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SHORT-TERM ALFALFA STANDS TO ENHANCE AGRICULTURAL AND ENVIRONMENTAL SUSTAINABILITY

Progress Report to PPI and FAR

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January 25, 1993

SUMMARY

This study was conducted to assess the benefits of short-term alfalfa stands in grain crop based rotations. Agronomic (yield, soil water, weed populations), environmental (extraction of deep-leached soil N), and economic parameters were investigated in field experiments located at Winnipeg and Portage la Prairie, MB. Wheat after one and two years of alfalfa had fewer weeds than wheat following barley. Although alfalfa consistently used more water than annual grain crops, the risk of drought was no greater for wheat following alfalfa than for wheat following other annual crops. Alfalfa consistently used more water than annual crops below 120 cm. Wheat following two years of alfalfa had a higher efficiency of water use. It was speculated that this was due to improvement in soil structure from the alfalfa (ie., "biological tillage"). Alfalfa effectively extracted deep-leached soil nitrogen, while annual crops did not. Depth of soil N extraction with alfalfa was 120 cm in the year of establishment, and 180 cm in year two, and 210 cm in year three. A 1000 acre farm-scale model was developed to compare the economics of an annual crop rotation with forage-containing crop rotations. Results indicated that it is profitable to introduce alfalfa into a wheat-pea-barley rotation. The optimal length of alfalfa stand was five years, however, shorter stands were also profitable.

INTRODUCTION AND OBJECTIVES

Including perennial forage crops such as alfalfa or alfalfa/grass mixtures in rotation with annual grain crops addresses many of the concerns of prairie agriculture. For example, forages increase soil organic matter and soil aggregation (Campbell et al. 1990), reduce energy consumption in crop production (Rice and Biederbeck 1983), reduce the N fertilizer requirement in subsequent grain crops (Bowren and Cooke 1975), extract deep-leached nitrates (Peterson and Russelle 1991), and suppress weeds (Siemens 1963; Mupondwa et al. 1992). In certain instances, short-term forage stands may provide the only effective method for dealing with herbicide resistant weeds.

In the Black soil zones of western Canada, approximately 12% of all arable land is seeded to tame forage crops at any one time. While the average stand lengths of alfalfa and alfalfa/grass mixtures in this region are six and seven years, respectively (Mupondwa et al.

1992), shorter stands lengths may also be profitable (Campbell et al. 1990). One of the most important advantages of using shorter-term stands is that more acres can be "treated" with forage crops without increasing the total forage acreage in a region. This is especially important given that the forage acreage in the eastern half of the prairies is not expected to increase very much in the near future (Mupondwa et al. 1992).

It is well known that perennial crops such as alfalfa use more water than annual grain crops (Hoyt and Leitch 1983). In wetter areas of the prairies, greater water use by alfalfa may be a positive feature, while in drier areas of the Great Plains (and in dry years in the "wetter" areas), greater water use by the forage crop often leads to water shortages in the following crops. Water management in soil systems is also important in order to prevent environmental contamination by water-soluble compounds such as nutrients, salts, and pesticides.

Efficiency of water use can be described in two ways-"WUE" and "efficient water use". While WUE is a well-defined and well recognized term, efficient water use (EWU) is not. EWU, as proposed by Pierce and Rice (1988):

$$EWU = ET/W_a \text{ X } Yield/ET,$$

where ET is growing season evapotranspiration and W_a is water available during a given period of time (eg. one year, multiple years, etc.). The first term in this equation represents the recovery efficiency (RE). The second term is the traditional measure of WUE (ie., yield per unit ET). The second term is also referred to as the physiological efficiency (PE). The concept of EWU is more comprehensive than WUE because it considers recovery of water from the soil system. Essentially, EWU is WUE modified by crop and soil management factors such as crop rotation or tillage system.

Given this background, the objectives of this study are to:

1. To evaluate the effect of one and two three year alfalfa stands on agronomic and environmental parameters.

2. Evaluate the role of alfalfa in grain crop based crop rotations on the basis of efficient water use (EWU) as defined by Pierce and Rice (1988).

3. Using a 1000 acre farm-scale model, to determine the economic optimum alfalfa stand length for farmers to use.

METHODS AND MATERIALS

The Crop Rotation Experiment. Rotation experiments were established on an Osborne clay soil at Winnipeg and on a Newdale clay-loam soil at Portage la Prairie, MB in the spring of 1990. Rotations under investigation are: 1) spring wheat (Roblin) - field pea (Victoria) - barley (Heartland), and 2) alfalfa (OAC Minto) for 1 to 8 years - wheat - pea - barley. Each annual crop plot is split into a N fertilized (to soil test recommendations) and an unfertilized subplot (all other nutrients added to both subplots). This way the N contribution of the alfalfa to subsequent crop(s) can be measured.

The alfalfa is managed intensively (2 to 3 cuts per year). Alfalfa crops are evaluated each year for yield and crude protein content. Grain crops are also evaluated each year for yield and grain protein content.

Weed populations in wheat following alfalfa vs. wheat following barley were monitored in 1991 and 1992. Square meter areas within the subplots were left unsprayed, and the emerging weeds were identified and counted at wheat tillering and heading. Weeds were removed by hand after counting.

Soil Nitrate and Soil Water Extraction. Samples for soil nitrate-N determination were taken in late October in 1990, 1991 and 1992 at the Winnipeg crop rotation trial using a Giddings soil corer. The soil was sampled at 30 cm increments to a depth of 240 cm (1990 and 1991) or 300 cm (1992). Two cores were taken from each subplot. Soil was air dried and analyzed for nitrate-N using standard methods (MB soil testing lab and Norwest Labs, Wpg.).

A 240 cm neutron access tube was installed in the centre of each plot. Soil moisture levels were determined in late fall each year of the study using a Troxler model 4330 soil moisture gauge. Volumetric surface soil moisture (0 to 10 cm) was determined gravimetrically.

The final study to be discussed here is one which considers the effect of different alfalfa cultivars on RE in the establishment year. This project is being conducted by Mr. D.M. Bonner (MSc project, Dept. of Plant Science, U of M). Field studies were conducted in 1991 and 1992 at Winnipeg to evaluate soil water extraction of Nitro, Excalibur, Wilson, Rangelander, Legend, and Alfa-graze. Crops were established in each year and no companion crop was used. Parameters under investigation include soil water extraction (to a depth of 240 cm) and crop yield.

RESULTS AND DISCUSSION

1. **Grain Yield Following Forage Crops**. Wheat yields (no added N plots) following one or two years of alfalfa were as high or higher than fertilized wheat yields following barley (Table 1). Therefore, under the conditions of this study, very short-term alfalfa stands appeared to be able to supply enough N for at least one cereal crop.

2. **Economics of Short-Term Alfalfa Stands**. The economic viability of introducing alfalfa into a cereal/legume rotation was assessed using a combination of enterprise budgets and basic present day value measures. A 405 ha (1000 acre) farm was chosen as the representative farm for this study. In the first scenario (equipment for handling forages already owned by farmer), the five year alfalfa stand (A-A-A-A-A-W-P-B) generated the greatest annuity ha^{-1} ($204.68), exceeding the annuity generated by the wheat-pea-barley rotation by approximately $88. In scenario two (forage equipment had to be purchased), the five year alfalfa stand was again found to be the most profitable rotation. Sensitivity analysis of the results of scenario one and two indicated that the ranking of the relative rotations is stable across alfalfa yields (ranging from 3.3 to 5.0 $t\ ha^{-1}$) and alfalfa prices (ranging from $55.60 to $36.50 $tonne^{-1}$).

   While the five year forage stand provided the highest returns, shorter-term (two to four year) stands were also profitable. The profitability of shorter stands would increase if alternative methods for killing the stand would be used (such as chemical control in a ZT system). Note: For further detail on economic analysis, see attachment 1.

3. **Soil Nitrogen Extraction**. Nitrate-N levels in the top 120 of soil in 1990 were significantly lower following barley and one year of alfalfa than in the non-crop area (Figure 4a). It was concluded that both crops extracted nitrate-N to 120 cm. The similarity in nitrate extraction patterns for alfalfa and barley was attributed to the very dry conditions in late-summer and fall in 1990, which severely limited alfalfa regrowth after the first cut. By the end of the second growing season, the alfalfa crop had extracted nitrate-N to a depth of 180 cm, while the cereal containing rotation (wheat following barley) only extracted N to a depth of 90 cm (Figure 4b). The distribution of soil nitrate-N and soil water in the fall of 1991 were similar for the respective treatments (data not shown), indicating that nitrate extraction was closely associated with soil water extraction. By the end of the third growing season, alfalfa had extracted N to depth of 210-240 cm (Figure 1), while the annual crop rotation still was only able to extract N to a depth of 90 cm.

4. **Soil Water Use**. In the year of establishment, alfalfa extracted significant amounts of water to a depth of 130 cm at Winnipeg and 90 cm at Portage (data not shown). In the second year of the stand, alfalfa extracted water to a depth of 160 cm (Figure 2). While the alfalfa extracted more water below 90 cm than annual crops, the amount of water in the main rooting zone of spring wheat (upper 90 cm of soil) was similar in all crop rotations by the end of the second growing season (Figure 2). By the end of the third year, alfalfa had extracted more water than annual crops in all depths between 50 and 150 cm (Figure 3). These results indicate that in years when growing season precipitation was close to the long-term average, including short-term alfalfa stands did not seriously increase the risk of drought in following wheat crops. Similar results were observed in northern Alberta by Hoyt and Leitch (1983). Results of this study would have been quite different if conditions had been drier.

5. **Impact of Including Short-Term Alfalfa Stands in Cereal-Based Rotations on RE and PE.** The current U of M crop rotation studies have not been in place long enough to properly evaluate the long-term effects of crop rotation on EWU. However, sufficient data is available to assess the impact of a two-year alfalfa stand on the RE and PE of a wheat crop.

   Efficient water use (ie., RE and PE) was determined for the 1992 wheat crop that followed either a two-year alfalfa stand or pea-barley. All of the treatments had similar ($P>0.05$) levels of soil profile water in the spring of 1992. Therefore, all wheat crops (those after alfalfa and barley) had access to similar amounts of soil water. Results at Winnipeg indicated that wheat following a two year alfalfa stand had a higher RE than wheat following pea and barley, and that N fertilization (80 kg ha^{-1}) enhanced RE even in wheat following alfalfa (Table 2). Results from the Portage la Prairie experiment indicated no effect of previous crop on RE in wheat (data not shown).

   Greater recovery of soil water by wheat in the alfalfa-containing rotation at Winnipeg indicated that something about the previous alfalfa crop allowed the wheat crop to extract more water from the soil. The fact that RE was higher in the N fertilized plots (Table 1) clearly indicates that N fertility played an important role in increasing RE. The positive effect of N on water extraction in wheat is well documented in the literature. A second contributing factor may have been improved soil structure. The introduction of macropores, especially into the very heavy clay soils at Winnipeg, may have enhanced soil exploration by wheat roots. This type of "biological tillage" has been reported previously for alfalfa by Blackwell et al. (1990).

The hypothesis of biological tillage is supported by other results from the Winnipeg rotation study. For example, wheat following alfalfa was able to extract more water, especially below 70 cm than wheat following barley (Table 3). While N fertilizer also resulted in greater soil water extraction, it had little effect below 70 cm (Table 3). These results suggest that alfalfa made a unique contribution to RE in wheat that could not be duplicated entirely by simply adding N fertilizer. The positive effect of N fertilizer on RE of wheat after a two-year alfalfa stand (Table 3) suggests that while two years of alfalfa may be sufficient to improve soil structure, it may not supply enough soil N to enable the wheat to fully exploit these soil structure benefits.

There was no effect of crop rotation on RE at the Portage la Prairie site. This may be due to the fact that the soil strength is not as great as at the Winnipeg site, and therefore, any benefits in terms of soil structure are not as important. The lower overall RE at Portage (RE=52%) compared with Winnipeg (RE=68%) was partly attributed to precipitation patterns in 1992. The Portage site received a greater proportion of precipitation after the wheat was harvested compared with the Winnipeg site. Lower RE at Portage may also reflect greater losses by deep drainage, however, this parameter was not assessed.

As expected, RE was highest for the alfalfa crop (Table 2). This reflects the longer growing season and the deeper rooting of the alfalfa crop at these sites (Entz et al. 1992).

Note: Physiological efficiency not discussed here.

6. **Role of "Annual Alfalfa" in Improving EWU of Cropping Systems**. A two year study was conducted to assess the establishment year RE of a number of different alfalfa cultivars. Cultivars included non-dormant, semi-dormant and dormant cultivars. The water extraction pattern of these cultivars is shown in Figure (4). In both years, water extraction for the different alfalfa cultivars was compared with a non-crop area (summerfallow). Results show that in both years of the study, all cultivars extracted water to a depth of 150 cm in the year of establishment (Figure 4). The two non-dormant cultivars (Nitro and Wilson) used a bit more water between 150 and 190 cm in 1992. The most dormant cultivar (Rangelander) used slightly less water than other cultivars.

The crop in these trials was cut for hay twice in the year of establishment; once in early August, and a second time in mid-October. The water extraction by depth for the first and second cut periods is given in Figure (5). In both years of the study, the pattern was similar; the maximum depth of water extraction was 110 to 130 cm during the first growth cycle, and deeper during the second growth cycle (Figure 5). One difference between 1991 and 1992 was that water extraction was not as deep 1992. This was attributed to the cool summer conditions in 1992 which likely reduced soil temperature, thereby limiting rooting depth.

Results of this study indicate that sole-seeded alfalfa can extract water to a depth of 150 to 210 cm in the year of establishment. Because this is deeper than most annual crops in short-season areas such as Manitoba (only sunflower would be expected to grow deeper roots), including even one year of alfalfa in an annual crop rotation would increase the overall RE of the system. 'Nitro' appeared to be a superior cultivar with respect to water extraction and forage yield (data not shown).

7. **Weed suppression using short-term alfalfa stands.** Field measurements at Portage la Prairie in 1992 indicated that populations of annual weeds were lower in wheat that followed two years of alfalfa than in wheat following pea-barley. Including the two year alfalfa stand in the rotation reduced the populations of wild oat, green foxtail and redroot pigweed by approximately 95%, 80%, and 64%, respectively.

CONCLUSIONS

Results of this study indicate that short-term alfalfa stands provide a number of agronomic and environmental benefits over straight grain rotations. While the economic analysis provided here must be regarded as preliminary, the results suggest that shorter alfalfa stand lengths should be used.

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Table 1. Influence of previous crop on wheat yield at Winnipeg and Portage la Prairie in 1991 and 1992. (W_{nf} - no N fertilizer; W_f - 80 kg ha^{-1} N fertilizer)

Crop Rotation	Winnipeg	Portage	Winnipeg	Portage
	1991		1992	
AA$\underline{W}_{nf}$	42.6	49.9	53.1	51.7
AA$\underline{W}_f$	44.0	44.3	59.6	45.7
PB$\underline{W}_{nf}$	36.9	36.5	52.8	40.5
PB$\underline{W}_f$	42.3	47.9	54.6	55.2
AA$\underline{W}_{nf}$ - PB$\underline{W}_f$ =	+0.3	+2.0	-1.5	-3.5

Table 2. Influence of previous crops on EWU (kg ha^{-1} mm^{-1} ET) of Katepwa wheat (W) at Winnipeg in 1992.

Crop Rotation	RE	PE	EWU
AAW_{nf}	.57	135.9	77.4
AAW_{f}	.67	131.3	87.9
PBW_{nf}	.54	138.6	74.8
PBW_{f}	.61	128.0	78.0
$AAA_{(w93)}$	.85	269.0	228.6
AAA	.86	346.2	297.7

f - 80 kg N ha^{-1}

Table 3. Influence of previous crop on soil water extraction between spring and harvest in the 10 to 130 cm soil profile for Katepwa wheat (W) at Winnipeg in 1992.

Soil Depth (cm)	AAW_{nf}	AAW_{f}	PBW_{nf}	PBW_{f}	LSD (0.05)
0 - 10	-	-	-	-	-
10 - 30	2.02	1.62	0.43	1.30	1.39
30 - 50	1.58	1.80	0.83	1.50	0.93
50 - 70	0.65	1.24	0.29	0.85	0.74
70 - 90	-0.21	0.67	0.13	0.20	0.88
90 - 110	-1.01	0.33	-0.07	-0.08	0.93
110 - 130	-1.35	0.05	-0.29	-0.28	0.91
Net Extraction	1.68	5.71	1.32	3.49	

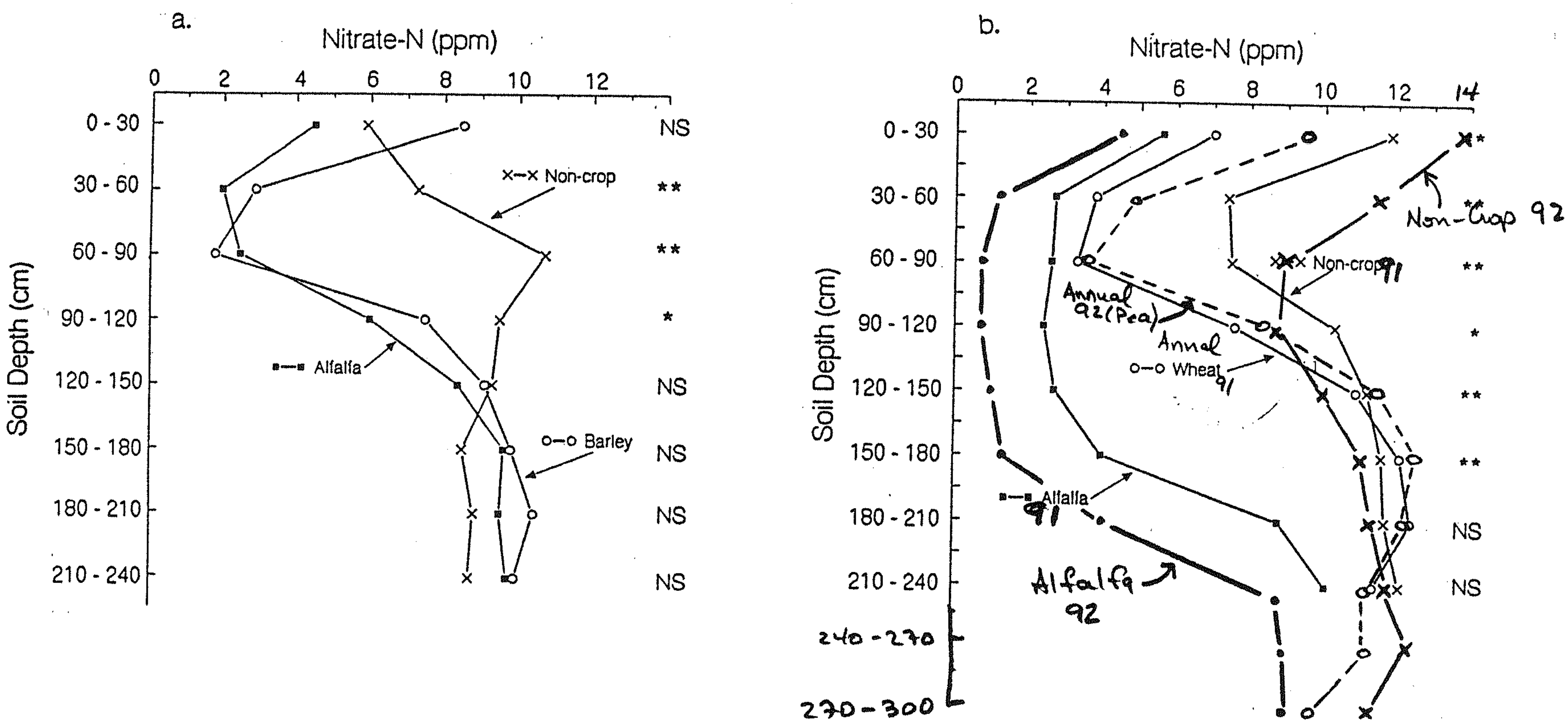


Figure 1. Influence of crop rotation on soil NO_3-N concentration (0-240 cm) in October of 1990 (a) and 1991 (b) at Winnipeg. (*, **, significant at 0.05 and 0.01 prob. levels, respectively; NS, not significant. (1992 added to 1b.).

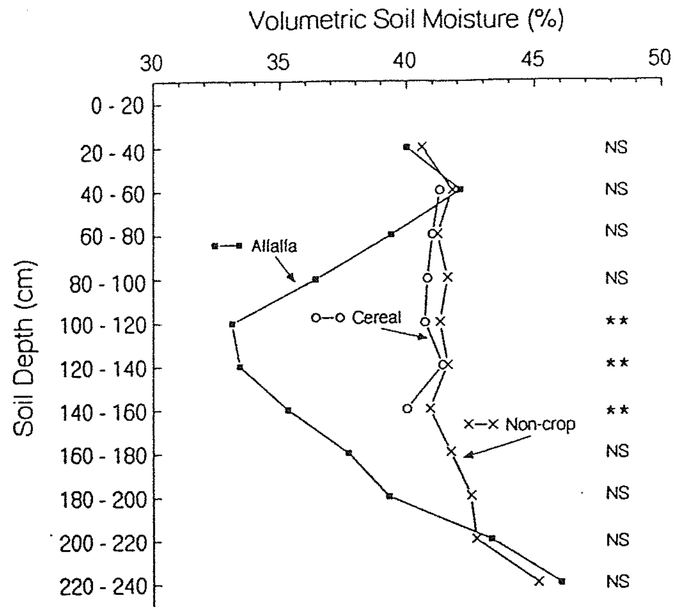


Figure 2. Influence of crop rotation on volumetric soil water content in Nov., 1991 at Winnipeg. (**, sign. at 0.01 prob.; NS, not significant).

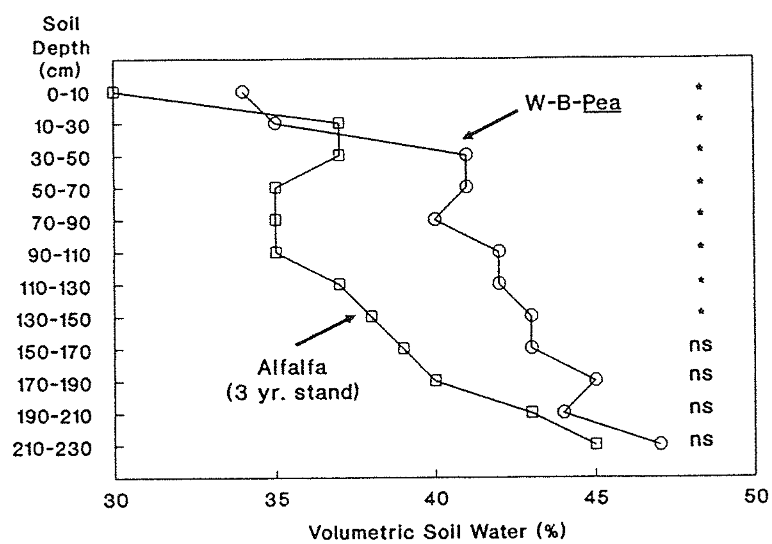
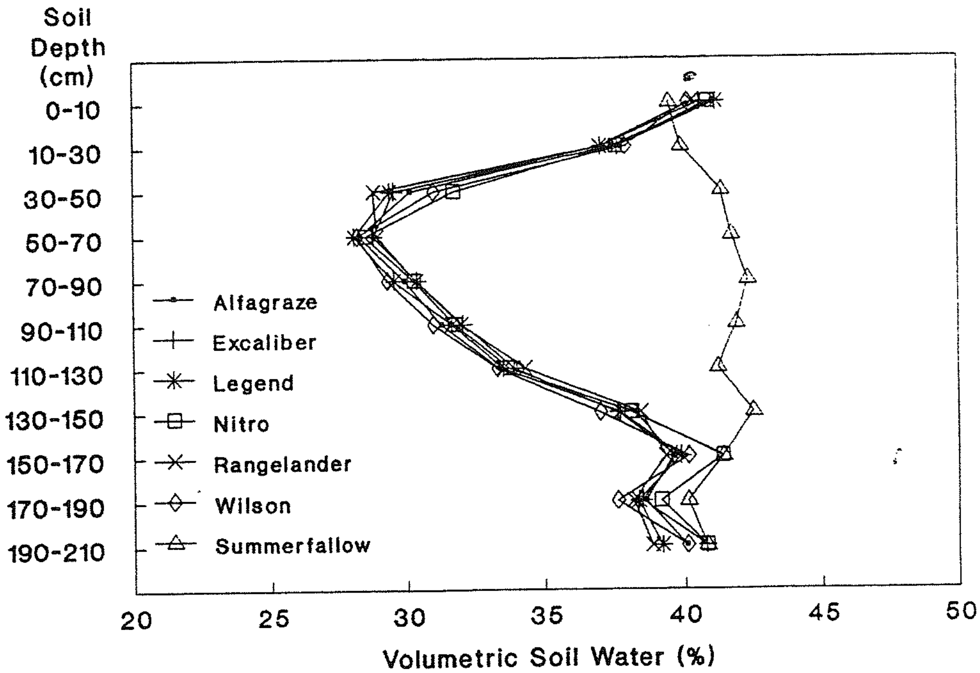


Figure 3. Influence of crop rotation on volumetric soil water content in Nov., 1992 at Winnipeg. (*, sign. at 0.05 prob., NS, not significant).



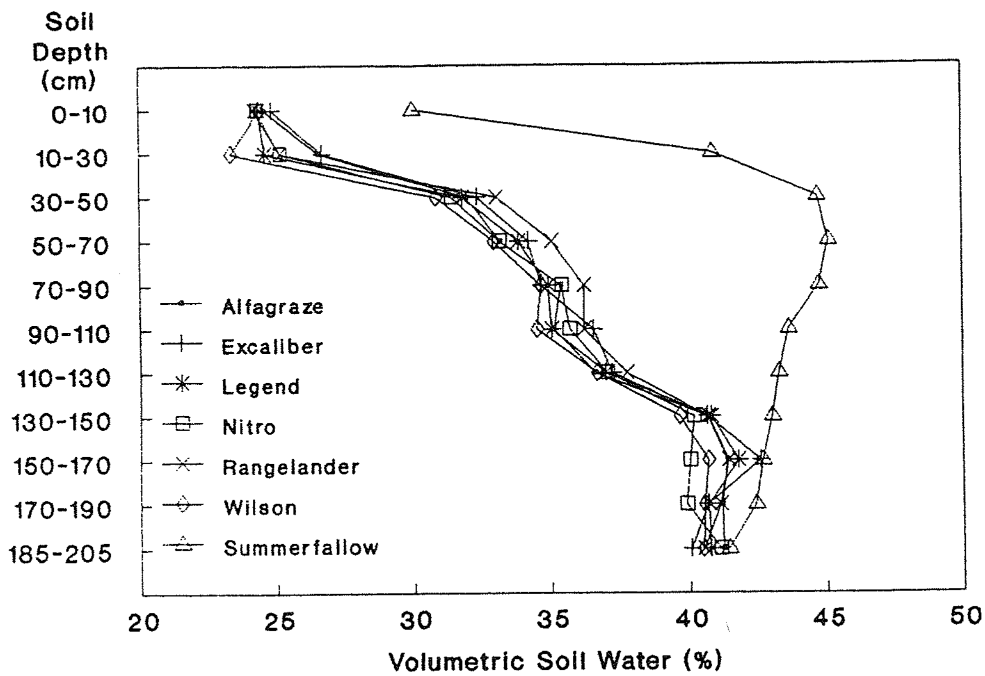
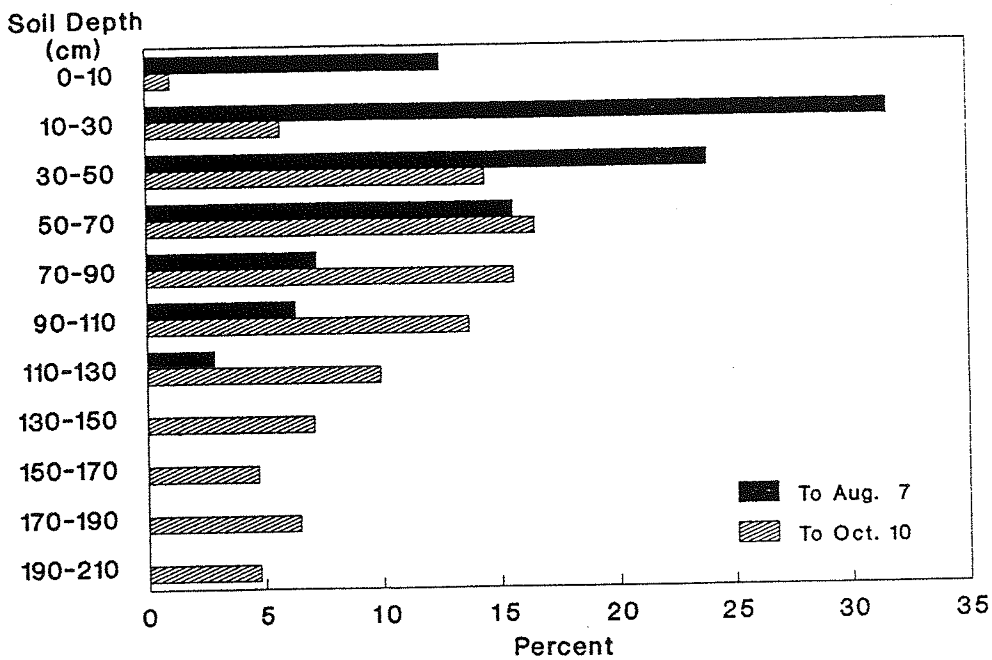


Figure 4. Volumetric soil water content in mid-October for six alfalfa cultivars in the establishment year at Winnipeg in 1991 (upper) and 1992 (lower).



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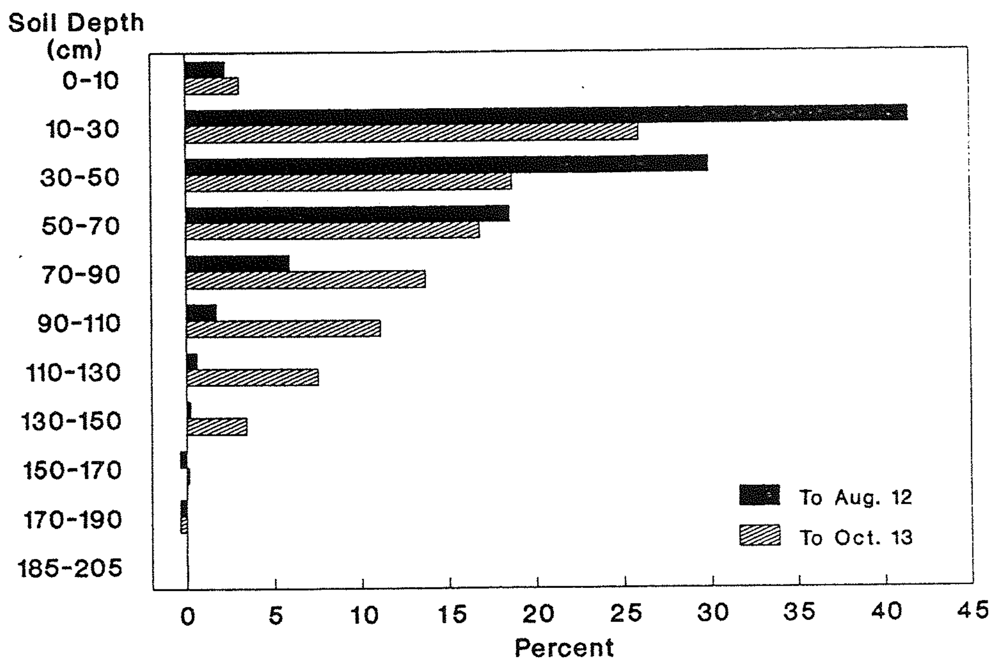

1992

Figure 5. Percent of soil water depletion (May to mid-October) by depth for six alfalfa cultivars during first and second cut growth: Winnipeg in 1991 (upper) and 1992 (lower).