b	(0.41)
50-70	0.8a	0.3b	0.2b	(0.36)
70-90	0.2	0.0	0.0	ns
90-110	0.2	0.1	0.0	ns
110-130	0.3	0.2	0.1	ns
Net Extraction	9.0a	5.3b	4.6b	

[1] Rotation: wheat-pea-barley-wheat
[2] Rotation: 3 years of alfalfa-wheat
[3] Fertilizer N (kg ha^{-1}) added to 1992 wheat crop

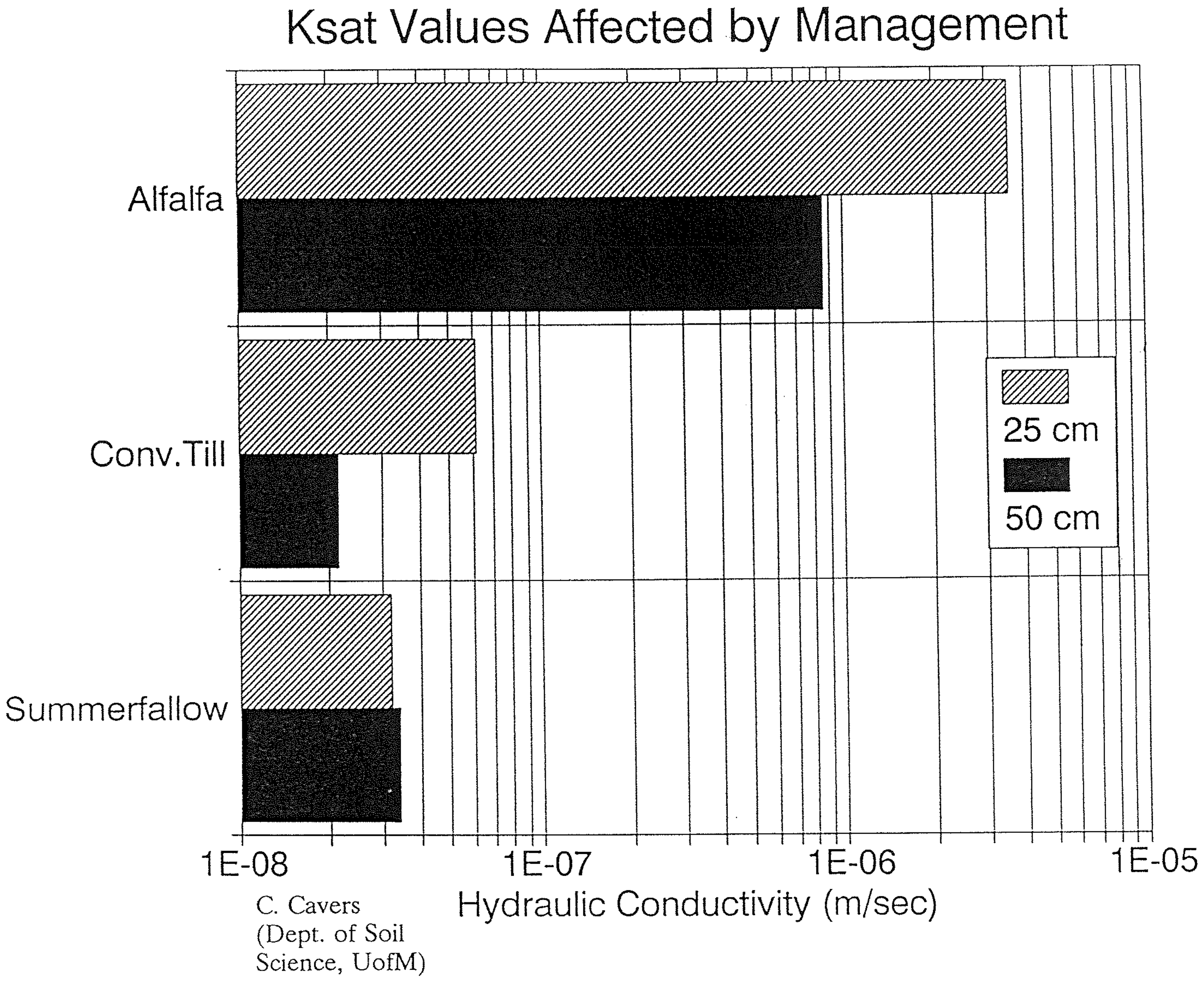

Figure 1. Hydraulic conductivity of a Black Lake clay soil at Winnipeg as influenced by crop rotation. Alfalfa refers to a three year alfalfa stand; Conv. till refers to rotation #2; Summerfallow refers to the continuous fallow treatment.

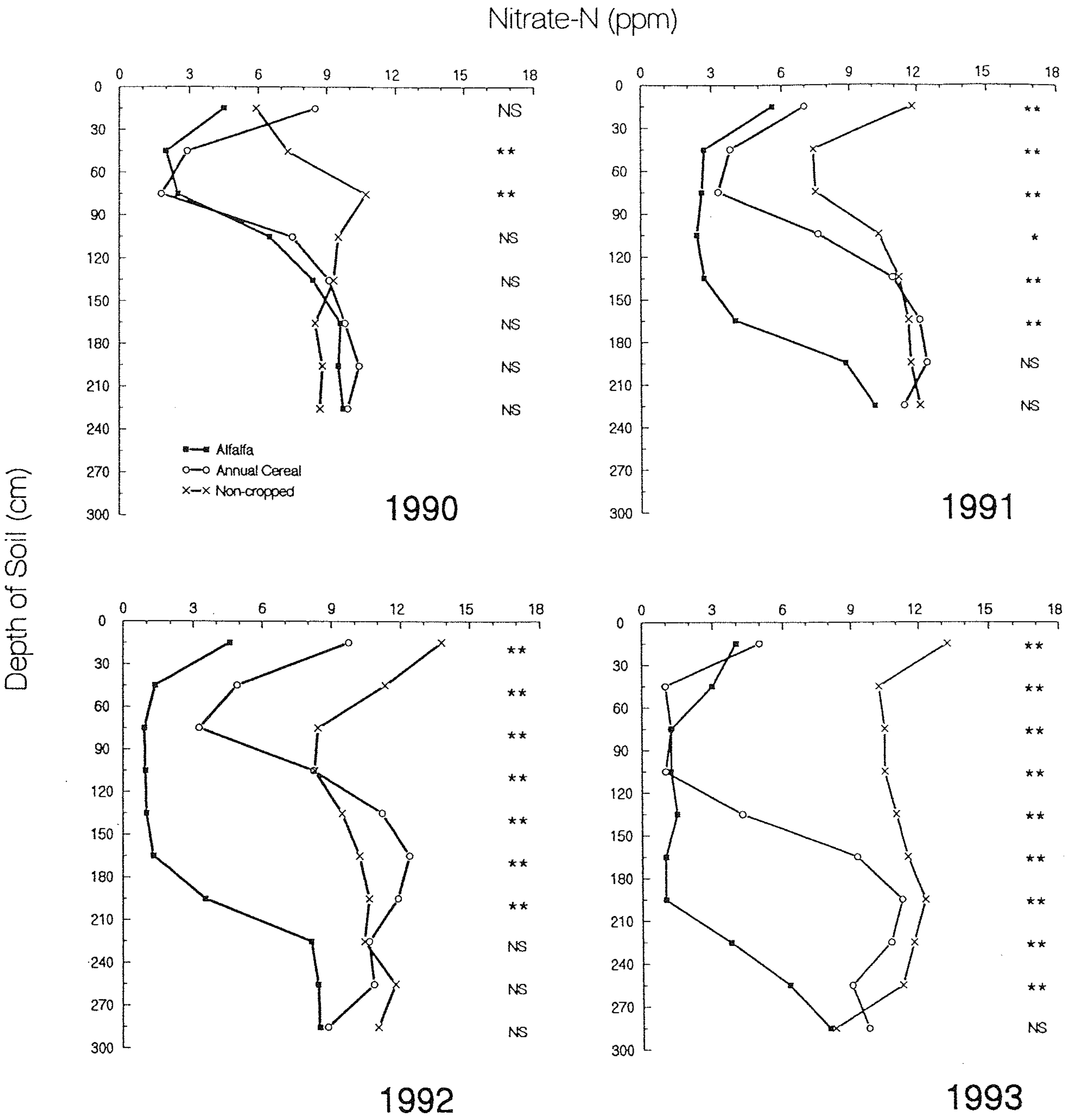

Figure 2. Effect of alfalfa, annual grain crops or non-cropped fallow on nitrate-N concentrations in soil profiles (Black Lake clay) at Winnipeg, 1990 to 1993. *, ** indicate significant differences at P=0.05 and 0.01, respectively.

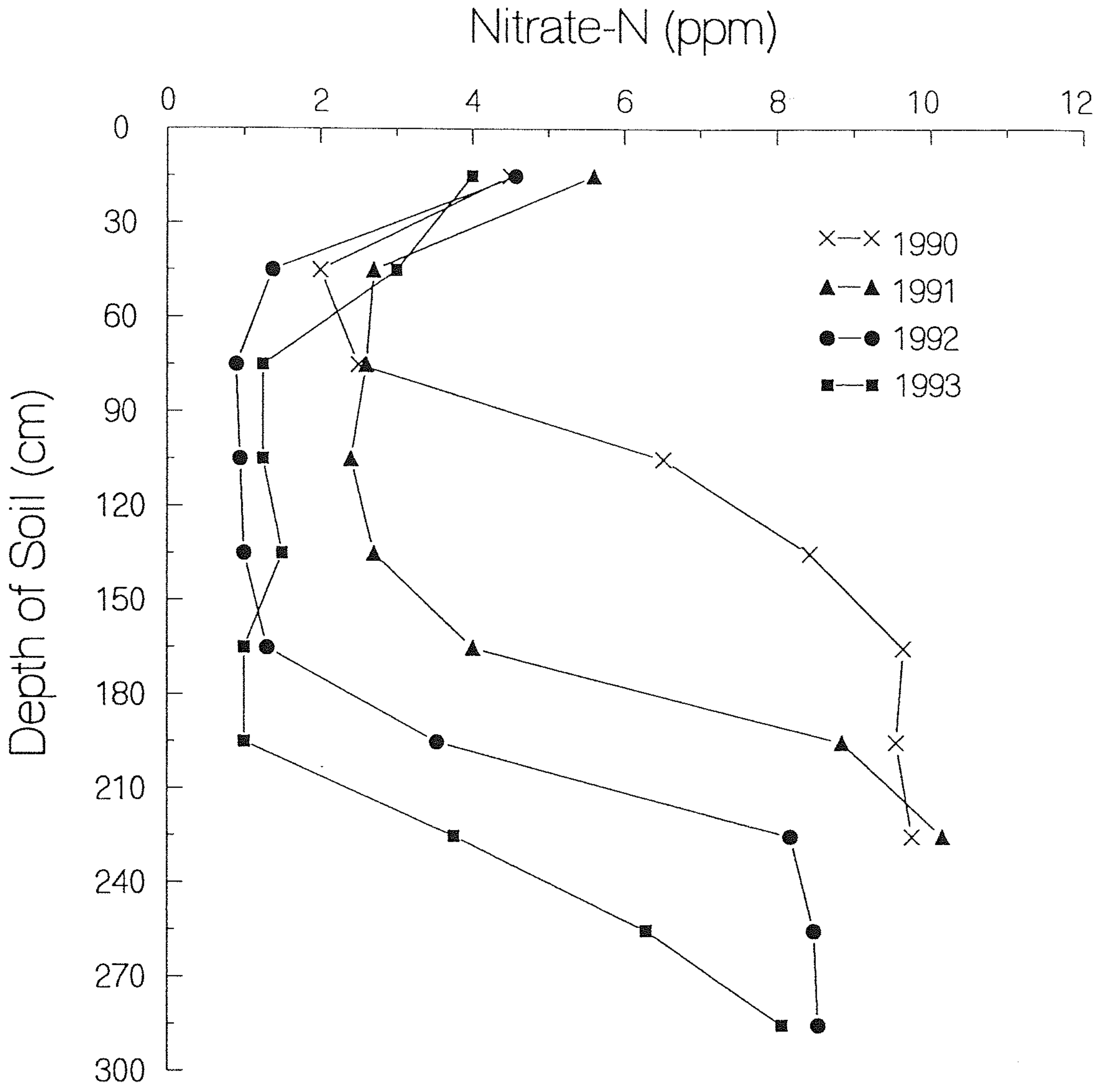

Figure 3. Nitrate-N concentration down a Black Lake clay soil for years 1990-1993.

Winnipeg, 1990-1992

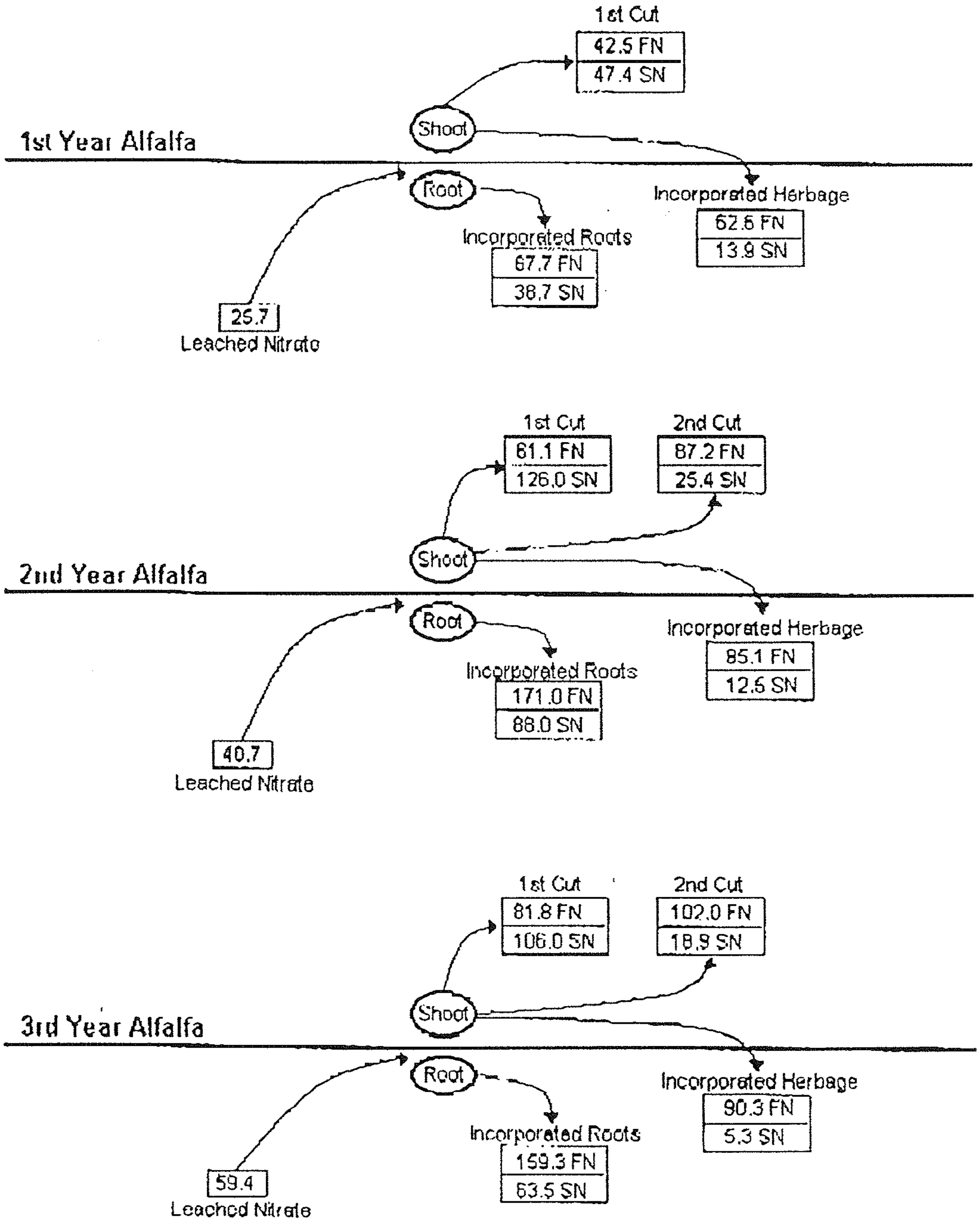

Figure 4. Partitioning of nitrogen into hay or incorporated roots and herbage for one, two and three years of alfalfa at Winnipeg. FN - nitrogen derived from symbiotic N_2 fixation. SN - nitrogen derived from soil sources. Leached nitrate - nitrate extracted from the 0.9 to 2.4 m soil depth zone.

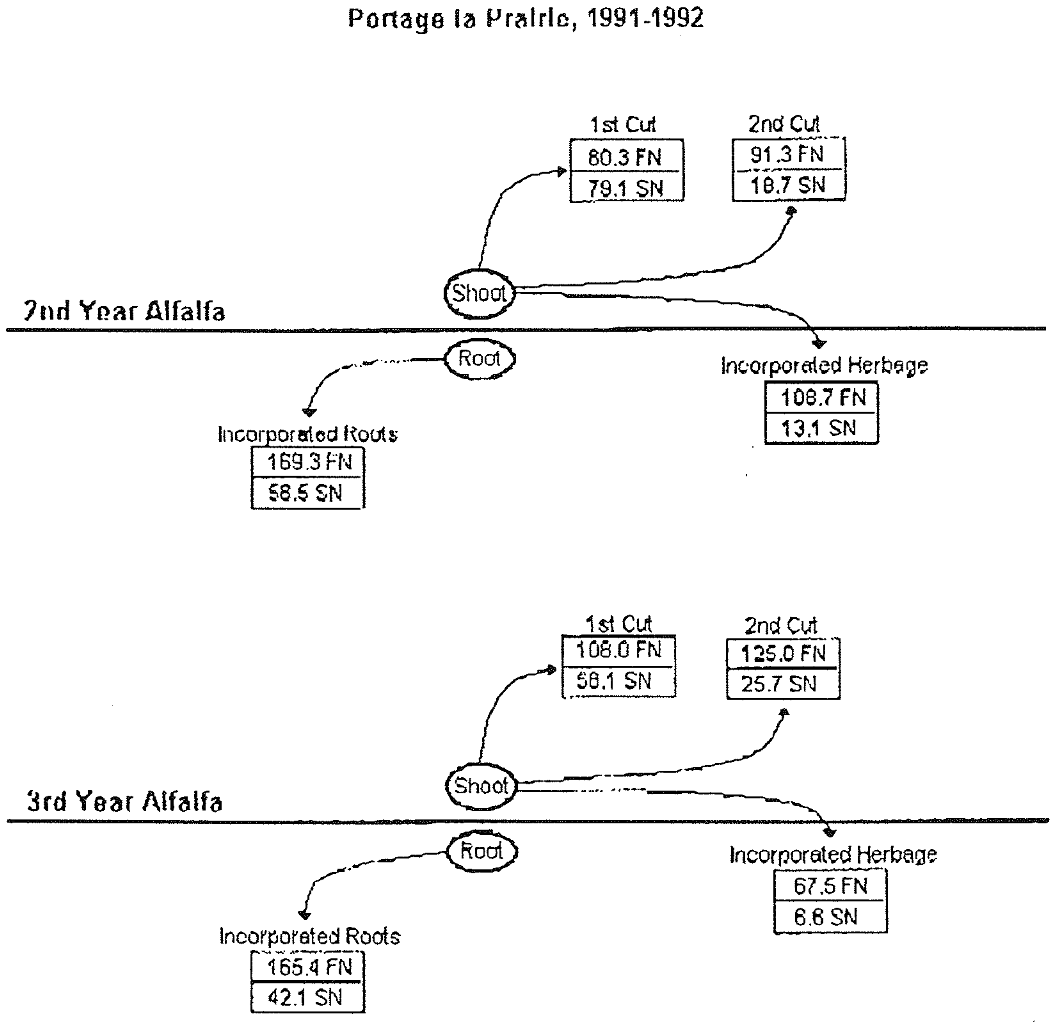

Figure 5. Partitioning of nitrogen into hay or incorporated roots and herbage for two and years of alfalfa at Portage la Prairie. FN - nitrogen derived from symbiotic N_2 fixation. SN - nitrogen derived from soil sources.

Table 4. Change in soil available phosphorous levels (ppm) over a four year period (1990 minus 1993) under three different management systems at Winnipeg, MB.

Soil Depth	Average Soil Phosphorous at Beginning of Study (1990)	Annual Crop Rotation[1]	Continuous Alfalfa	Continuous Fallow	LSD (0.05)
(cm)	---- ppm ----				
0-30	45.6	5.6	8.5	3.6	ns
30-60	22.3	10.6	6.8	11.8	ns
60-90	7.9	3.0	3.5	0.6	ns
90-120	5.8	2.6	3.5	0.4	ns
120-150	5.7	1.9	3.8	1.4	ns
150-180	4.2	0.8	2.4	1.4	ns
180-210	3.8	-0.8	2.0	0.3	ns
210-240	3.5	-0.7	0.3	0.1	ns

[1] Annual crop rotation: Wheat (90), Pea (91), Barley (92), Wheat (93).

Appendix 1. Nitrogen Uptake in Wheat Following Alfalfa

Table 6. N Uptake in the wheat whole shoot (soft dough stage) and the grain (crop maturity) at Winnipeg and Portage la Prairie in 1992.

		Winnipeg - 1992		Portage la Prairie - 1992	
Crop Sequence	Fertility kg N ha^{-1}	Shoot N Uptake kg N ha^{-1}	Grain N Uptake kg N ha^{-1}	Shoot N Uptake kg N ha^{-1}	Grain N Uptake kg N ha^{-1}
Alf-Alf-Wheat[z]	0	163.2*ab*	77.7*ab*	137.5*a*	77.2*a*
Alf-Alf-Wheat	80	221.3*a*	90.7*ab*	153.9*a*	71.4a
Pea-Bar-Wheat	0	96.1*b*	67.7*b*	68.6*b*	37.2*c*
Pea-Bar-Wheat	80	154.4*ab*	95.6*a*	146.7*a*	47.3*b*
CV (%)[y]		10.8	27.6	21.2	12.4
Crop Sequence		NS[x]	NS	NS	**
Fertility		NS	NS	*	NS
Crop*Fertility		NS	NS	NS	NS

[z] Wheat sampled in 1992 was preceded by 2 years of alfalfa. The alfalfa-wheat sequence received N fertilizer in the wheat phase only. The annual (pea-barley-wheat) sequence received (or did not receive) N fertilizer in all three years of the rotation.

[y] Coefficient of variation (%).

[x] Analysis of variance. NS, non-significant. *,** Significant at $P < 0.05$ and 0.01, respectively.

a-c Means within a column followed by the same letter are not significantly different at $P < 0.05$ by LSD.

Appendix 2. Yields of Crops in N Extraction Rotations

Table A1. Yield (grain/forage and protein) of crops in rotation trial at Winnipeg that were sampled for subsoil nitrogen, 1990 to 1993.

		Grain/Forage Yield	Protein Yield[1]
		--- kg ha^{-1} ---	--- kg ha^{-1} ---
1990	Wheat	2,485	454
	Alfalfa	1,897	352
1991	Pea	1,779	439
	Alfalfa	15,251	2,707
1992	Barley	7,806	983
	Alfalfa	13,777	2,789
1993	Wheat	2,021	351
	Alfalfa	11,764	2,249

[1] Protein yield for grain crops represents seed protein only.

Alfalfa in 1990 cut once, while alfalfa in 1991-1993 cut three times per year.

All crops fertilized to soil test recommendations once per year.

Appendix 3. Soil water extraction of crops in N extraction study

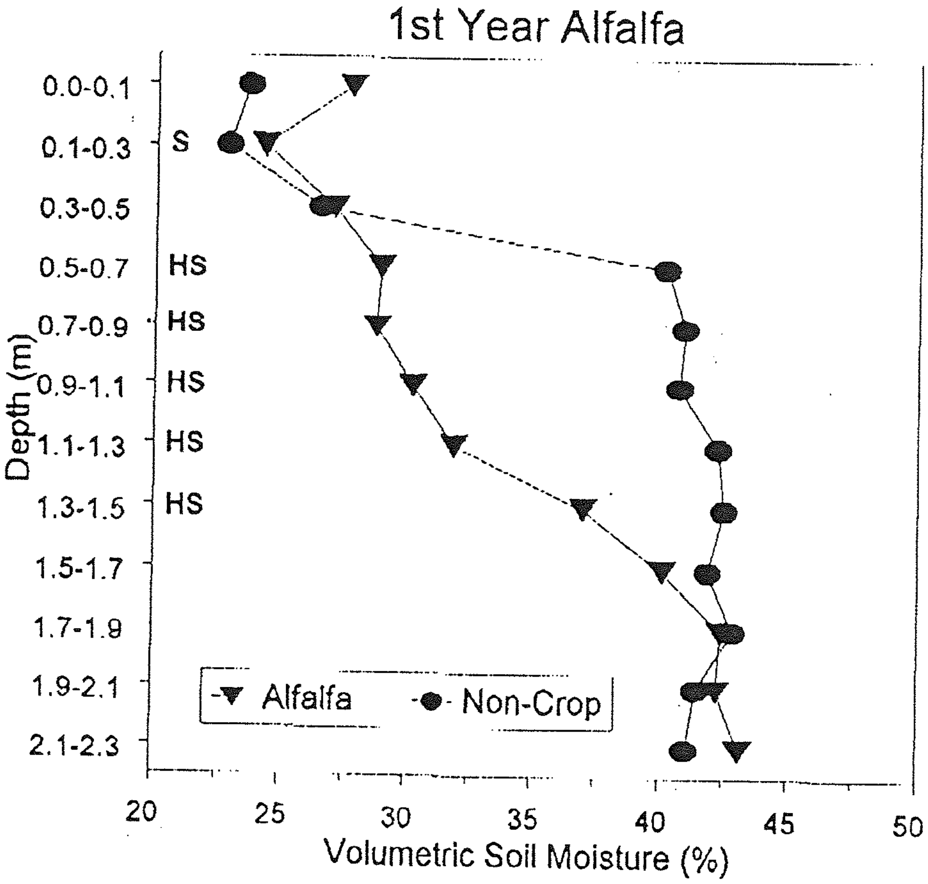

Figure A1. Water extraction by first year alfalfa relative to a non-crop control at Winnipeg in the fall of 1990. S, HS - analysis of variance significant at $P<0.05$ and 0.01, respectively.

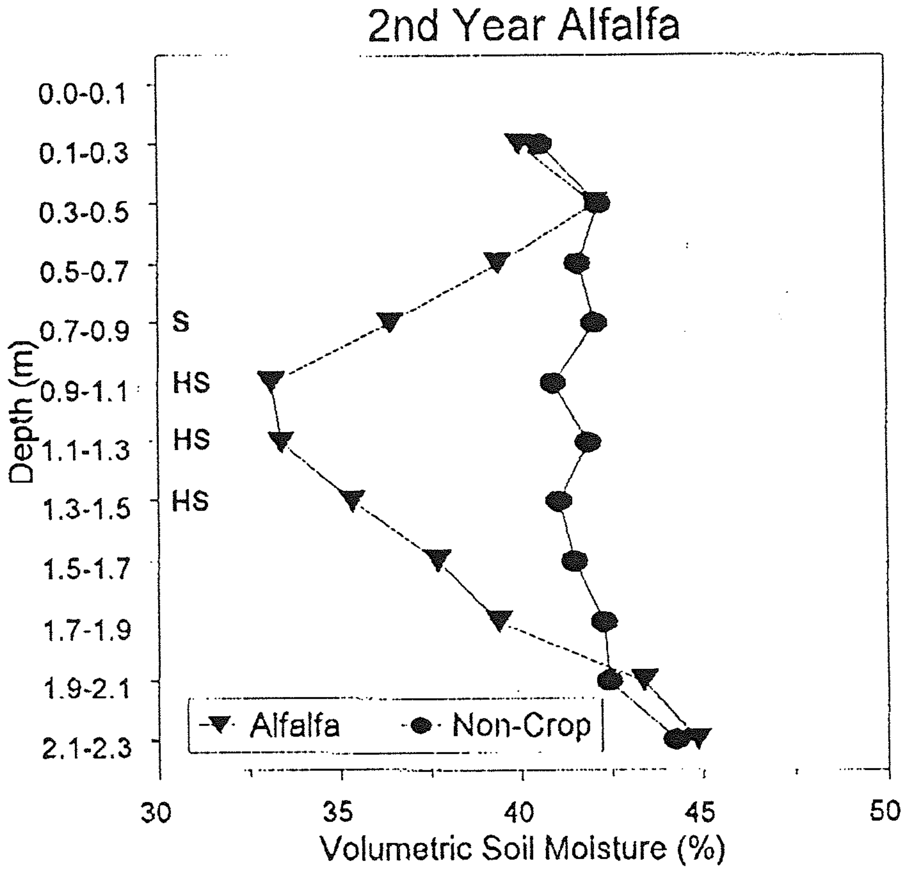

Figure A2. Water extraction by second year alfalfa relative to a non-crop control at Winnipeg in the fall of 1991. S, HS - analysis of variance significant at $P<0.05$ and 0.01, respectively.

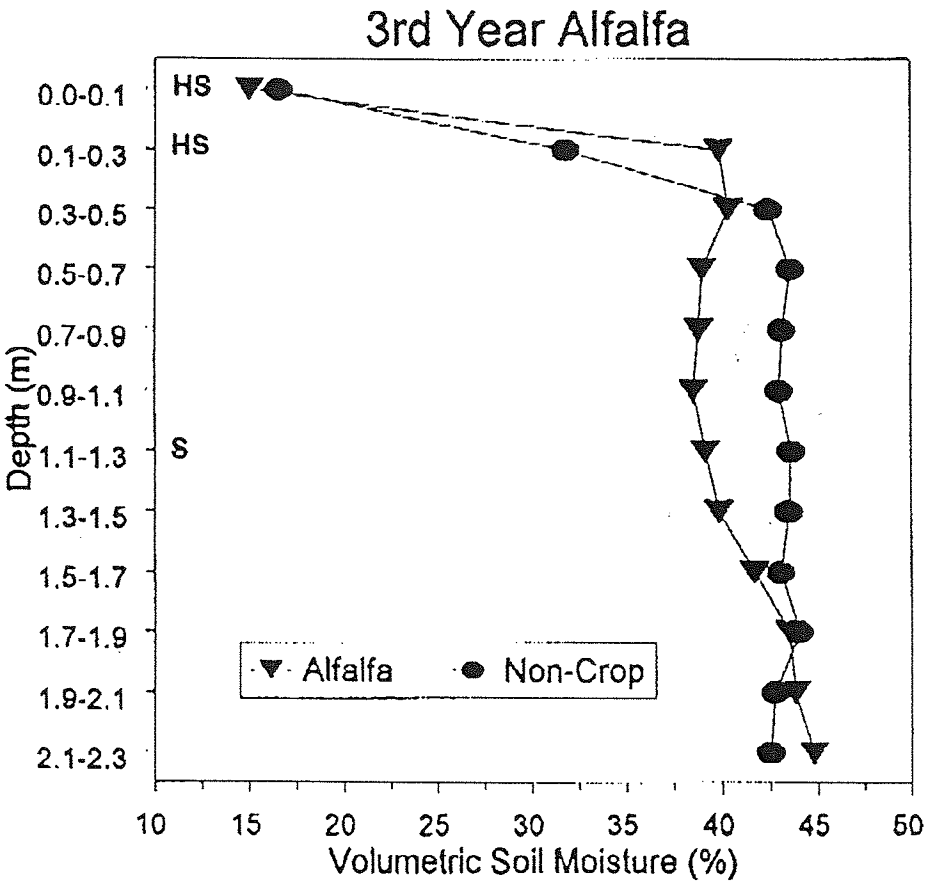

Figure A3. Water extraction by third year alfalfa relative to a non-crop control at Winnipeg in the fall of 1992 (a very wet year). S, HS - analysis of variance significant at $P<0.05$ and 0.01, respectively.

Appendix 4. Economic Analysis

Chapter 2: Economically Optimum Stand Length for Alfalfa in Cereal/Legume Rotations

Sian Mooney and Dr. Scott Jeffrey

Economic Analysis

The economic viability of introducing alfalfa into a cereal/legume crop rotation is assessed using a combination of enterprise budgets and basic present value accounting measures. This analysis is used to i) determine if it is profitable to include alfalfa in the rotation; and ii) determine the economically optimal length of alfalfa stand.

Enterprise budgets are calculated for each individual crop (i.e., wheat, barley, peas and alfalfa). In estimating these budgets, factors such as the nitrogen fixing capabilities of alfalfa and the expected trend in alfalfa yields are incorporated. The enterprise budgets are combined into rotations on a whole-farm basis in order to compare the expected net returns from each complete rotation. Budgets are calculated for the following six rotations:

1. Wheat-Pea-Barley (WPB)
2. Alfalfa-Wheat-Pea-Barley (AWPB)
3. Alfalfa-Alfalfa-Wheat-Pea-Barley (2AWPB)
4. Alfalfa-Alfalfa-Alfalfa-Wheat-Pea-Barley (3AWPB)
5. Alfalfa-Alfalfa-Alfalfa-Alfalfa-Wheat-Pea-Barley (4AWPB)
6. Alfalfa-Alfalfa-Alfalfa-Alfalfa-Alfalfa-Wheat-Pea-Barley (5AWPB)

The expected net returns for each rotation are evaluated using a present value framework, which allows for consideration of the timing of returns as well as the fact that each rotation spans a different time period.

Methodology

Individual enterprise budgets are estimated for each crop that is included in the six crop rotations. An enterprise budget contains a detailed summary of the costs and inputs required for a particular production enterprise. Enterprise budgets provide a convenient means of summarizing the projected costs and returns for an enterprise (Boehlje and Eidman 1984).

Field trial and representative Manitoba data are used to determine the crop management practices (e.g., tillage practices) and quantity of inputs required for each crop. These estimates are then used to calculate the operating costs associated with production of each crop. These operating costs include expenses associated with seed, fertilizer, chemicals, machinery (repairs and maintenance), crop insurance and labour. The costs of wheat, peas and barley are adjusted in each rotation in order to account for the nitrogen fixing capacity of alfalfa. This has the effect of reducing the nitrogen fertilizer requirements. Also, individual alfalfa budgets are estimated for each year of the stand, in order to account for the expected trend in alfalfa yields over time. A discussion of the assumptions and calculations associated with the budget estimations is provided in the section dealing with data requirements.

Individual enterprise budgets are combined by crop rotation and the returns from each rotation are calculated. As each rotation spans a different time period these net revenues are adjusted, using present value accounting methods, to enable a comparison based on an annuity income stream for each alternative. A present value approach is used to find the current value of future income streams expected from each crop rotation. Net present value is calculated as:

$$NPV = -INV + \sum_{n=1}^{K} \frac{I_n}{(1 + d)^n} + \frac{SV_n}{(1 + d)^K} \qquad (1)$$

INV = Initial Value
NPV = Net Present Value
K = Number of Time Periods
I_n = Net cash inflow in period n
d = Discount rate
SV_n = Salvage Value

The net present value represents the profitability in terms of present (current) dollars of a stream of future expected incomes. The discount rate represents the opportunity cost of the investment or alternatively could be considered to reflect the required rate of return from the crop rotation (investment). If the introduction of a new crop rotation did not require the purchase of new machinery, there are no entries in the initial investment or salvage value portions of the NPV formula. An example including an initial investment (for example the purchase of new machinery) is presented below.

Example

Assume a four year rotation of alfalfa-wheat-peas-barley. Net revenues for each crop are calculated as:

$$PY - C = \text{Net revenue} \qquad (2)$$

Where:

PY = Present value

C = Cost

Net revenues from each crop are added over each rotation. Each net revenue is discounted in accordance with the second term in formula (1). Their sum is the total present values of the income stream from the rotation. An example of the calculation procedure is presented in table 2.1.

The value of the first term in equation (1) (INV) is simply the purchase price of any equipment that must be acquired by the farmer for the new rotation. The purchase price is discounted every year until the end of the time period of the rotation. The remaining value represents the salvage (resale) value of the machinery. This salvage value is also discounted in the final year of the rotation and treated as if it were additional income from the rotation. The present value of each crop rotation is calculated in this way. However the relative profitability of each rotation cannot be compared on the basis of present value alone as each rotation spans a different time period. The present values generated by each rotation are compared on an equal basis by calculating the annuity which is the equivalent yearly income stream generated by each rotation. This enables the yearly income from each rotation to be directly compared. The annuity is calculated as:

$$A = \frac{NPV}{\frac{1}{d}\left(1 - \frac{1}{(1 + d)^{K}}\right)} \qquad (3)$$

Where:

A = Annuity
NPV = Net Present Value
K = Number of years
d = Discount Rate

Table 2.1 **Present Value Calculation**

Year and crop	Net Revenue	Discount Factor	Present Value
1. Alfalfa	I	d	$\frac{I}{(1 + d)}$
2. Wheat	I_2	d	$\frac{I_2}{(1 + d)^2}$
3. Pea	I_3	d	$\frac{I_3}{(1 + d)^3}$
4. Barley	I_4	d	$\frac{I_4}{(1 + d)^4}$
		Total	$\sum_{n=1}^{4} \frac{I_n}{(1 + d)^n}$

The yearly income expected from each rotations are compared in order to rank each rotation on the basis of expected income. Sensitivity analysis is used to test the stability of net revenue ranking from each ration in response to variations in yield and price. The price of alfalfa is varied until the annuity equivalent from rotations containing alfalfa equal those for the base rotation (wheat-pea-barley). The same technique is applied to the yields of alfalfa. Yields are varied until the annuity from each alfalfa rotation is equal to the annuity for the base rotation. The degree to which it is possible to vary prices and yields before the rankings of the results change provides an indication of the degree of stability, or confidence for the calculated solutions.

Data

A 405 hectare (1000 acre) farm was chosen as the representative farm for this study. It is assumed that initially the land is totally devoted to the base rotation (wheat-peas-barley) and that the equipment set available for cultivation reflects this production choice. Table 2.2 indicates the farm equipment needed to cultivate wheat-peas-barley prior to the potential adoption of alfalfa. Additional machinery is required to produce alfalfa. This machinery can be bought, hired or a combination. Two scenario's are considered in this study. Scenario one considers a farm only containing the equipment in Table 2.2. who must then purchase the additional equipment needed to produce alfalfa. Table 2.3 indicates the additional equipment required to produce alfalfa and their approximate costs assuming that good condition used equipment, approximately six to eight years old will be purchased. Scenario 2 considers a farm which already possessed the necessary equipment to produce alfalfa. Enterprise budgets are calculated for each rotation assuming that owned equipment is used in most operations. A fertilizer

Table 2.2 Machinery Required to Produce Wheat-Pea-Barley Rotation

Machinery	Size	1986 List Price $[a]	Cumulative Hours of Use[b]	Fuel Consumption litres/hr[c]
Press Drill	28 feet	29820	364.50	
Field Cultivator	35 feet	14542	368.55	
Harrow	60 feet	5130	141.75	
Field Sprayer	80 feet	7320	182.25	
Self Propelled Swather	30 feet	35100	402.97	18.2
Tractor with loader	120 Hp	58500	1715.17	30.0
4 W.D. Tractor	200 Hp	97500	797.85	35.0
Heavy Cultivator	30 feet	14850	429.30	
Tandem Truck	12 tonne	40000	150.00	13.95[d]

[a] Machinery prices supplied by Doug Jackson, Manitoba Agriculture. Prices are 1984 averages adjusted by an index of farm inputs.

[b] Estimate of Cumulative hours of use assuming 1986 as purchase year and 405ha cultivated each year.

[c] Personal communication, Don Johnson, Agricultural Engineering, University of Manitoba.

[d] Assuming speed 20 miles per hour. Actual consumption of 6.5 miles per gallon obtained in personal communication, Don Johnson, Agricultural Engineering, University of Manitoba.

Table 2.3 Additional Machinery Required to Produce Alfalfa

Machinery	Size	Used Price $[a]	Cumulative Hours of Use[b]	Fuel Consumption litres/hr[c]
PTO Baler		7500	661.5	
Self Propelled Swather	18 feet	9000	349.65	13.64
Bale Mover	10 bales	7500		

[a] Machinery prices represent an average of prices quoted by local Manitoba dealers and the Manitoba Co-operator for "good used equipment", approximately seven years old.

[b] Assuming 150ha cultivated for seven years.

[c] Personal communication, Don Johnson, Agricultural Engineering, University of Manitoba.

spreader is the only rented piece of equipment. The cultivation practices used to produce the crop must be documented in order to calculate the cost of fuel, lubrication, labour and repairs. Table 2.4 presents a summary of the cultivation practices used to produce each crop. These practices were recommended in personal communications with Manitoba farmers. The perennial alfalfa variety chosen for the rotation field trials is OAC Minto. However, given the small amount of data available on its performance in field trials, yield data for a "generic" hay type alfalfa variety is used in the net revenue calculations. Table 2.5 shows the expected yields of alfalfa by year for different lengths of stand, in addition to the expected contribution of N_2 (nitrogen) in years following the rotation. These alfalfa yields are expected to range from a minimum of 2 tonnes/ha to 12 tonnes/ha, although the maximum yield varies slightly depending on the age of the stand. Yields for wheat and barley (Table 2.6) are crop trial averages provided by the Department of Plant Science, University of Manitoba. Pea yields are 1975 to 1990 Manitoba averages obtained from the Manitoba Agriculture Yearbook (Manitoba Agriculture, Various Years). Farm gate prices for wheat, peas and barley are 1985 to 1990 provincial averages (Manitoba Agriculture 1990), alfalfa prices are an average of 1989 to 1992 lower range prices provided by Manitoba Agriculture Table 2.7 .

Prices of seed, fuel, fertilizer and chemicals are also estimated. Fertilizer costs are based on actual experimental data generated from the available trial data for this experiment, at the Portage la Prairie and Winnipeg sites. Fertilizer is applied according to soil test recommendations. Chemical costs and application rates are also obtained from trial data provided by this experiment from the Portage and Winnipeg sites.

Nitrogen fertilizer costs for wheat and barley following alfalfa are adjusted to reflect the nitrogen fixating capacity of alfalfa after different lengths of stand. Peas do not receive nitrogen

Table 2.4 Cultivation Practices

Cultivation Practice[a]	Wheat	Pea	Barley	Alfalfa First Year	Alfalfa Established	Alfalfa Kill off Practices
Spring Fertilizer	X	X	X			
Cultivate	X	X	X	X		
Harrow	X	X	X	X (twice)		
Seed with Press Drill	X	X	X	X		
Weed Control	X	X	X	X		
Swath	X	X	X	X (twice)	X (twice)	
Combine	X	X	X			
Bale				X (twice)	X (twice)	
Deep Cultivation	X	X	X			X (three times)

[a] Practices chosen in consultation with Gary Martins and Sylvio Sabourin, Manitoba Farmers.

Table 2.5 Expected yearly alfalfa yields and Nitrogen Contribution

Rotation	Year in Rotation Yield tonnes/ha[a]					Nitrogen contribution in Following Years Kg/ha[a]		
	1	2	3	4	5	1	2	3
A	5.200					40		
A-A	5.200	6.760				70	40	15
A-A-A	5.200	6.760	6.760			75	50	30
A-A-A-A	5.200	6.760	6.760	6.084		85	55	35
A-A-A-A-A	5.200	6.760	6.760	6.084	5.476	100	60	40

[a] Personal communication, Department of Plant Science, University of Manitoba. Figures are approximate.

Table 2.6 Average yields for Wheat, Peas and Barley, 1975 to 1990.

	Crop Yield Tonnes/ha	
Wheat	Pea	Barley
2.353	1.767	3.766

Source: Manitoba Agriculture Yearbook (Various Years).
Personal communication, Manitoba Agriculture Personnel.

Table 2.7 Average Prices of Wheat, Peas, Barley and Alfalfa H

Year	Wheat	Pea	Barley	Alfalfa (a)
		$ per tonne		
1985	145.00	211.00	99.00	
1986	112.00	190.00	78.00	
1987	99.00	194.00	71.00	
1988	173.00	215.00	128.00	
1989	149.00	187.00	115.00	60.00
1990	109.00	178.00	90.00	60.00
1991				55.00
1992				55.00
Average	131.17	195.83	96.83	57.50

Source: Manitoba Agriculture. 1990. Manitoba Agriculture Yearbook 1990.

(a) Personnal communication, Manitoba Agriculture.

fertilizer in the control rotation wheat-pea-barley. Although peas may use the nitrogen left by the alfalfa there is no reduction in fertilizer costs.

In addition to crop production costs, a discount rate for calculating net present value is needed. The discount rate is an important choice. It essentially indicates the minimum acceptable rate of return for an investment; that is, a cut off point for judging whether or not an investment is desirable (Boehlje and Eidman 1984). The discount rate is calculated from an average of the 1991 five year Guaranteed Investment Certificate (GIC) adjusted for inflation. GIC are chosen because they represent a fairly safe (risk-free) investment. Each income flow is discounted by 8.02 percent.

Results

The net returns from each crop and each crop rotation are presented in Table 2.8. Detailed enterprise budgets and their underlying calculations are presented in Appendix 1. However, as indicated previously, their net returns cannot be compared directly as each rotation spans a different length of time. The present value of the income stream from each rotation is calculated and then converted into an annuity to enable the returns from the rotations to be compared on an equal basis. Two scenarios are compared, one in which it assumed that the equipment required to produce alfalfa is already present on the farm (scenario 1) and the second where that equipment must be purchased (scenario 2). These net present values and annuity figures for each scenario are presented in Table 2.9. The annuity values generated for both scenarios suggest that it is profitable to incorporate alfalfa into a wheat-pea-barley rotation. It is apparent that as alfalfa is incorporated for longer periods of time, the expected yearly net income increases, although at a decreasing rate. In scenario 1, rotation 6 (A-A-A-A-A-W-P-B) generates the greatest annuity

Table 2.8 Annual Costs and Returns per Hectare

Rotation	Average Yield	Average Price	Operating Expenses	Labour	Returns
Rotation 1					
Wheat-Peas-Barley					
Wheat	2.353	131.37	193.80	12.85	102.46
Peas	1.767	195.83	246.67	11.57	87.79
Barley	3.766	96.83	187.58	12.85	164.23
Total					354.49
Rotation 2					
A-W-P-B					
Alfalfa	5.200	57.50	168.13	27.93	102.94
Wheat	2.353	131.37	170.31	12.85	125.95
Pea	1.767	195.83	246.67	11.57	87.79
Barley	3.766	96.83	187.58	12.85	164.23
Total					480.92
Rotation 3					
A-A-W-P-B					
Alfalfa	5.200	57.50	157.92	22.33	118.75
Alfalfa	6.760	57.50	83.78	23.36	281.56
Wheat	2.353	131.37	156.79	12.85	139.47
Pea	1.767	195.83	246.67	11.57	87.79
Barley	3.766	96.83	187.58	12.85	164.23
Total					791.81
Rotation 4					
A-A-A-W-P-B					
Alfalfa	5.200	57.50	157.92	22.33	118.75
Alfalfa	6.760	57.50	72.68	17.94	298.08
Alfalfa	6.760	57.50	83.78	23.36	281.56
Wheat	2.353	131.37	154.53	12.85	141.73
Pea	1.767	195.83	246.67	11.57	87.79
Barley	3.766	96.83	174.05	12.85	177.76
Total					1105.677
Rotation 5					
A-A-A-A-W-P-B					
Alfalfa	5.200	57.50	157.92	22.33	118.75
Alfalfa	6.760	57.50	72.68	17.94	298.08
Alfalfa	6.760	57.50	72.68	17.94	298.08
Alfalfa	6.084	57.50	83.78	23.36	242.69
Wheat	2.353	131.37	150.83	11.57	146.71
Pea	1.767	195.83	246.67	11.57	87.79
Barley	3.766	96.83	171.8	12.85	180.01
Total					1372.12
Rotation 6					
A-A-A-A-A-W-P-B					
Alfalfa	5.200	57.50	157.92	22.33	118.75
Alfalfa	6.760	57.50	72.68	17.94	298.08
Alfalfa	6.760	57.50	72.68	17.94	298.08
Alfalfa	6.084	57.50	72.68	17.94	259.21
Alfalfa	5.476	57.50	83.78	23.36	207.71
Wheat	2.353	131.37	150.83	11.57	146.71
Pea	1.767	195.83	246.67	11.57	87.79
Barley	3.766	96.83	169.55	12.85	182.26
Total					1598.594

Table 2.9 Present Value and Annuity by Rotation

Rotation	Present Value Existing Equipment $	Annuity $	Present Value Purchased Equipment $	Annuity $
Rotation 1 W-P-B	300.38	116.60	300.38	116.60
Rotation 2 A-W-P-B	393.48	118.86	352.06	106.35
Rotation 3 A-A-W-P-B	637.98	159.88	591.93	148.34
Rotation 4 A-A-A-W-P-B	864.38	187.11	814.91	176.40
Rotation 5 A-A-A-A-W-P-B	1039.94	199.91	987.93	189.91
Rotation 6 A-A-A-A-A-W-P-B	1175.19	204.68	1121.30	195.30

($204.68), exceeding the annuity generated by the wheat-pea-barley rotation by approximately $88. Rotation 5 (A-A-A-A-W-P-B) is second best, its yearly revenues exceeding those of wheat-pea-barley by approximately $83. In scenario 2, rotation 6 is also the most profitable, exceeding the annuity generated by wheat-pea-barley by approximately $78. The only change in the rankings of the rotations in each scenario is the profitability of rotation 2. In scenario 1 rotation 2 is slightly more profitable that the base rotation, however, with the additional costs of purchasing equipment its revenues decline below those of the base rotation in scenario 2. In each scenario the optimal length of alfalfa stand is 5 years, based on the yields and prices used in this study (note that the technique used does not account for risk, this could affect the rankings of the rotations). Given that revenues are increasing at a decreasing rate it would be of interest to consider rotations that incorporate alfalfa for longer than five years to ascertain at what point revenues start to decline. Given the small increase in the annuity value between rotations 5 and 6, it is likely that in both scenarios revenues will begin to decline in a rotation with six years of alfalfa.

Sensitivity analysis of the results of scenario 1 and 2 indicate that the ranking of the relative rotations is stable. Alfalfa yields in year one were decreased and yields in subsequent years reduced according to the initial percentage differences in yields between each year. In scenario 1, alfalfa yields in rotations 4, 5 and 6 can drop by approximately 36 percent before their annuities become equivalent to wheat-pea-barley (Table 10). In scenario 2 alfalfa yields in the same rotations can be reduced by 32 percent. It was not possible to obtain the coefficient of variation for alfalfa yields. It is assumed that the variation in alfalfa yields will be similar to yield variations of other hay crops. The coefficient of variation for all hay yields in Manitoba is 0.18, indicating that yields deviate from the average by approximately 18 percent. It is clear

Table 2.10 Yield Sensitivity of Rotation Rankings

Rotation	Breakeven Yield Existing Equipment Kg/ha	Present Value $	Annuity $	Breakeven Yield Purchased Equipment Kg/ha	Present Value $	Annuity $
Rotation 1						
W-P-B		300.32	116.58		300.32	116.58
Wheat	2.353			2.353		
Peas	1.767			1.767		
Barley	3.766			3.766		
Rotation 2						
A-W-P-B		385.45	116.44		386.60	116.78
Alfalfa	5.050			5.850		
Wheat	2.353			2.353		
Pea	1.767			1.767		
Barley	3.766			3.766		
Rotation 3						
A-A-W-P-B		464.35	116.37		462.87	116.00
Alfalfa	3.720			4.100		
Alfalfa	4.836			5.330		
Wheat	2.353			2.353		
Pea	1.767			1.767		
Barley	3.766			3.766		
Rotation 4						
A-A-A-W-P-B		537.65	116.39		537.62	116.38
Alfalfa	3.350			3.630		
Alfalfa	4.355			4.719		
Alfalfa	4.355			4.719		
Wheat	2.353			2.353		
Pea	1.767			1.767		
Barley	3.766			3.766		
Rotation 5						
A-A-A-A-W-P-B		603.73	116.05		603.69	116.05
Alfalfa	3.270			3.500		
Alfalfa	4.251			4.550		
Alfalfa	4.251			4.550		
Alfalfa	3.826			4.095		
Wheat	2.353			2.353		
Pea	1.767			1.767		
Barley	3.766			3.766		
Rotation 6						
A-A-A-A-A-W-P-B		667.56	116.27		605.40	116.37
Alfalfa	3.300			3.630		
Alfalfa	4.290			4.719		
Alfalfa	4.290			4.719		
Alfalfa	3.861			4.247		
Alfalfa	3.475			3.822		
Wheat	2.353			2.353		
Pea	1.767			1.767		
Barley	3.766			3.766		

that the solution is not sensitive to yield changes of this degree. A similar degree of stability for both solutions is exhibited in response to a change in alfalfa price (Table 11). Prices can vary by the same percentage as yields.

Conclusions

It is profitable to introduce alfalfa into a wheat-pea-barley rotation. The optimal length of alfalfa stand is five years based on the data and rotations considered in this analysis. It is possible that revenues from a six year stand may exceed those of a five year stand, however the difference between their yearly revenues would not be very large. Shorter lengths of stand are also profitable. In both scenarios, annuities generated by rotations that include two years of alfalfa still exceed those of the base rotation (wheat-pea-barley). The economic benefits arising from the nitrogen fixating capacity of alfalfa could be enhanced if barley were to follow wheat in the rotation rather than peas. Peas do not receive nitrogen fertilizer in the initial rotation and therefore the economic benefits of a potential reduction in nitrogen costs are lost on this crop. In summary, initial calculations indicate that alfalfa is a viable crop to introduce into a cereal/legume rotation, the optimal length of stand being five years.

Potential for Further Analysis

The results of the economic analysis have provided some useful information concerning the viability of including alfalfa into cereal/legume rotations. However, further analysis is warranted in several areas relating to alfalfa production. Some of these areas are summarized in the following points:

i) impact of using a cover crop in establishing the alfalfa stand, in terms of

Table 2.11 Price Sensitivity of Rotation Rankings

Rotation	Breakeven Price Existing Equipment	Present Value	Annuity	Breakeven Price Purchase Equipment	Present Value	Annuity
	$	$	$	$	$	$
Rotation 1						
W-P-B		300.38	116.60		300.38	116.60
Wheat	131.37			131.37		
Peas	195.83			195.83		
Barley	96.83			96.83		
Rotation 2						
A-W-P-B		384.34	116.10		385.75	116.53
Alfalfa	55.60			64.50		
Wheat	131.37			131.37		
Pea	195.83			195.83		
Barley	96.83			96.83		
Rotation 3						
A-A-W-P-B		462.98	116.03		464.65	116.45
Alfalfa	41.00			45.50		
Alfalfa	41.00			45.50		
Wheat	131.37			131.37		
Pea	195.83			195.83		
Barley	96.83			96.83		
Rotation 4						
A-A-A-W-P-B		537.01	116.25		538.63	116.60
Alfalfa	37.00			40.20		
Alfalfa	37.00			40.20		
Alfalfa	37.00			40.20		
Wheat	131.37			131.37		
Pea	195.83			195.83		
Barley	96.83			96.83		
Rotation 5						
A-A-A-A-W-P-B		606.67	116.62		605.74	116.44
Alfalfa	36.30			38.80		
Alfalfa	36.30			38.80		
Alfalfa	36.30			38.80		
Alfalfa	36.30			38.80		
Wheat	131.37			131.37		
Pea	195.83			195.83		
Barley	96.83			96.83		
Rotation 6						
A-A-A-A-A-W-P-B		667.83	116.32	40.10	604.49	116.20
Alfalfa	36.50			40.10		
Alfalfa	36.50			40.10		
Alfalfa	36.50			40.10		
Alfalfa	36.50			40.10		
Alfalfa	36.50			131.37		
Wheat	131.37			195.83		
Pea	195.83			96.83		
Barley	96.83					

economic viability;

ii) impact of substituting a different crop for peas (e.g., canola or flax), in order to better utilize the nitrogen that has been fixed by the alfalfa;

iii) evaluation of the economic viability of annual alfalfa varieties in cereal/legume/oilseed rotations;

iv) an evaluation of including alfalfa into cereal/legume/oilseed rotations, in terms of risk efficiency.

Appendix 5. Zero-Tillage Forage Establishment

Zero-Tillage Establishment of Alfalfa and Meadow Bromegrass
as Influenced by Previous Annual Grain Crop

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ABSTRACT

Conventional forage establishment techniques (i.e. preseeding tillage) can result in soil erosion and inefficient water use during the establishment period, and may result in poor plant establishment. Using a zero-tillage (ZT) system may overcome these limitations. The first experiment, conducted under favourable post-seeding moisture conditions, compared establishment, plant development, growth, and dry matter production of alfalfa (Medicago sativa L.) and meadow bromegrass (Bromus biebersteneii Roem and Shult.) under ZT and conventional tillage (CT) following three different annual crops. Significant previous crop X tillage system interactions in both years, indicated that forage crop establishment and dry matter production were lower under ZT than CT when the preceding crop was wheat (Triticum aestivum L.), however, no significant differences were observed when the preceding crop was either field pea (Pisum sativum L.) or canola (Brassica napus L.). Significant previous crop X forage species interactions for crop establishment indicated that while alfalfa was unaffected by previous crop type, emergence of meadow bromegrass was reduced when wheat was the previous crop. Significant previous crop X tillage system interactions for plant development indicated that development of both forage species was temporarily delayed under ZT when wheat was the previous crop. No treatment effects were observed for year after establishment dry matter production. A second experiment, conducted under conditions of post-seeding drought, assessed the impact of spring wheat straw management on establishment of alfalfa and meadow bromegrass under CT and ZT. Superior establishment of both alfalfa and meadow bromegrass under ZT was attributed to higher levels of soil water under ZT. Straw management (removal vs. returned to land) had no effect on either forage species. Results of these studies indicate that ZT is a feasible alternative for establishing forage crops, even where levels of previous crop residue are very high.

Including perennial forages in rotation with annual crops is regarded as one of the most important soil improving and conserving techniques available in modern agriculture (Hargrove and Frye 1987). Perennial forages increase soil organic matter (Campbell et al. 1990), improve soil structure and soil fertility (Thiagalingam et al. 1991), and reduce soil erosion (Stinner and House 1989).

Establishment is perhaps the most difficult phase in the forage production system. Forage seedlings are especially vulnerable to soil moisture deficits because the small seeds are sown near the surface (Sheaffer 1989). Conventional seedbed preparation techniques (i.e. a number of preseeding tillage operations) dry out the seedbed (Unger 1990) and increase the risk of soil erosion (Sturgul et al. 1990); it is common for only one third of alfalfa seeds to produce seedlings (Decker et al. 1973). Current approaches to reduce erosion during the forage establishment period (i.e. the use of companion crops) can reduce forage herbage yield the year after establishment (Waddington and Bittman 1983).

A better approach may be to use the zero-tillage (ZT) system where forages are direct-seeded into annual crop stubble. It is known that ZT creates conditions conducive to successful establishment of small-seeded crops: 1) firm seedbed for shallow seeding, 2) higher soil moisture levels at spring seeding, especially in the surface soil layer (Gauer et al. 1982), and 3) residue to protect seedlings from wind erosion and from desiccation by wind (Koch 1992).

The limited amount of research on ZT forage establishment in annual crop rotations indicates that while forage crop establishment can often be as high (Forney et al. 1985; Wolf et al. 1985; Hart and Dean 1986) or higher (Stout et al. 1990) under ZT compared with CT, certain limitations exist. For example, high levels of previous crop residue can interfere with growth of ZT crops (Cochran et al. 1977), and can limit the amount of light reaching the soil surface (Wolf and White 1992). Allelopathic effects from phytotoxic substances produced from decaying residues have been shown to inhibit germination and establishment of subsequent crops (Hicks et al. 1989). Wolf and White (1992) concluded that previous crop residue had to be removed for successful establishment of alfalfa under

ZT conditions, while Bahler et al. (1987) suggested that successful ZT alfalfa establishment in oat stubble was achieved only if weeds and invertebrate pests (slugs) were controlled.

Both alfalfa and meadow bromegrass are routinely seeded in the arable lands of western Canada. Alfalfa is grown mainly for hay and pasture, while meadow bromegrass is most desirable as a pasture grass, often in combination with alfalfa (Smoliak 1990). Current alfalfa and alfalfa/grass mixtures in the eastern prairies are six and eight years, respectively (Mupondwa et al. 1993), however, shorter stands are also profitable (Jeffrey et al. 1993). Shorter stand lengths would allow producers to distribute the soil-improving benefits of forages to more hectares without increasing the total forage hectareage. Improvements in forage establishment techniques should reduce reluctance of producers to adopt shorter stand lengths.

The objectives of this study were: 1) to evaluate, in detail, the establishment, development, growth, and dry matter production of alfalfa and meadow bromegrass under ZT and CT following field pea, canola, and spring wheat, 2) to compare the relative response of these two important forage species to ZT, and 3) to investigate the effect of spring wheat straw management on the establishment of alfalfa and meadow bromegrass in the two tillage systems.

METHODS AND MATERIALS

Experiment One:

This experiment was conducted in 1990 and 1991 at the University of Manitoba Plant Science field research station, Portage la Prairie, MB (50°N, 98°W) on a Neuhorst clay loam soil. The experimental design was a split-split plot with tillage system (CT and ZT) as the mainplot, previous crop (spring wheat (Triticum aestivum L.), canola (Brassica napus L.), and field pea (Pisum sativum L.)) as the subplot, and forage species (alfalfa (Medicago sativa L.) and meadow bromegrass (Bromus biebersteinii Roem. and Shult.) as the sub-subplot. The sub-subplots were 4 m x 10 m and each treatment was replicated 4 times.

The CT treatment consisted of two passes (in opposite directions) with a double disk in the fall and a shallow cultivation, harrowing, and packing immediately prior to seeding in spring. No tillage operations were performed on the ZT plots. The ZT and CT treatments had been in place for 6 and 3 years, respectively. Subplots of spring wheat (cv. Katepwa), canola (cv. Westar), and field pea (cv. Victoria) were harvested in August of 1989 and 1990 using a plot combine. The residue from each crop was returned to the plot area. Once uniformly distributed over the plot area, the residue was chopped using a rotary mower set at a height of approximately 12 cm. The average length of the straw residue after chopping was 20 to 25 cm. The amount of residue returned from each previous crop was determined by measuring total aerial biomass immediately prior to harvest (Poppe 1991).

Alfalfa (cv. OAC Minto) was seeded at a rate of 354 and 404 viable seeds m^{-2} in 1990 and 1991, respectively. The alfalfa was inoculated with Rhizobium meliloti prior to seeding. Meadow bromegrass (cv. Regar) was seeded at a rate of 301 and 264 viable seeds m^{-2} in 1990 and 1991, respectively. Seeding date was May 27 in 1990 and May 22 in 1991. Certified seed of both forage species was used. Forages were seeded using a Noble Model 2000 hoe-drill (Nobleford, AB) (seed distributed using a seed distribution cone) with a row spacing of 15 cm to a depth of 1.5 cm in 1990 and 2.5 cm in 1991. The amount of previous crop residue present on both the CT and ZT plots was determined immediately after seeding using the line-transect method (Sloneker and Moldenhauer 1977).

The entire plot area received a broadcast application of 10 kg ha^{-1} nitrogen and 45 kg ha^{-1} of P_2O_5 prior to seeding in 1990 and 1991. The same fertilizer rates were applied in early spring the year after establishment. Weeds were controlled with appropriate herbicides which included an application of glyphosate at 2.5 L ha^{-1} immediately prior to seeding in spring. Weed control was less than optimum in 1990 as annual broadleaf weeds invaded the plot approximately one month after seeding. These weeds were removed when the forage was harvested 98 days after seeding (DAS). No weed problems were encountered the year after establishment (i.e. in 1991). Weed control was excellent in the experiment established in 1991.

Stand establishment and plant development stage were monitored every seven to ten days until approximately 30 DAS. Plant population density was determined by counting the number of plants in the same randomly selected 0.45 m^2 area in each sub-subplot. Percent emergence was calculated as plants per unit area divided by number of viable seeds per unit area. Plant development stage was measured on 10 randomly selected plants in each sub-subplot. Alfalfa development stage was measured by counting the number of fully emerged trifoliate leaves. Development stage of meadow bromegrass was determined using the Haun growth stage scale (on mainstem) (Haun 1973), and by counting the number of tillers per plant. Aerial dry matter (DM) production was determined on randomly selected 0.45 m^2 areas in each sub-subplot 31, 51, and 98 DAS in 1990 and 32, 60, and 134 DAS in 1991. Cutting height was 1 cm. Samples were dried at 70°C for a minimum of 48 hours before weighing. In 1991, the entire plot area was cut 60 DAS, and therefore, the DM harvest 134 DAS represents regrowth. Aerial DM production the year after establishment was determined in mid-June (10% bloom for alfalfa; heading stage for meadow bromegrass) from a 1 m^2 sample within each sub-subplot. The basal area (crown area estimation only) was assessed in early spring in the year after establishment (1991 study only) using the point-quadrat method (Lodge and Gleeson 1984). The sampling area in each sub-subplot was $0.5m^2$.

Volumetric soil water content between 0 and 10 cm (measured in 1991 only) was determined for each subplot at the time emergence counts were taken.

Experiment Two:

This experiment examined the effect of hard red spring wheat (cv. Roblin) straw management on the establishment of alfalfa and meadow bromegrass under CT and ZT. The experiment, which was conducted in 1992 only, was again established on a Neuhorst clay loam at Portage la Prairie, MB. The experimental design was a split-split plot with straw management (returned and removed) as the main-plot, tillage system (CT and ZT) as the subplot, and forage species (alfalfa and meadow bromegrass) as the sub-subplot. The wheat straw management treatments were applied in the fall of 1991. In the straw returned treatment, wheat straw was chopped and spread using a field-scale combine. After chopping, the straw was 10 to 15 cm in length. In the straw removed treatment, wheat straw was windrowed behind the combine, then baled.

Tillage operations and forage cultivars used were the same as in experiment 1. Inoculated alfalfa was seeded at a rate of 404 viable seeds m^{-2} and meadow bromegrass was seeded at 301 viable seeds m^{-2}. This experiment was seeded on May 20, 1992. Sub-subplots were evaluated for percent residue cover immediately prior to seeding using the techniques described in experiment 1. The amount of wheat straw returned to the plot area was estimated based on wheat grain yield and harvest index data.

Plant emergence and population density, and plant development stage were determined using methods described in experiment 1. Aerial DM production was determined 70 DAS on randomly selected 1 m^2 areas (alfalfa: 6-7 trifoliate stage; meadow bromegrass: Haun stage 4.6 with the third tiller visible). Volumetric soil water was determined for the 0 to 10 cm and 10 to 30 cm soil depth increments in each subplot at seeding and at intervals during the crop emergence period.

Daily maximum and minimum air temperature and daily precipitation were monitored throughout the growing season for both experiments. All data were subjected to analysis of variance (Statistical Analysis Systems Institute, 1986). Mean separations were conducted using the Fischer Protected least significant difference (LSD) test at the $p=0.05$ level, after GLM indicated significant ($P < 0.05$) differences. Significant interaction ($P < 0.05$) mean separations (for two-way and three-way interactions) were calculated using the technique described by Gomez and Gomez (1984). Homogeneity of error variances was checked using the maximum F test (Rohlf and Sokal 1969), however, since error variances for most parameters at the two sites (experiment 1) were not homogeneous, sites were analyzed separately.

RESULTS AND DISCUSSION

Experiment One

In 1990 and 1991, precipitation during the establishment period was close to or above the long-term average while air temperature was slightly above average (Table 1). Therefore, environmental conditions for crop establishment were satisfactory in both years of the study. No significant treatment effects on soil water content between 0 and 10 cm were observed in 1991 (data not shown). Therefore, the soil water-conserving benefits of the ZT system (Gauer et al. 1982) were not expressed in this study.

In 1990, residue returned to the land averaged 5900, 7700, and 8600 kg ha^{-1}, for canola, field pea and wheat, respectively, while in 1991, residue returned averaged 5000, 4500, and 7600 kg ha^{-1} for canola, field pea and wheat, respectively. The average aerial non-grain yield of hard red spring wheat in south-central Manitoba is approximately 6500 kg ha^{-1}. In the present study, the amount of previous crop residue returned was similar in the CT and ZT treatments. The percent residue cover for wheat, canola and field pea plots immediately after seeding was 92%, 82% and 60%, respectively under ZT, and 31%, 25% and 17%, respectively under CT. Measurements of previous crop residue mass and percent residue cover clearly point out that ZT forage establishment in this study was assessed under extremely high residue conditions, especially for wheat.

Crop Establishment In 1990, percent emergence of alfalfa decreased during the period 9 to 21 DAS (Table 2), presumably due to intraplant competition, while percent emergence of meadow bromegrass increased over the same time period. This suggests that alfalfa reached its maximum emergence percentage earlier than meadow bromegrass. In 1991, percent emergence of both forage species increased between 9 and 25 DAS (Table 2). Total emergence averaged 43% in 1990 and 31% in 1991, comparable to the levels observed by Decker et al. (1973).

Significant previous crop X forage species interactions were observed 21 DAS in 1990 and 19 DAS in 1991. In both years, the basis for the interaction was the same: percent emergence of alfalfa was unaffected by previous crop type, while percent emergence of meadow bromegrass was lower following wheat compared with canola or field pea (Table 2). These results for alfalfa in the present study differ from those of Wolf and White (1992) who found that heavy residue had to be removed for successful establishment of alfalfa under ZT conditions. A significant three way (tillage X previous crop X forage species) interaction for crop establishment was observed on the third sampling date (25 DAS) in 1991. This interaction was attributed to a differential response of alfalfa and meadow bromegrass to previous crop type in the ZT system. Percent alfalfa emergence was unaffected by tillage type or previous crop (Table 2). While there was no significant difference in percent emergence of meadow bromegrass following the three previous crops in the CT system, percent emergence of meadow bromegrass was significantly lower following wheat compared with field pea or canola in the ZT system (Table 2).

The aforementioned results indicate that establishment of meadow bromegrass was more negatively affected by wheat residue than alfalfa, especially under ZT. Possible causes for lower establishment of meadow bromegrass following wheat are physical obstruction by the previous crop residue (Cochran et al. 1977), root diseases (no leaf diseases were observed on any of the meadow bromegrass plots), or allelopathic chemicals released from decaying wheat residue. Hicks et al. (1989) attributed a 21% reduction in cotton emergence in wheat stubble to the presence of allelopathic substances. Limiting the amount of wheat residue overcame the negative effects. Surface soil temperatures are often lower under ZT than CT (Gauer et al. 1982), and it is possible that alfalfa and meadow bromegrass differ in their response to soil temperature depression under ZT.

It is worth noting that all alfalfa treatments in 1990 and 1991 achieved a plant population density of approximately 100 plants m^{-2}, an optimum plant population for establishment year alfalfa

(Meyer 1985).

Crop Development Crop development stage was monitored in the 1991 experiment only. Because different development stage scales were used for each forage species, alfalfa and meadow bromegrass were analyzed separately (each analyzed as a split plot).

A significant tillage X previous crop interaction 19 DAS indicated that alfalfa plant development was similar under CT and ZT when field pea and canola were the previous crops, however when wheat was the previous crop, development of alfalfa was significantly greater under CT compared to ZT (Table 3). Tillage X previous crop interactions ($P<0.05$) for both alfalfa and meadow bromegrass plant development 32 DAS indicated that plant development was similar for all three previous crops under CT, however under ZT, plant development was reduced when wheat was the previous crop (Table 3). Tiller number per meadow bromegrass plant (data not shown) 32 DAS was also significantly ($P<0.05$) affected by previous crop type (3.6 tillers per plant for meadow bromegrass following field pea and canola vs. 2.6 tillers per plant for meadow bromegrass following wheat), however, no tillage X previous crop interaction was detected. No significant differences were detected 60 DAS for either forage species.

Results of this study indicate that development of both alfalfa and meadow bromegrass were delayed temporarily in the ZT system when wheat was the previous crop. This is similar to the findings of Huggins and Pan (1991), who observed less branching and decreased shoot mass in winter lentil that had been zero-tilled into wheat stubble. They attributed the negative response to the shading effect of the wheat stubble which significantly reduced photosynthetically active radiation. Others have attributed slower plant development under ZT to lower soil temperatures (Fortin and Pierce 1991).

Aerial Dry Matter Production In 1990, significant previous crop X forage species interactions for DM production were detected 31 and 51 DAS. In both cases, the reason for the interaction was significantly lower DM production for meadow bromegrass when wheat was the previous crop (Table 4). Dry matter production of alfalfa, on the other hand, was unaffected by previous crop type on these sampling dates (Table 4). A significant tillage X previous crop interaction for DM production 98 DAS was attributed to the fact that yields of both forage species were similar under CT and ZT when field pea and canola were the previous crops, however, when wheat was the previous crop, forage yields were reduced under ZT (Table 4). The magnitude of the DM yield depression by ZT 98 DAS in 1990 was much greater for meadow bromegrass than for alfalfa (Table 4). Low forage DM production in 1990 compared with 1991 was attributed to invasion of annual weeds approximately 30 DAS.

In 1991, significant tillage X previous crop interactions for DM production were detected on all sampling dates (32, 60 and 134 DAS). Once again, the basis for these interactions was the fact that forage DM production was reduced in the ZT system when wheat was the previous crop, but unaffected by previous crop in the CT system (Table 4).

Results of experiment 1 indicated that, in terms of DM production, both forage species were negatively affected by the heavy residue in the ZT wheat treatment (Table 4). Therefore, even though stand establishment of alfalfa was not seriously affected by the heavy wheat residues (Table 2), DM yield was. Stout et al. (1990) also observed lower DM production of alfalfa established under ZT. In their study, lower yields of alfalfa following corn or rye were attributed to shading of the emerging seedlings by the heavy crop residue. A similar explanation may apply in the present study.

Year after Establishment Second year forage DM yields were determined for both the 1990 and 1991 studies. The lack of significant tillage X previous crop interactions for this parameter (Table

5) indicated that any negative effects due to previous crop type observed in the establishment year (Table 4) did not carry over into the second year. Similar year after establishment DM yields in 1990 and 1991 also indicated that the annual weeds present in the 1990 establishment year did not appear to have had any lasting negative effects on forage production. The absence of significant treatment differences for amount of basal stem area (Table 5) suggests that compensatory growth occurred in plots where low plant population densities were observed in the establishment year.

Based on the results of DM production the year after establishment, it appeared that the ZT system had no long-term effects on forage yield, even when the preceding crop was wheat. These results differ from those where companion crops were used in the establishment year. For example, Waddington and Bittman (1983) working in the Black soil zone of Saskatchewan, reported that a wheat companion crop reduced second year (first cut) yield of both alfalfa (38%) and smooth bromegrass (42%), compared to where no companion crop was used. Therefore, ZT establishment of forages into heavy crop residue in the present study had fewer negative consequences for second year forage DM production than the use of a companion crop in the Saskatchewan study.

Experiment Two

Conditions in 1992 were drier and cooler than in the two previous years (Table 1). Only 9 mm of precipitation was received during the period 11 days prior to seeding and 26 DAS. The amount of wheat straw spread in the straw return treatment in 1992 was estimated at 6600 kg ha^{-1}. Therefore, experiment two was conducted under lower residue conditions than experiment one. The amount of residue cover was not affected by straw removal in the ZT plots (removed - 85%, returned - 86%), however in the CT plots, straw removal significantly ($P<0.05$) reduced residue cover (removed - 32%, returned - 40%).

Crop Establishment Because no significant interactions involving forage species were observed in experiment two, crop establishment data was expressed as plant population density instead of percent emergence. Significant tillage effects for plant population density were observed on each sampling date in this study. In every instance, plant stand was greater under ZT than CT (Table 6). At 35 DAS, plant population densities (averaged over forage species) were approximately 200 plants m^{-2} in the ZT treatment and approximately 75 plants m^{-2} in the CT treatment. The higher plant population densities in the ZT treatment would not only be expected to produce higher quality forage (Meyer 1985), but would also compete better with weeds.

Superior forage plant establishment under ZT in this experiment was attributed to higher levels of soil moisture during the post-seeding period (data not shown). For example, plant population density of alfalfa ($r=0.99^{*}$) and meadow bromegrass ($r=0.97^{*}$) 35 DAS was correlated with volumetric soil water content in the 10 and 30 cm soil depth during the establishment period.

Crop Development Forage plant development stage was measured 22, 30, and 40 DAS. Forage species were again analyzed separately. A significant straw management X tillage interaction for alfalfa 22 DAS, indicated that while straw management did not affect trifoliate number of alfalfa under CT, trifoliate number per plant in the ZT treatment was higher where straw had been returned (0.9 vs 0.6). These results are opposite to those from the 1991 experiment, where high residue under ZT temporarily delayed alfalfa development (Table 3). A possible explanation for the different responses is that, in 1991, phenological development under ZT was limited by soil temperature, while in 1992, development rate of alfalfa was affected more by soil water. No significant treatment effects for Haun stage were observed for meadow bromegrass in this study (data not shown). Observations of plant development in experiment two indicate that while alfalfa responded positively to ZT, meadow bromegrass was unaffected.

Plant height for both alfalfa and meadow bromegrass was significantly greater under ZT compared with CT at 12, 15, and 22 DAS (data not shown), indicating superior growing conditions in the ZT system. Borstlap and Entz (1994) also have observed height increases of crops grown under ZT in Manitoba.

Aerial Dry Matter Production No significant differences in forage DM production 70 DAS (10% bloom stage of alfalfa; heading stage for meadow bromegrass) were observed for either the tillage or straw management treatments (Table 6). The absence of treatment differences for DM production, despite large differences in plant population densities, was attributed to compensatory growth of plants in the CT treatments. This compensatory growth was made possible by the adequate precipitation between the final emergence count and the time of DM assessment (Table 1).

SUMMARY AND CONCLUSIONS

This study provided a detailed analysis of establishment, seedling development and growth of alfalfa and meadow bromegrass under ZT and CT. The performance of both forage species was unaffected or enhanced by ZT when canola or field pea were the preceding crops. However, when the preceding crop was wheat, results were variable. Under conditions of high post-seeding precipitation and above average levels of wheat straw residue (1990 and 1991 studies), establishment and early growth of meadow bromegrass, and to a lesser extent, alfalfa, was often reduced under ZT. However, under conditions of low post-seeding precipitation and average wheat straw residue levels (1992 study), establishment and seedling development of both alfalfa and meadow bromegrass was enhanced by ZT. Similar to previous studies (eg. Lafond et al. 1992), superior crop performance under ZT under dry conditions in the present study was attributed to greater soil water conservation.

Meadow bromegrass appeared to be less well adapted to ZT than alfalfa when the preceding crop was wheat. For example, in 1990 and 1991 (wet conditions and high residue levels), meadow bromegrass was more negatively affected by ZT than alfalfa. In 1992 (drier conditions and average residue levels), meadow bromegrass did not always benefit from ZT to the same extent as alfalfa. Further research to determine the performance of alfalfa and meadow bromegrass mixtures under ZT is required.

Despite some negative effects of ZT on establishment and first year growth of meadow bromegrass, and to a lesser extent alfalfa, no differences between tillage system or previous crop type were observed for DM yield in the year after establishment. These observations indicate that ZT is a feasible alternative for establishing alfalfa and meadow bromegrass, even when the preceding crop is wheat. The ZT system should provide many of the establishment year benefits of a companion crop (eg. protection from blowing soil) with less competition for resources, especially water.

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Table 1. Monthly mean air temperature and precipitation at Portage la Prairie, Manitoba, in 1990, 1991 and 1992, and the 30-year average (1961-1990)[z]

	Temperature (C)					Precipitation (mm)			
	1990	1991	1992	Avg		1990	1991	1992	Avg
May	10.2	14.1	12.8	11.6		34.0	59.0	12.6	54.3
June	18.0	18.8	15.4	17.1		133.6	75.0	44.0	75.0
July	19.2	19.5	16.3	19.8		53.6	95.0	109.0	76.9
August	19.9	20.3	16.3	18.4		42.6	10.0	49.0	78.8
Sept.	14.0	12.2	10.8	12.5		19.2	68.0	50.0	49.2
Avg.	16.3	17.0	14.3	15.9	Total	283.0	307.0	264.6	334.2

[z] Environment Canada Atmospheric Environment Service, Winnipeg, Manitoba, R3C 3V4. The 30-year average (1961-1990) is the most recent period for which data has been compiled.

Table 2. Influence of tillage system and previous crop type on percent emergence of alfalfa and meadow bromegrass at Portage la Prairie in 1990 and 1991. Highlights of analysis of variance are included.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	1990			1991		
			9 DAS	16 DAS	21 DAS	9 DAS	19 DAS	25 DAS
			% emergence					
CT	Canola	Alfalfa	89	54	42	14	15	36
CT	Canola	Brome	40	63	67	9	19	34
CT	Pea	Alfalfa	62	37	27	25	24	34
CT	Pea	Brome	35	48	52	9	17	38
CT	Wheat	Alfalfa	57	42	40	20	23	36
CT	Wheat	Brome	33	58	55	6	14	47
ZT	Canola	Alfalfa	61	54	38	15	17	29
ZT	Canola	Brome	30	56	67	4	17	33
ZT	Pea	Alfalfa	61	60	34	26	15	27
ZT	Pea	Brome	40	63	68	3	13	26
ZT	Wheat	Alfalfa	43	42	26	14	20	29
ZT	Wheat	Brome	15	14	12	2	10	10
L.S.D.^{z}			NS	NS	NS	NS	NS	16
TS			NS	NS	NS	NS	NS	*
PC			NS	NS	NS	*	NS	NS
FS			**	NS	*	***	***	***
TS X PC			NS	NS	NS	NS	NS	NS
TS X FS			NS	NS	NS	NS	NS	NS
PC X FS			NS	NS	*	NS	*	NS
TS X PC X FS			NS	NS	NS	NS	NS	*

*, **, ***Significant at the 0.05, 0.01 and 0.0001 probability levels, respectively.

^{z}LSD applies to the three-way interaction only.

NS = nonsignificant.

Table 3. Influence of tillage system and previous crop type on development stage of alfalfa (as indicated by trifoliate leaf number per plant) and meadow bromegrass (as indicated by Haun stage) at Portage la Prairie in 1991.

Tillage System (TS)	Previous Crop (PC)	19 DAS	25 DAS	32 DAS	60 DAS
		---------------- alfalfa (trifoliate leaf number) ----------------			
CT	Canola	1.3	3.6	9.0	49.8
CT	Pea	1.6	4.8	10.9	57.3
CT	Wheat	1.8	4.5	10.9	54.8
ZT	Canola	1.3	3.9	10.1	54.0
ZT	Pea	1.1	4.0	12.3	50.0
ZT	Wheat	1.0	3.6	6.6	59.0
L.S.D.[z]		0.7	NS	2.0	NS
		----------- meadow bromegrass (Haun stage) ----------			
CT	Canola	2.0	3.6	4.7	6.1
CT	Pea	2.3	3.4	4.8	6.2
CT	Wheat	2.0	3.6	4.9	5.6
ZT	Canola	2.0	3.1	4.7	6.5
ZT	Pea	2.1	3.0	4.6	6.1
ZT	Wheat	2.0	3.0	4.1	6.2
L.S.D.[z]		NS	NS	0.2	NS

[z] L.S.D. applies to the two-way interaction.

Table 4. Influence of tillage system and previous crop type on dry matter production of alfalfa and meadow bromegrass at Portage la Prairie. Highlights of analysis of variance are included.

Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	1990			1991		
			31 DAS	51 DAS	98 DAS	32 DAS	60 DAS	134 DAS
			kg ha^{-1}					
CT	Canola	Alfalfa	16	388	2371	244	6542	6514
CT	Canola	Brome	69	656	1490	47	2658	7454
CT	Pea	Alfalfa	11	263	2321	388	5907	6342
CT	Pea	Brome	65	542	1561	58	2503	7030
CT	Wheat	Alfalfa	6	326	2495	536	8173	7594
CT	Wheat	Brome	44	393	1923	77	2653	7634
ZT	Canola	Alfalfa	10	238	2336	402	6651	7460
ZT	Canola	Brome	37	475	2155	50	2516	7285
ZT	Pea	Alfalfa	8	529	2030	438	7304	7617
ZT	Pea	Brome	44	358	1836	52	2969	7903
ZT	Wheat	Alfalfa	4	176	1773	174	6715	6354
ZT	Wheat	Brome	18	153	418	24	287	3120
L.S.D.[z]			NS	NS	NS	NS	NS	NS
TS			NS	NS	NS	NS	NS	NS
PC			*	*	*	NS	*	NS
FS			***	***	**	***	***	NS
TS X PC			NS	NS	*	*	*	*
TS X FS			NS	NS	NS	NS	NS	NS
PC X FS			*	*	NS	NS	NS	NS
TS X PC X FS			NS	NS	NS	NS	NS	NS

*, **, *** Significant at the 0.05, 0.01 and 0.0001 probability levels, respectively.

[z] LSD applies to the three-way interaction only.

NS = nonsignificant.

Table 5. Influence of tillage system and previous crop type on year after establishment dry matter production and basal area of alfalfa and meadow bromegrass at Portage la Prairie. Highlights of analysis of variance are included.

			Dry Matter Yield		Basal Area
Tillage System (TS)	Previous Crop (PC)	Forage Species (FS)	1990[z]	1991	1991
			---- kg ha^{-1} ----		-- % --
CT	Canola	Alfalfa	6632	6050	15.3
CT	Canola	Brome	4961	4255	17.3
CT	Pea	Alfalfa	6458	5768	18.8
CT	Pea	Brome	4976	4680	16.5
CT	Wheat	Alfalfa	6931	6008	17.0
CT	Wheat	Brome	3976	3820	16.5
ZT	Canola	Alfalfa	6442	6383	19.5
ZT	Canola	Brome	4905	4863	16.3
ZT	Pea	Alfalfa	6571	5535	18.0
ZT	Pea	Brome	5765	4560	17.5
ZT	Wheat	Alfalfa	6233	5840	19.0
ZT	Wheat	Brome	5248	3900	12.3
L.S.D.[y]			NS	NS	NS

[z] Year shown represents year of establishment.
[y] L.S.D. applies to the three-way interaction only.

Table 6. Influence of straw removal and tillage system on plant population density and dry matter yield of alfalfa and meadow bromegrass at Portage la Prairie in 1992. Highlights of analysis of variance are included.

Straw Management (SM)	Tillage System (TS)	Forage Species (FS)	Plant Population Density					Dry Matter Yield
			12 DAS	15 DAS	22 DAS	29 DAS	35 DAS	70 DAS
			plants m^{-2}					kg ha^{-1}
Removed	CT	Alfalfa	51	86	111	102	100	1886
Removed	CT	Brome	19	43	53	56	59	517
Removed	ZT	Alfalfa	135	188	215	221	221	1394
Removed	ZT	Brome	43	85	99	102	116	401
Returned	CT	Alfalfa	39	52	73	71	115	1698
Returned	CT	Brome	5	21	25	26	20	396
Returned	ZT	Alfalfa	147	218	270	308	294	1741
Returned	ZT	Brome	82	123	139	158	155	381
L.S.D.[z]			NS	NS	NS	NS	NS	NS
SM			NS	NS	NS	NS	NS	NS
TS			*	*	*	*	*	NS
FS			**	**	**	***	***	***
SM X TS			NS	NS	NS	NS	NS	NS
SM X FS			NS	NS	NS	NS	NS	NS
TS X FS			NS	NS	NS	NS	NS	NS
SM X TS X FS			NS	NS	NS	NS	NS	NS

*, **, ***Significant at the 0.05, 0.01 and 0.0001 probability levels, respectively.

[z] L.S.D. applies to the three-way interaction only.

NS = nonsignificant.

Appendix 6. Removing Alfalfa Using Herbicides Instead of Tillage

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Technical and Scientific
Papers Presented at a
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and Food Science Professionals

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USING HERBICIDES INSTEAD OF TILLAGE TO REMOVE FORAGE STANDS

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INTRODUCTION

The inclusion of perennial alfalfa in a rotational cropping system provides many agronomic benefits. However, the transition from alfalfa to successive crop in the rotation presents difficulty regarding alfalfa suppression, moisture conservation, and subsequent crop establishment. Consequently, many producers prolong the rotational turnover of alfalfa, thus extending the forage beyond the time of it's optimum productivity. Field experiments were established to address these rotational difficulties of alfalfa, and investigate alternative agronomic methods of managing alfalfa rotation.

The objectives of these studies were to 1) compare soil moisture conservation under different management methods of removing alfalfa from the rotation, 2) evaluate the ability of different herbicides to suppress alfalfa, and 3) to assess the feasibility of establishing Katepwa and Roblin wheat, and Bedford barley into chemically suppressed alfalfa residue.

MATERIALS AND METHODS

Field sites were established on perennial alfalfa in 1992 at Carman, Glenlea, and Holland to investigate soil moisture conservation. Experimental design was an RCBD with 4 blocks. Soil profile access tubes to 190 cm were centered within each 12 by 12 meter plot. Alfalfa was removed by tillage (T), herbicide (H), and herbicide and (delayed) tillage (H+T) after the first cut (1), second cut (2), and spring (3). Surface and profile soil moisture was monitored by a Troxler model 4300 depth moisture gauge. Fall and spring groundcover measurements were taken by the line transect method. Katepwa wheat was seeded with a Fabro no-till offset disc drill. The discussion will focus on soil moisture, and crop yield measurements.

A second study was conducted at Portage la Prairie in 1992, and Glenlea in 1993 to address crop establishment into suppressed alfalfa, effectiveness of herbicides in suppressing alfalfa, and time of alfalfa termination. Experimental design was a split-split-plot RCBD. Whole plot treatments were alfalfa suppression methods including rototiller (2 passes), Roundup 2.50 L ha^{-1} and 5.00 L ha^{-1}, Lontrel 0.75 L ha^{-1} and 1.50 L ha^{-1}, Banvel 0.75 L ha^{-1} and 1.25 L ha^{-1}, and an untreated plot for reference. Split-plot treatments were successive crop including Roblin wheat and Bedford barley. Split-split-plot treatments included post-sprayed and unsprayed treatment with Dyvel 1.26 L ha^{-1}. The experiment was repeated for mid-September and late-May alfalfa termination. Discussion will focus on crop yield and alfalfa regrowth.

A third experiment was established at Glenlea in the fall of 1992 to evaluate the ability of herbicides to suppress alfalfa. Alfalfa was suppressed with Roundup, Lontrel, Banvel, 2,4-D, and combinations of these herbicides (figure 4). Effectiveness of the treatments were evaluated the following spring in a non-crop environment by taking square meter quadrats of alfalfa regrowth on a dry weight basis.

RESULTS AND DISCUSSION

Soil Moisture Conservation

Soil moisture reserves during mid-October of the year of alfalfa removal were significantly different between treatments (figure 1). The date of alfalfa removal (D) at the first cut conserved greater amounts of soil moisture to 30 cm in the soil profile at Carman, and to even greater depths at Glenlea and Holland. The shorter interval of water use by alfalfa prior to it's termination in the first cut treatments, contributed to increased moisture storage. Differences in fall soil moisture reserves were also due to the method of alfalfa removal (M). Alfalfa removed by herbicide conserved greater moisture levels in the upper soil profile at Glenlea and Holland. Differences in spring soil moisture reserves to a 30 cm depth were due to the method of alfalfa removal (table 1). Moisture differences due to the date of alfalfa removal were diminished by overwinter moisture recharge of the soil profile. Herbicide treatments at Holland maintained higher soil moisture reserves to a 30 cm depth throughout the spring due to the method of alfalfa removal (figure 2). Residue cover on the field will slow moisture evaporation (Unger et al., 1988), allowing water to be conserved for crop growth. There were no differences in soil moisture in the soil profile to 190 cm at any of the locations during spring (table 1).

The method of alfalfa removal influenced grain yield at all three sites (table 1). Removal by herbicide achieved higher grain yields than tillage treatments at Carman and Holland. Grain yield was also influenced by the date of alfalfa removal at Carman and Holland. Considerable lodging in the tillage plots at Holland, and to a lesser extent at Carman, probably contributed to yield reductions in these treatments. Water use efficiency (WUE) was greatest in the herbicide treatments at Carman and Holland. Tillage treatments at Glenlea tended to have higher WUE than herbicide or herbicide + tillage treatments partly due to higher grain yields.

Alfalfa Suppression and Crop Establishment

Crop yield differed considerably in response to the initial alfalfa suppression treatment (figure 3). Fall application of Roundup 5.00 L ha^{-1}, Roundup 2.50 L ha^{-1}, and Lontrel 1.50 L ha^{-1} were superior to tillage in achieving higher yields at Portage la Prairie. At Glenlea, fall application of Roundup 5.00 L ha^{-1} and tillage were not different. Removal of alfalfa by tillage during spring gave higher yields than the herbicide treatments at both locations. Delayed kill of the alfalfa with the herbicides may have allowed greater competition of the alfalfa over that of tillage (Smith et al., 1992).

Postharvest alfalfa basal % was lower for fall removal by both Roundup treatments, and Lontrel 1.50 L ha^{-1} than tillage at Portage la Prairie. At Glenlea, Roundup 5.00 L ha^{-1} and tillage were not different in suppressing alfalfa by fall suppression. Better alfalfa suppression by spring removal was achieved with tillage at Portage la Prairie, however at Glenlea, Lontrel 1.50 L ha^{-1} and Roundup 5.00 L ha^{-1} were as effective as tillage in suppressing alfalfa. Alfalfa regrowth the following spring at Portage la Prairie was lower under the Roundup 5.00 L ha^{-1}, and Lontrel 1.50 L ha^{-1} treatments than tillage for fall suppression, however there was no difference among these treatments in their ability to suppress alfalfa under spring suppression.

No differences were evident in the competitive ability of wheat and barley to suppress alfalfa regrowth. Postspray treatment with Dyvel increased crop yield when there was sufficient alfalfa present to reduce crop yields. The postspray treatment also decreased post harvest alfalfa basal %, and as well, reduced alfalfa regrowth the following spring.

Application of herbicides in combination with one another generally suppressed alfalfa to a greater extent than herbicides applied alone (figure 4). Similar results were obtained by Button (1991) for visual assessment of alfalfa regrowth. The ability of Roundup to suppress alfalfa was enhanced considerably with the addition of 2,4-D or Banvel. Knake et al. (1992) reported that dicamba (Banvel) and 2,4-D combinations give good control of established alfalfa for no-till crop production.

CONCLUSIONS

Results of this study indicate that potential benefits can be derived by applying herbicides to remove alfalfa stands. Increased soil moisture, especially in the upper soil profile will often be the result of utilizing herbicides instead of tillage, however this will not always lead to higher crop yields. Herbicides applied in the fall are able to obtain crop yields as well or better than that of tillage, however spring applied tillage appears to realize higher crop yields over that of spring applied herbicide. For control of alfalfa into the following year, herbicides are able to achieve suppression as well or better than tillage.

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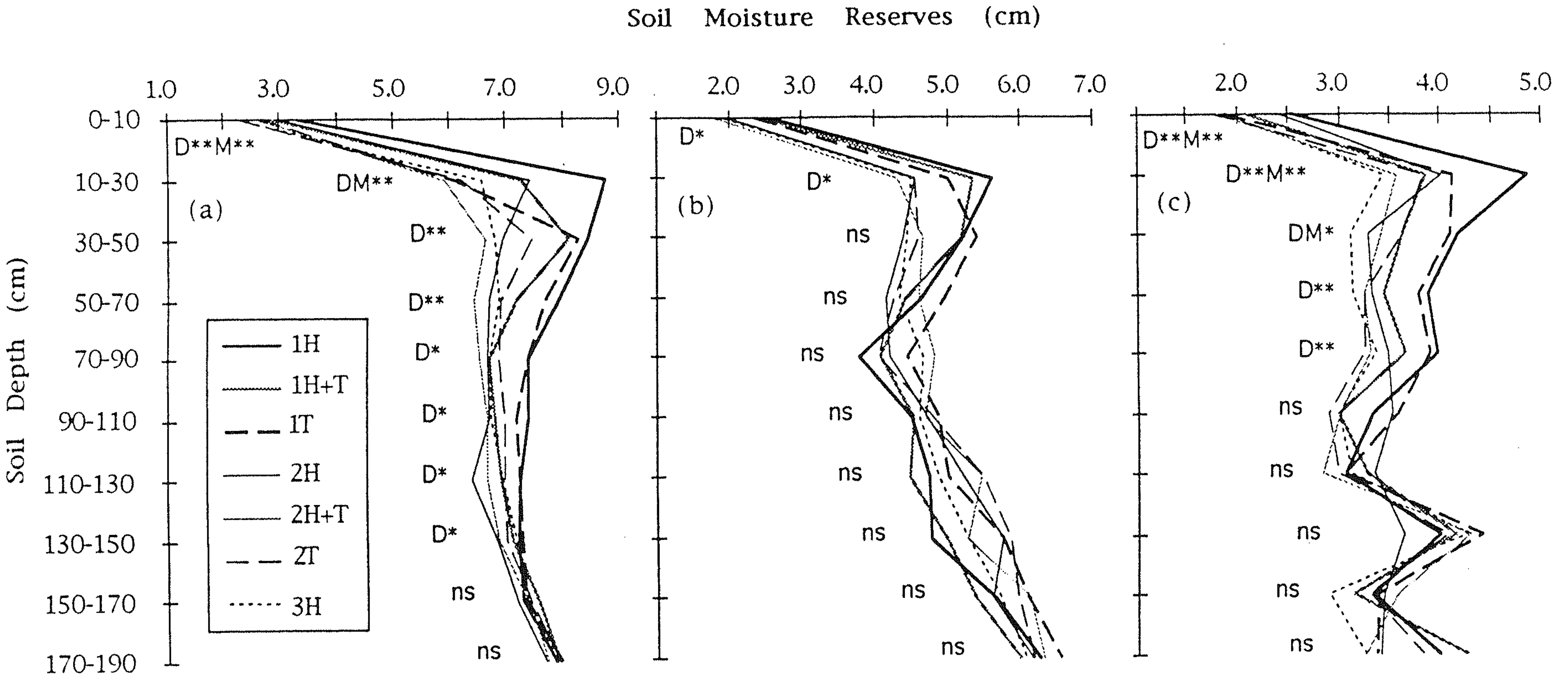

Figure 1. Soil profile moisture reserves in mid-October 1992, at Glenlea (a), Carman (b), and Holland (c), as affected by date (D), and method (M) of alfalfa removal. (*, **, significant at 0.05 and 0.01 probability levels; ns, nonsignificant).

Table 1. Spring soil water content, and grain yield and water use efficiency (WUE) of Katepwa wheat as affected by date (D), and method (M) of alfalfa removal. (*, **, significant at 0.05 and 0.01 probability levels; ns, nonsignificant).

	Alfalfa Removal		Spring Water		Grain Yield	WUE (grain)
Location	Date	Method	cm/30cm	cm/190cm	kg/ha	kg/ha/mm ET
Glenlea	1st cut	herbicide	11.60 M*	68.35 ns	1827.6 M*	4.1 D*
	1st cut	herb+till	11.20	73.09	1751.4	4.0
	1st cut	tillage	11.03	70.94	1860.5	4.4
	2nd cut	herbicide	11.51	69.37	1853.2	4.0
	2nd cut	herb+till	11.52	69.88	1667.9	3.7
	2nd cut	tillage	11.15	70.55	1834.9	4.1
	spring	herbicide	11.59	71.34	1678.6	3.6
Carman	1st cut	herbicide	9.43 ns	53.44 ns	2925.8 D*M**	8.2 ns
	1st cut	herb+till	9.06	54.50	2624.5	7.0
	1st cut	tillage	8.88	58.10	2481.2	7.2
	2nd cut	herbicide	9.24	59.89	2779.2	7.4
	2nd cut	herb+till	9.55	59.49	2782.3	7.2
	2nd cut	tillage	8.92	54.94	2534.8	6.7
	spring	herbicide	9.49	60.37	2624.5	6.7
Holland	1st cut	herbicide	8.98 M**	41.01 ns	2487.9 D**M*	6.2 D**M*
	1st cut	herb+till	8.13	44.28	2306.1	5.9
	1st cut	tillage	8.46	41.31	1940.0	5.1
	2nd cut	herbicide	9.07	42.59	2551.6	7.1
	2nd cut	herb+till	8.71	40.82	2523.0	6.2
	2nd cut	tillage	8.35	40.50	2488.2	6.4
	spring	herbicide	8.87	42.82	2394.3	6.3

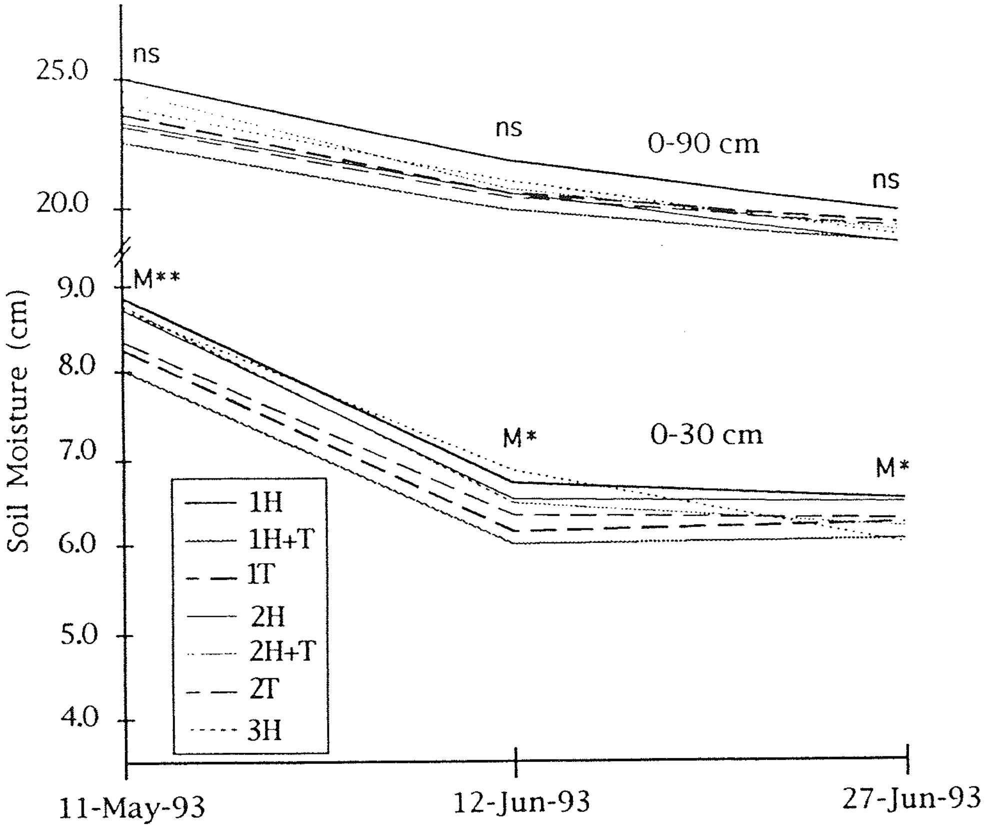

Figure 2. Soil profile moisture reserves to 30 cm and 90 cm at Holland during spring 1993, as affected by method (M) of alfalfa removal. (*, **, significant at 0.05 and 0.01 probability levels; ns, non-significant).

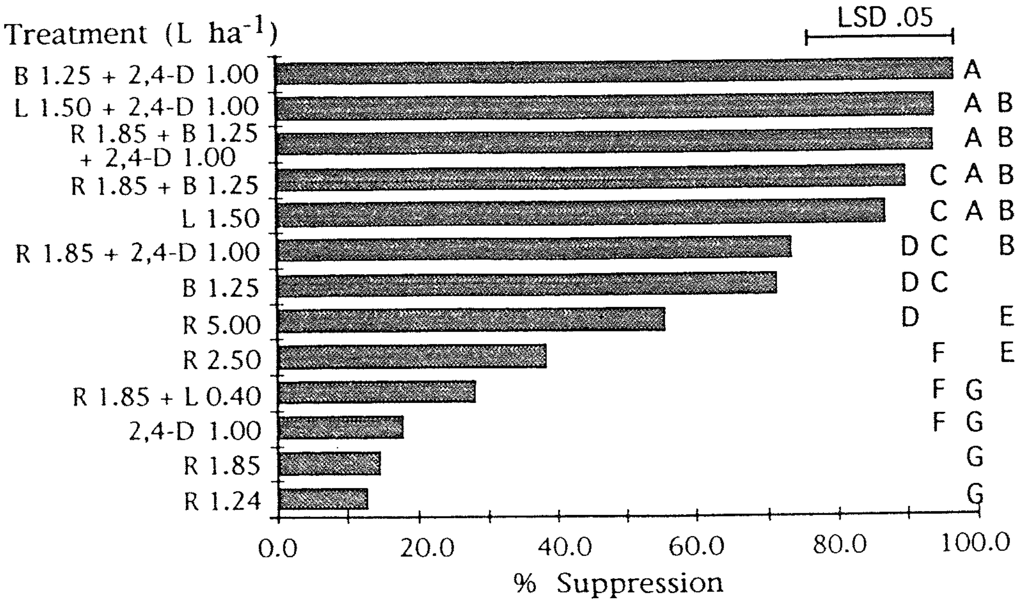

Figure 4. Fall alfalfa suppression at Glenlea MB. (sampled June 22, 1993). Means followed by the same letter are not significantly different (P < 0.05).

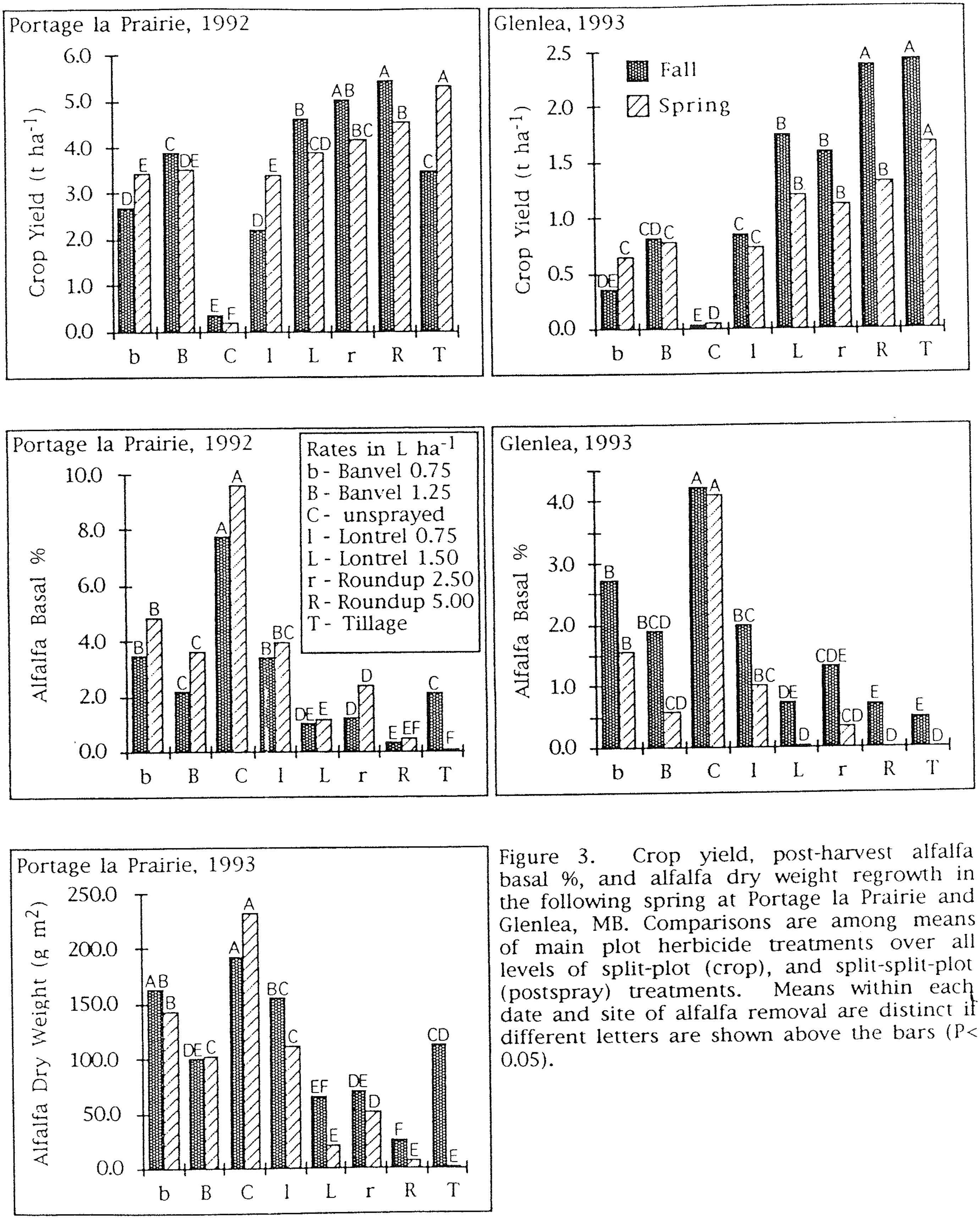

Figure 3. Crop yield, post-harvest alfalfa basal %, and alfalfa dry weight regrowth in the following spring at Portage la Prairie and Glenlea, MB. Comparisons are among means of main plot herbicide treatments over all levels of split-plot (crop), and split-split-plot (postspray) treatments. Means within each date and site of alfalfa removal are distinct if different letters are shown above the bars (P< 0.05).