INFLUENCE OF NITROGEN FERTILIZATION ON WINTER WHEAT ROOTING PATTERNS AND SOIL WATER EXTRACTION

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ABSTRACT

A partial excavation technique called the profile wall method was utilized in 1985 and 1986 to investigate effects of ammonium nitrate additions on rooting patterns of Norstar winter wheat (Triticum aestivum L.). Additional nitrogen was found to increase root growth, especially at tillering. Increases in soil water extraction were measured at the same time indicating a positive relationship between root density and soil water utilization.

Placement of the fertilizer in mid-row bands at seeding time did not change crop rooting patterns compared to spring broadcast nitrogen applications. Fall fertilization was actually less effective with respect to protein yield; broadcast applied treatments generally had higher grain yields and higher protein concentration.

Roots of winter wheat grew to an average 120 cm depth. Nitrogen fertilization did not affect final root depth. Environmental factors appeared to be important in determining root depth. Soil moisture limitations were observed at several locations in 1986.

INTRODUCTION

Modification of crop root systems by soil and management factors to increase root density and depth should be beneficial for increasing and stabilizing grain yields of dryland crops. Nitrogen fertilizer is one factor which is known to affect both root growth and utilization of soil profile water (Kmoch et al., 1957; Wilhelm et al., 1982). Bond et al. (1971) found that applied nitrogen increased vegetative growth and soil water extraction by wheat. It was also observed that in 2 of 3 years, this resulted in less water being extracted after heading. While many workers have reported increased root density and water use with added nitrogen, effects of added nitrogen on rooting depth appear much less dramatic (Kmoch et al., 1957; Wilhelm et al., 1982).

Lupton et al. (1974) suggested that the most important factors controlling rooting depth were soil and climatic conditions. Both soil temperature and soil moisture content are known to influence root growth (de Jong & Rennie, 1967). Kmoch et al. (1957) reported little root growth by wheat when soil moisture tension fell below -15 bars. Low soil moisture conditions in Saskatchewan winter wheat fields may be a factor as winter wheat crops are normally seeded into stubble.

The optimum temperature for root growth is generally less than for above ground plant parts. From available data it appears that temperature limitations in Saskatchewan winter wheat production should not be a factor in most years if a baseline temperature of 5 Celcius is assumed. Mean monthly soil temperatures at the 50 cm soil depth for May are 11.0°C at Outlook, 8.8°C at Saskatoon and 4.2°C at Wynyard (1). It appears therefore, that soil temperature limitations should be limited to cool spring conditions in northern agricultural areas of the province. Any limiation to root development which could restrict rooting depth could leave the crop susceptible to late season drought stresses.

The objective of this study was to 1) investigate the influence of nitrogen fertilization on root growth and water utilization by winter wheat in different climatic areas of Saskatchewan, 2) to compare effects of fall banded and spring broadcast nitrogen applications, 3) to investigate the relationship between rooting patterns and soil water use and 4) to investigate the relationship between rooting patterns and grain yield.

MATERIALS AND METHODS

Field experiments were established using a randomized complete block design with 3-4 replicates. A total of five locations were established over 1985 and 1986 and the sites differed in soil fertility, rotation, soil type and climate (Table 1). Two factors (rate and placement of nitrogen) were completely randomized within each block. Ammonium nitrate was applied at 0, 45 and 90 kg/ha; a 120 kg/ha rate was included at Perdue in 1985. Individual plots were 2.5 m wide and 10 to 30 m. long.

Norstar winter wheat (*Triticum aestivum* L.) was seeded between August 30 and September 8 at a rate of 75 kg/ha (90 kg/ha at Clair) using a small plot disc-press zero-tillage drill capable of mid-row banding with banding knives. Row spacing of 22.8 cm was used. Fall banded nitrogen was applied along with the seeding operation; the bands were placed 5-8 cm below the soil surface. Thirty kg/ha of P_2O_5 was applied with the seed. Spring applications of N were made between April 20 and May 1 using a dribble broadcaster.

Soil water depletion to 130 cm was measured using a neutron probe beginning in mid-May. Surface moisture (0-10 cm) was determined gravimetrically. Total water used was calculated as change in soil moisture plus growing season precipitation between May 15 and harvest.

Root investigations were conducted at tillering, heading and grain filling stages using the profile wall method (Bohm, 1979). A trench was dug in one replicate per site perpendicular to the direction of the plots. After the trench was dug, the profile wall was smoothed to obtain a vertical working face. A soil layer approximately 1.3 cm thick was removed using water under pressure. After nightfall, three 500 watt bulbs were used to illuminate the exposed roots and 35 mm slide photographs were taken. This operation was carried out after dark so as to give maximum contrast between roots and soil. The photographs were later illuminated onto a 3 x 3 cm grid and the intersections of the roots with the lines were measured for individual soil depths (0-10; 10-30; 30-50; 50-70; 70-90; 90-110; 110-130 cm). Rooting density was expressed as intersects/cm. The Perdue data was expressed as both intersects/cm and total root length (Tennant, 1976). Rooting depth was established in the field on the exposed wall.

At Watrous, where no direct root observations were made, rooting depth was established by soil moisture depletion patterns, a technique which has been previously used by Cholick et al. (1977).

Grain yield and yield component as well as seed protein were measured. Protein yield was calculated as grain yield (kg/ha) x % seed protein. Water use efficiency was calculated as kg grain/ha/cm total profile water use.

For the root density measurement, statistical analysis was done using locations as replicates. For crop water use and agronomic data, analyses were done on a per site basis. Each soil depth was analyzed individually, plus the total soil profile (0-130 cm) was analyzed as a whole. In addition, combined analysis using depth was also carried to investigate the influences of nitrogen on the relative distribution of roots and soil water extraction within the profile.

RESULTS AND DISCUSSION

Root development - While a final rooting depth of approximately 110 cm was achieved at all locations, the rates of rooting depth differed widely (Figure 1). At Perdue, the crop had reached its maximum depth much earlier in the growing season than at the other sites. From the information in Table (2), it is clear that soil temperature did not appear to be the limiting factor to rooting depth. For all locations root depth temperature was at least 8.5 celsius, with the lowest soil temperature recorded at Perdue. Low soil moisture content appeared to limit the rooting depth (Figure 2). Root growth between tillering and heading was found to be closely related to amounts of available soil moisture in the soil layer directly below the deepest roots.

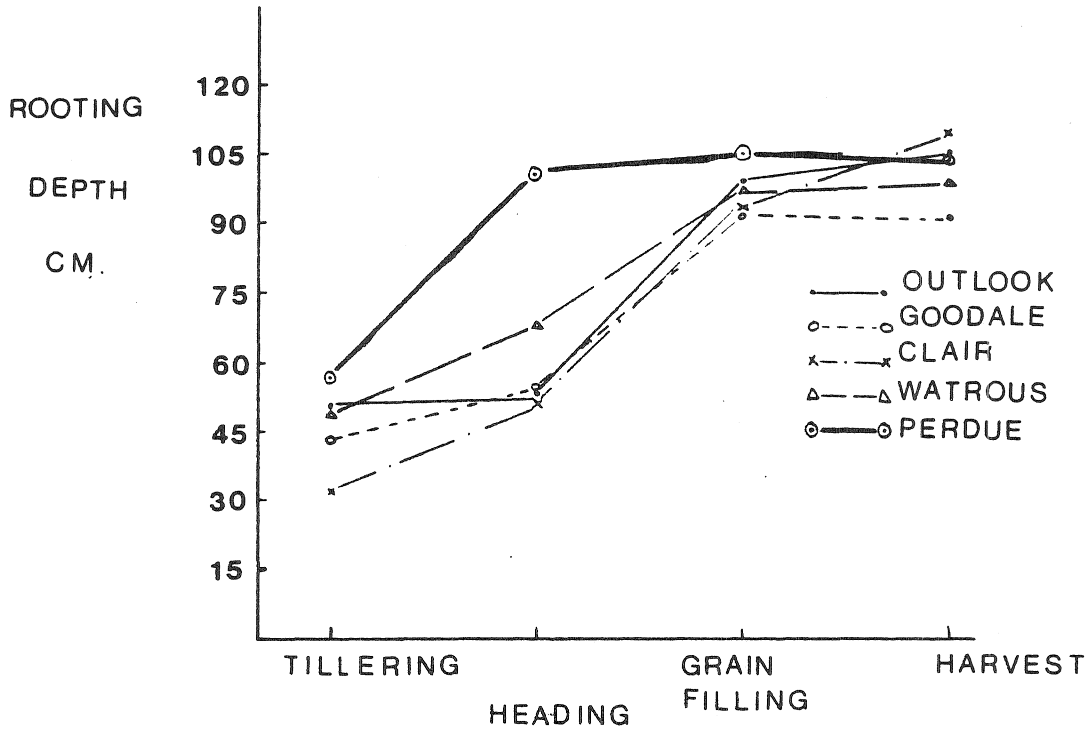
Table 1. Pertinent agronomic, soil and climatic information

Location	Soil Test NO_3-N kg/ha	Growing season precip (cm)	Previous crop	Soil association	Soil type
Outlook 1986	54	21.5	Canola	Elstow	silty loam
Goodale Farm 1986	29	21.5	Canola	Elstow	silty loam
Clair 1986	18	17.3	Barley	Yorkton	loam
Watrous 1986	51	16.2	Barley	Weyburn	clay loam
Perdue 1985	70	11.6	Chem fallow	Elstow	clay loam

Table 2. SOIL TEMPERATURES AT ROOTING DEPTH.

Zadok's growth stage	Location	Rooting Depth (cm)	Soil Temperature (C) 50 cm	Soil Temperature (C) 100 cm
31	Outlook	49	14.7	9.1
	Goodale	43	11.3	5.3
	Clair	35	11.8	6.5
end of May	Watrous	50	-	-
	Perdue	56	10.5	6.0
58-60	Outlook	52		12.6
	Goodale	56		9.3
	Clair	50		9.9
mid-June	Watrous	70		-
	Perdue	99		8.5

FIGURE 1.


ROOTING
DEPTH
CM.
120
105
90
75
60
45
30
15
TILLERING
HEADING
GRAIN FILLING
HARVEST
OUTLOOK
GOODALE
CLAIR
WATROUS
PERDUE

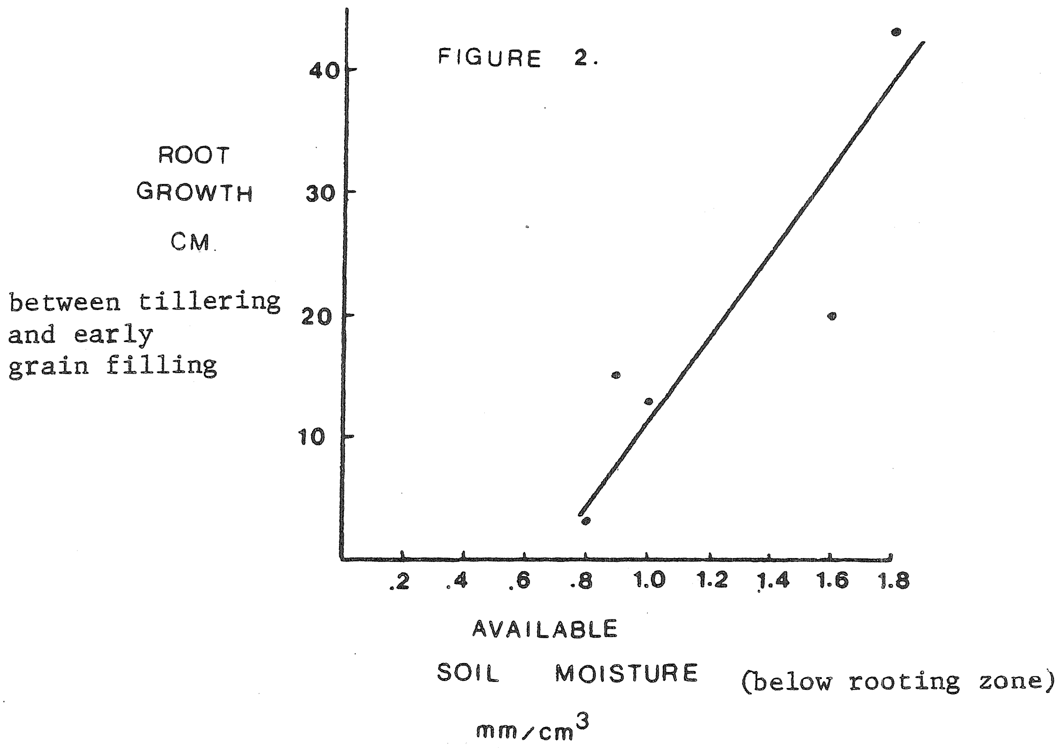


FIGURE 2.
ROOT
GROWTH
CM.
between tillering
and early
grain filling
40
30
20
10
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
AVAILABLE
SOIL MOISTURE
(below rooting zone)
mm/cm3

Measurements of root density indicated that root growth generally increased from early in the growing season to grain filling (Table 3). Maximum densities for the Outlook and Goodale Farm locations were achieved at heading with a downward shift in the rooting pattern between heading and grain filling. Similar observations in cotton have been made by Klepper and co-workers (1973). They attributed their observation to death of upper roots due to desiccation and considerable proliferation at lower depths. At Clair, maximum root density was not observed until early grain filling (Table 3). This location may have had more below ground growth later in the season as the crop here was phenologically less developed by the time moisture conditions improved in late June. As a result, it made better use of this moisture than the crops at Outlook and Goodale; the difference being reflected in a higher water use efficiency at Clair (Table 6). Only data for the July 3 sampling date at Perdue is given in Table (3). By July 3, the crop at this site had achieved its maximum root density and depth .

Combined means for all locations in 1986 indicated that the distribution of roots within the profile was significantly affected by depth (Table 4) with most roots located in the upper soil profile. By mid-June, an average of 90% of the roots were located in the top 30 cm. By early to mid-July however, roots were more evenly distributed with an average of 85% of roots located in the upper 70 cm of the 110 cm root zone.

Nitrogen effects on root development - No significant effects of nitrogen or placement were observed for any of the sampling dates, even where fairly large differences in rooting patterns were observed (Table 3 and 4). Similar results have been reported by Kmoch et al. (1957) who

Table 3. Root density of Norstar winter wheat for 1985 and 1986

Crop growth stage	Depth (cm)	Root intersects/cm: Outlook 1986	Goodale 1986	Clair 1986	Perdue 1985
Tillering	0-10	.22	.65	.46	-
	10-30	.27	.29	.09	
	30-50	.03	.11	0	
		.52	1.05	.55	
Heading	0-10	2.01	1.00	1.54	-
	10-30	1.02	.66	.87	
	30-50	.53	.21	.11	
	50-70	.01	.02	.06	
		3.57	1.89	2.58	
Grain filling	0-10	1.31	.33	1.48	.37
	10-30	.38	.39	1.13	.53
	30-50	.17	.23	.54	.49
	50-70	.17	.20	.46	.55
	70-90	.11	.02	.24	.35
	90-110	.01	.01	.01	.05
		2.15	1.18	3.86	2.34

Table 4. Root density of Norstar winter wheat for the 1986 combined sites (root intersects/cm)

Crop growth stage	Depth (cm)	Additional nitrogen (kg/ha): 0		45		90	
		†BC	‡BD	BC	BD	BC	BD
Tillering	0-10	.40	-	.37	.45	.51	.38
	10-30	.14		.20	.23	.38	.13
	30-50	.04	-	.02	.01	.20	.05
		.59		.61	.69	1.09	.57
	depth*	N*D - N.S.		P*D - N.S.			
Heading	0-10	1.37	-	1.59	1.58	1.57	1.40
	10-30	.90		.87	.75	.82	.87
	30-50	.25		.24	.15	.12	.188
	50-70	.02		.03	0	.05	.03
		2.55		2.75	2.48	2.58	2.49
	depth**	N*D - N.S.		P*D - N.S.			
Grain filling	0-10	1.04	-	1.01	.96	1.17	1.05
	10-30	.57		.76	.65	.78	.44
	30-50	.34		.40	.43	.27	.16
	50-70	.33	-	.43	.27	.23	.12
	70-90	.01		.19	.14	.10	.10
	90-110	.01		.14	.01	.01	.01
		2.31		2.95	2.49	2.57	1.90
	depth **	NxD - *		P*D - N.S.			

*,** - Statistically significant at the 5% and 1% level, respectively.
[1]*D - nitrogen by depth interaction
[2]P*D - placement by depth interaction
†BC - broadcast fertilizer application
‡BD - band fertilizer application

found that this type of work often lacks the precision to detect significant differences between treatments. Lack of significance in our case was likely due to the limited sample and replicate numbers. Also, yields in 1986 were generally low (below the 2800 kg/ha average) and crop responses to nitrogen were small.

Despite the lack of significance, it appeared that next to environmental conditions, the greatest effect on root growth was nitrogen rate. This was especially clear from the 1985 results at Perdue (Figure 3). For the combined 1986 sites, any influence of nitrogen was limited to the tillering period with little effect at later growth stages (Figure 4).

Placement of nitrogen had no apparent effect on root density. Firstly, root photographs indicated no evidence of localization of roots around the banded area. Root densities in the 0-10 cm depth were very similar for both placement methods (Table 4). These observations indicated that the fertilizer nitrogen had likely been moved away from the placement area. Such movement could be expected as significant amounts of water would have moved through this area between early September and mid-May. Also, soil temperatures by the middle of May were high enough to have allowed nitrification of any bound NH_4^+. Generally, band placement resulted in fewer roots; the most striking observation of this was at Perdue in 1985 (Figure 5).

Soil Water Extraction - Crop water use was measured at regular intervals during the growing season beginning in mid-May. The data reported

Table 5. Influence of added nitrogen on crop water use from mid-May to May 30-June 3

Location	Soil depth (cm)	Applied nitrogen kg/ha: 0		45		90		Rate effect
		[1]BC	[2]BD	BC	BC	BC	BD	
Outlook	0-10	.90	-	.90	.90	.90	.90	
	10-30	1.36		1.30	1.25	1.50	1.67	
	30-50	.73		.71	.65	.39	.43	
		2.99		2.91	2.80	2.79	3.00	N.S.
	P*D	N.S.						
	N*D	**						
Goodale Farm	0-10	1.68		1.65	1.57	1.70	1.72	
	10-30	1.34		1.12	1.19	1.28	1.42	
	30-50	.28		0	0	0	0	
		3.3		2.77	2.76	2.98	3.14	N.S.
	P*D	N.S.						
	N*D	*						
Clair	0-10	1.42	-	1.42	1.42	1.42	1.42	
	10-30	1.18		1.14	1.32	1.77	1.38	
	30-50	.42		.54	.41	.80	.39	
		3.12		3.10	3.15	3.99	3.19	N.S.
	P*D	N.S.						
	N*D	**						
Watrous	0-10	2.03		2.03	2.03	2.03	2.03	
	10-30	1.41		1.60	1.99	1.47	1.49	
	30-50	.20		.30	.93	.48	.38	
		3.64		3.93	4.95	3.98	3.90	N.S.
	P*D	N.S.						
	N*D	*						
Perdue	0-10	1.02	1.02	1.53	1.32	1.30	1.21*	
	10-30	1.34	.21	1.70	1.32	1.60	1.85	
	30-50	1.15	.74	1.19	.55	1.25	1.39	
	50-70	.46	0	.68	.30	.52	.35	*
		3.47	1.97	5.10	3.49	4.67	4.80	N.S.
	P*D	N.S.						
	N*D	N.S.						

[1]BC - broadcast fertilizer application
[2]BD - banded fertilizer application

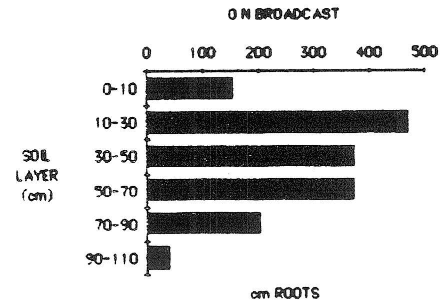
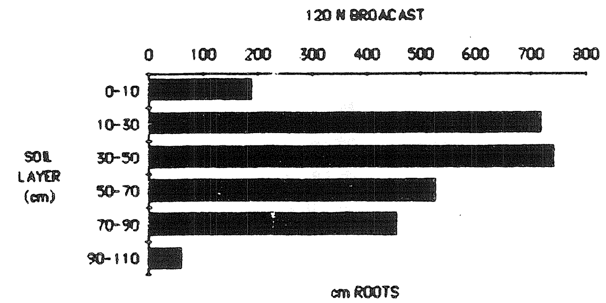
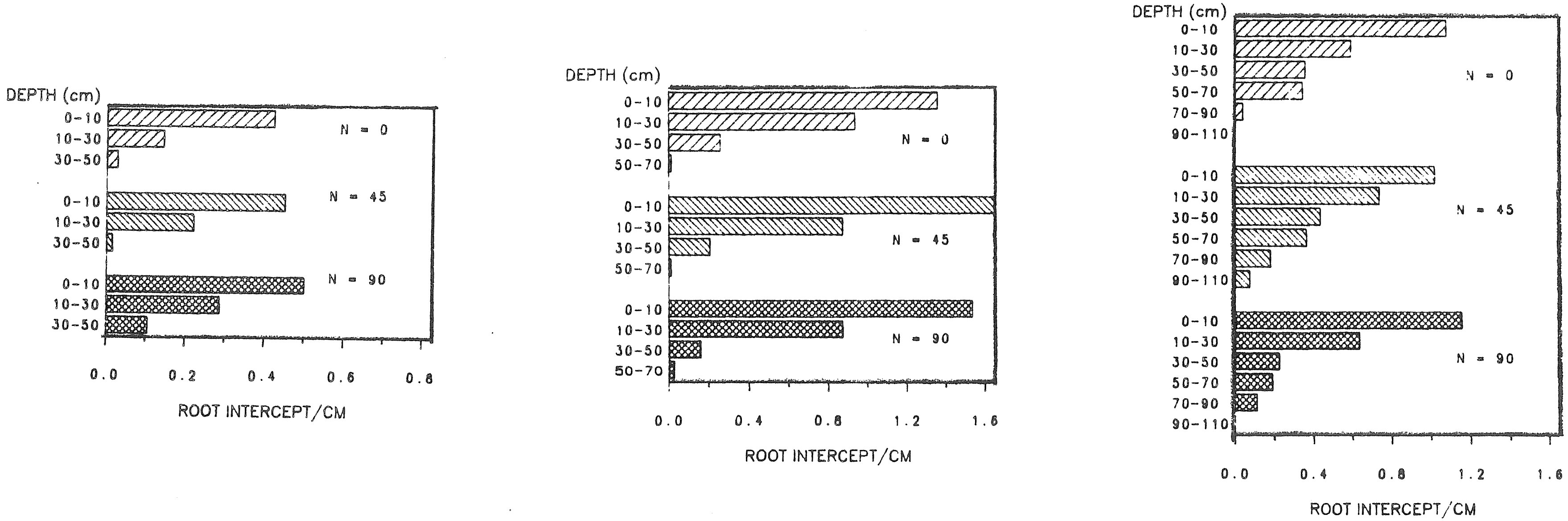


FIGURE 3. Influence of additional nitrogen on root growth of Norstar winter wheat at Perdue, SK., 1985





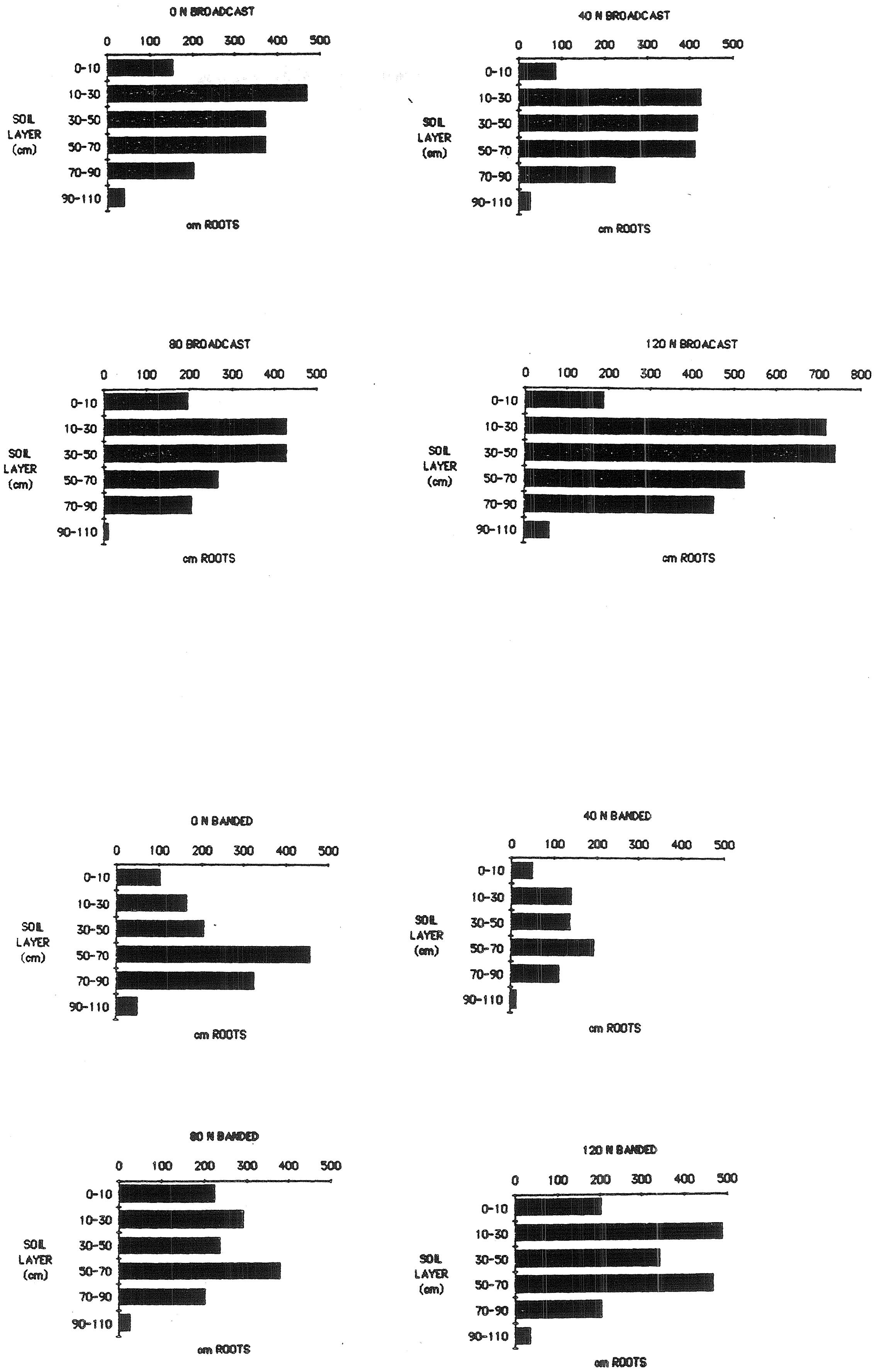
ROOT DENSITY AS A FUNCTION OF DEPTH AND NITROGEN RATE (kg/ha), AT TILLERING, 1986

ROOT DENSITY AS A FUNCTION OF DEPTH AND NITROGEN RATE (kg/ha), AT HEADING, 1986

ROOT DENSITY AS A FUNCTION OF DEPTH AND NITROGEN RATE (kg/ha), AT GRAIN FILLING, 1986

FIGURE 4 Influence of additional nitrogen on root growth of Norstar winter wheat

Figure 5. Influence of nitrogen fertilization and placement on root growth



here will begin with water use for the early part of the growing season; between mid-May and May 30-June 3 (Table 5). The interaction between placement and depth (P*D) and nitrogen rate and depth (N*D) are given. The influence of rate alone was found to be significant at Perdue only. Nitrogen by depth interactions were significant at all other locations, and in all of these cases represented increased water use at lower depths when nitrogen was added. Placement by depth interactions were never significant indicating that placement of the nitrogen did not influence the location within the profile from which water was extracted.

Water use between mid-May, anthesis and harvest are shown in Table (6). Only at Perdue was total growing season water use affected (P = .0529). No significant effects were observed for total profile water for any other locations or at any other dates. At Outlook and Goodale, total water use was less where nitrogen was applied; an observation indicating drought stress (Olson et al., 1964).

Highlights of the analyses indicate that most significant effects occurred between mid-May and anthesis (Table 7). Few effects were observed between anthesis and harvest. Briefly, the effects at the individual locations were as follows: At Outlook, additions of nitrogen increased early season water use (significant for the 10-30 cm depth). A similar effect was found at Goodale, plus more water was used at depth by banded treatments. At Clair, additional nitrogen increased early season water use ($p<.05$ for the 10-30 cm depth) and resulted in more water used at depth. Addition nitrogen resulted in the same early season effect at Watrous. The N*P interaction for Watrous showed an inconclusive trend. At Perdue the major point of interest was the higher amount of water used between anthesis and harvest for broadcast treatments (Table 6).

Table 6. Influence of added nitrogen on crop water use and water use efficiency

Location	Nitrogen rate kg/ha	cm water use May 15 to anthesis [1]BC	[2]BD	cm water use anthesis to harvest BC	BD	cm water use May 15 to harvest BC	BD	Water use efficiency kg/ha gain/cm water BC	BD
Outlook	0	12.75	-	10.36	-	23.11	-	70.2	-
	45	12.18	12.63	10.22	11.21	22.40	23.84	65.5	51.9
	90	12.24	12.46	9.30	9.97	21.54	22.43	85.0	97.1
Goodale Farm	0	16.44	-	8.11	-	22.60	-	60.5	-
	45	14.74	16.75	7.55	9.59	20.33	24.39	69.0	61.4
	90	16.12	16.48	6.82	7.85	20.99	22.37	68.0	68.1
Clair	0	10.68	-	9.58	-	20.26	-	100.2	-
	45	9.68	10.33	10.68	9.97	20.36	20.31	110.8	102.1
	90	11.53	9.76	9.20	10.27	20.73	20.04	114.9	101.2
Watrous	0	10.41	-	6.61	-	17.01	-	61.6	-
	45	12.95	11.49	5.48	5.36	18.43	16.84	76.9	68.0
	90	12.12	12.77	6.31	6.28	18.43	19.05	94.8	61.6
Perdue	0	5.36	4.49	20.77	21.11	26.13	25.61	127.2	140.9
	45	6.68	5.70	20.31	19.50	27.00	25.28	167.2	168.9
	90	6.68	6.40	20.05	20.05	26.74	26.46	158.0	156.5
						p= (.0526)			

[1]BC - broadcast fertilizer application.
[2]BD - band fertilizer application.

Table 7. Highlights of the analyses of variance for crop water use by depth

Location	Interaction	mid-May to anthesis	Anthesis to harvest	mid-May to harvest
Outlook	N*Depth	*	NS	*
	P*Depth	NS	NS	NS
	N*P	NS	NS	NS
Goodale Farm	N*Depth	**	NS	**
	P*Depth	NS	NS	NS
	N*P	NS	NS	**
Clair	N*Depth	**	NS	**
	P*Depth	NS	NS	NS
	N*P	NS	NS	NS
Watrous	N*Depth	*	NS	**
	P*Depth	NS	NS	NS
	N*P	NS	NS	**
Perdue	N*Depth	NS	NS	NS
	P*Depth	NS	*	NS
	N*P	NS	NS	NS

*,**Statistically significant at the 5 and 1% level, respectively.

In summary, fertilizer effects on crop water use patterns were confined mainly to the period before anthesis and to the upper 50 cm of the soil profile. Nitrogen effects in the latter half of the growing season were confined to the lower regions of the soil profile where additional fertilizer resulted in slightly more water being used.

Grain yield, protein and protein yield - Yields of grain generally increased with additional nitrogen rates however the response was significant for the Perdue site only (Table 8). No significant effects of placement were measured. Poor responses in 1986 were likely due to the very high moisture stress measured during the critical tillering to anthesis growth stages of that year (Gross et al., 1987). There were however significant effects of nitrogen on protein concentration (Table 9) and protein yield (Table 10). As protein yield is a combination of grain yield and percent protein, it will be used here to compare nitrogen effects. Since grain yield and protein concentration were generally lower for banded treatments, it stands to reason that protein yield should be less as well. Over all 5 sites protein yields were an average of 13.8% lower for banded treatments (Table 11). Therefore, band placement in early September was not as efficient as broadcast at the end of April. It should be noted that fall banding in winter wheat production is done at seeding (early September). Losses or at least reduced efficiency of the additional nitrogen could be expected. The 13.8% lower response to added nitrogen when banded, support the provincial guidelines which state 10% less efficiency with fall banding compared with spring broadcast applications (2).

Table 8. Influence of Additional Nitrogen on Grain Yield of Norstar Winter Wheat

Location	Nitrogen rate kg/ha	Grain Yield kg/ha — Placement method: BC	Grain Yield kg/ha — Placement method: BD
Outlook	mean	1641	1680
Goodale Farm	mean	1400	1464
Clair	mean	2223	2045
Watrous	mean	1405	1123
Perdue	0	3324	3609
	45	4528	4271
	90	4227	4143
		*	*

BC - broadcast fertilizer application
BD - banded fertilizer application

*,** - statistically significant at the 5% and 1% level, respectively.

Table 9. Influence of Additional Nitrogen on Seed Protein Concentration

Location	Nitrogen rate kg/ha	Percent Protein — Placement method: BC	Percent Protein — Placement method: BD
Outlook	0	12.0	12.0
	45	14.0	13.1
	90	14.4	13.2
		*	*
Goodale Farm	0	10.5	10.5
	45	12.5	12.3
	90	13.5	12.9
		*	*
Clair	0	10.7	11.8
	45	13.0	12.9
	90	13.7	13.2
		*	*
Watrous	0	10.8	11.1
	45	12.9	13.7
	90	14.1	13.6
		*	*
Perdue	0	10.1	10.2
	45	11.4	10.9
	90	12.2	11.8
		*	*

BC - broadcast fertilizer application
BD - banded fertilizer application

*,** - statistically significant at the 5% and 1% level respectively

Table 10. Influence of Additional Nitrogen on Protein Yield

Location	Nitrogen rate kg/ha	Protein Yield kg/ha Placement method BC	BD
Outlook	0	195.2	194.8
	45	209.5	162.0
	90	261.1	287.2
		NS	NS
Goodale Farm	0	148.5	152.5
	45	181.2	198.1
	90	211.2	207.0
		NS	NS
Clair	0	216.8	242.0
	45	264.3	244.9
	90	269.1	268.1
		*	*
Watrous	0	111.6	111.6
	45	178.2	141.7
	90	235.4	150.7
		*	*
Perdue	0	335.7	368.1
	45	516.1	465.5
	90	515.6	488.8
		*	*

Protein Yield = Grain Yield * Percent Protein
BC - broadcast fertilizer application
BD - banded fertilizer application
*,** - statistically significant at the 5% and 1% level, resectively.
NS - non-significant

Table 11. Comparison between Fall Broadcast and Spring Banded Treatments

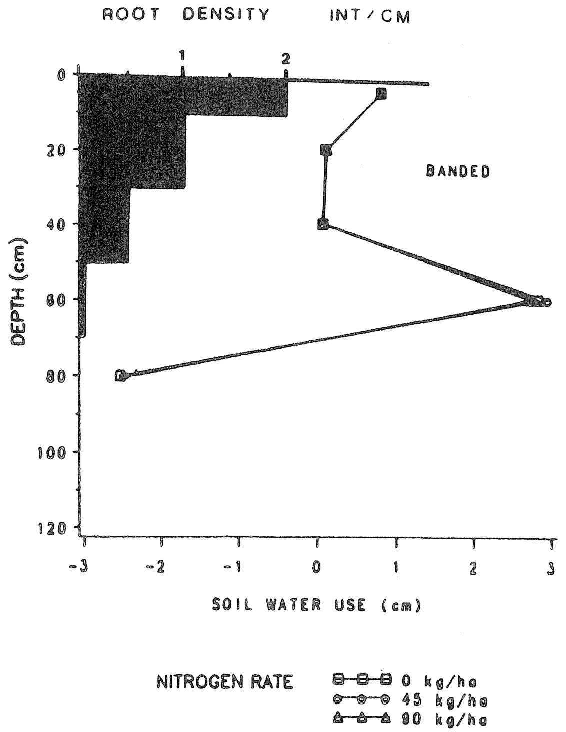
Location	Nitrogen rate kg/ha	Increase in protein yield: broadcast over banded placement (%)
Outlook	0	
	45	29.3
	90	9.0
Goodale Farm	0	
	45	-8.5
	90	2.0
Clair	0	
	45	7.9
	90	0.0
Watrous	0	
	45	25.7
	90	56.2
Perdue	0	
	45	10.8
	90	5.4
	Overall Mean	13.8 %

SUMMARY

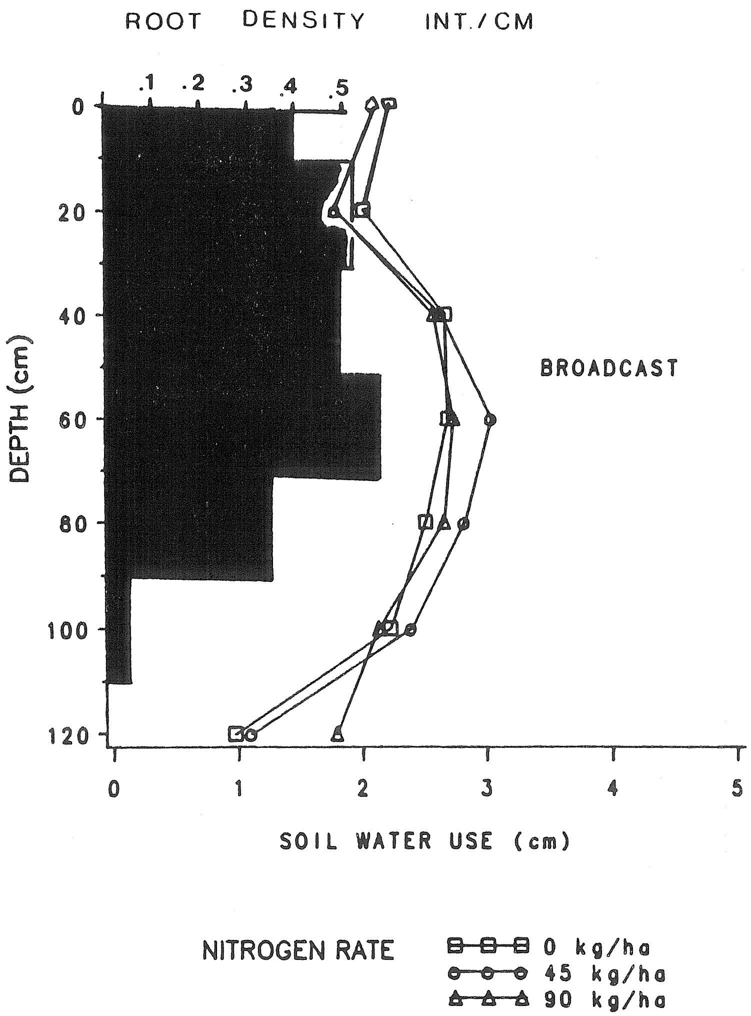
Relationship between roots and soil water extraction - A relationship between rooting depth and depth of soil water extraction can be observed from the data shown in Figure (6). For both the June 16 and harvest dates, the zone of soil water extraction coincided with the bottom of the rooting zone.

With respect to the relationship between root density and soil water extraction, we know that additions of nitrogen increased the rate of root growth (Figure 3) and soil water depletion (Table 5). Thereby, we can infer that the increased soil water use was caused by the presence of more roots feeding in the soil profile. While this inference is likely quite realistic, another factor which could have influenced the rate of soil water depletion was the amount of above ground growth. Although it has not been discussed here, it is known that additional top growth increases the "sink" for soil water causing a larger transpiration stream. Whatever the reason, it is clear that the relationship between root density and soil water use is real. It could be suggested that this relation would hold until soil water reserves become depleted; a common phenomena in dryland agriculture.

Relationship between roots and grain yield - Since no direct comparisons between these two plant parts were made, a direct relationship is difficult to establish. However, it was observed that grain yield generally increased with increased root density. This is especially true when comparing the root densities and grain yield at Goodale and Clair. Higher grains yields at Clair coincided with higher root densities. Rooting depth at heading may also have been a factor. Perdue had a much deeper root system at the heading stage and also produced a much higher



SOIL WATER USE BETWEEN MAY 13 AND JUNE 16
OUTLOOK, SASKATCHEWAN, 1986



SOIL WATER USE BETWEEN MAY 17 AND AUGUST 15
PERDUE, SASKATCHEWAN, 1985

FIGURE 6. Relationship between soil water use zone and rooting zone.

grain yield compared to the other sites.

The role of nitrogen - Additional nitrogen clearly affected the below ground plant parts by increasing the vegetative growth of roots. Higher levels of root density in the soil resulted in more water being extracted especially during the first half of the growing season. The effect of increasing soil water extraction between tillering and anthesis appears to be a positive one as this period is most sensitive to water deficits. This may be why grain yields have been shown to be relatively stable, even where nitrogen fertilization has resulted in less available water in the latter half of the growing season (Viets, 1962). Another reason for this could be that additional nitrogen can result in better exploration of deep water reserves. Under conditions of high moisture, the ability of fertilized crops to utilize more of the available water (Olson et al., 1964) becomes an important factor to achieving higher yields. The relationship of nitrogen response and different moisture environments for winter wheat in Saskatchewan has been shown by Fowler et al. (1987).

Environmental effects - Roots clearly require an environment favourable for their growth if they are to achieve maximum depth and maximum density. It appears that soil moisture (and possibly soil temperature) is the most important factors determining root growth of winter wheat (and probably all other crops) in Saskatchewan. Crop root systems appear as susceptible to stress conditions as above ground plant parts.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge financial support from the Canada-Saskatchewan Economic Regional Development Agreement.

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