1976

SOIL PLANT NUTRIENT RESEARCH REPORT

compiled by

T.J. Hogg and J.L. Henry

Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan

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ACKNOWLEDGEMENTS

This report summarizes the field research investigations on soil fertility carried out during the 1976 season by the staff of the Department of Soil Science, University of Saskatchewan, Saskatoon. These investigations were supported by research funds provided from the following sources: The Saskatchewan Department of Agriculture, Canada Department of Agriculture, Western Co-operative Fertilizers Limited, Imperial Oil and Isihara Sangyo Kaisha Ltd.

In soil fertility research, it is vital to conduct experiments under a wide variety of soil and climatic conditions. Almost all of the investigations were carried out on individual farms throughout the province. Without the generous cooperation of the many farmers involved, it would be impossible to conduct research of this type. A sincere thank you is extended to all farmers who put up with considerable inconveniences to accommodate these experiments.

All field operations associated with the placement of field plots including seeding, irrigation, routine maintenance and harvest were carried out by summer assistants including Sharon Brown, Bill Chapman, George Delparte and Judy Kneeshaw. As well, Paul Kneeshaw and Mervin Manthey assisted during seeding.

Nitrogen and phosphorus content of plant material were performed by the Crop Development Centre and Dorothy Czarnota of the Department of Soil Science. The Saskatchewan Soil Testing Laboratory performed all routine soil analyses.

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INTRODUCTION

Recent research has shown that phosphate placed in a band below and to the side of the seed can lead to substantial yield increases for crops like flax, rapeseed and peas. There is a need to test these results under a wider range of soil and climatic conditions and for a wider range of crops.

The purpose of this study was to determine the effect of phosphate placement on the growth of fababeans, peas, field beans, lentils, flax and rapeseed under irrigated and dryland conditions.

This was a joint project between the Crop Development Center and the Department of Soil Science, University of Saskatchewan.

EXPERIMENTAL METHODS

The site selected for the experiment was on an Elstow loam soil in the South Saskatchewan Irrigation Project. This site had been planted to wheat in 1975. The plot was duplicated to provide a dryland and an irrigated treatment.

Soil analyses from samples taken at seeding time indicated low to medium levels of phosphorus according to current soil test benchmarks (Table 1.1.1) Nitrogen levels (0-60 cm) were in the low to medium range.

The cultivars used were: fababeans - Erfordia; peas - Trapper; beans - Aurora; lentils - P.I. 179307; flax - Redwood

Table 1.1.1 Spring soil analyses for P placement experiment on Elstow loam (Pederson site).

Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
			kg/ha*			
Irrigated peas and fababeans						
0-15	7.4	0.3	8	12	640	24
15-30	7.6	0.3	5	7	270	23
30-60	8.0	0.6	14	10	590	48
60-90	8.0	2.1	20	14	800	48
Irrigated lentils and beans						
0-15	7.5	0.4	10	18	650	24
15-30	7.9	0.4	8	10	250	24
30-60	8.0	0.8	20	14	500	48
60-90	8.0	2.6	38	18	680	48
Irrigated rapeseed and flax						
0-15	7.7	0.4	11	16	500	24
15-30	7.9	0.3	10	8	230	16
30-60	8.2	0.6	18	12	480	48
60-90	8.3	1.2	20	12	600	48
Dry peas and fababeans						
0-15	7.5	0.4	10	17	560	24
15-30	7.7	0.4	9	10	250	24
30-60	8.1	0.6	12	12	540	48
60-90	8.3	1.4	18	12	640	48
Dry lentils and beans						
0-15	7.4	0.4	13	16	605	19
15-30	7.7	0.4	13	9	260	22
30-60	8.0	0.4	20	10	520	48
60-90	8.3	0.9	20	10	630	48
Dry rapeseed and flax						
0-15	7.5	0.4	15	13	620	24
15-30	7.7	0.3	13	7	250	24
30-60	8.1	0.4	26	8	580	36
60-90	8.1	1.4	42	8	700	48

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

65; rapeseed - Tower.

The plots were rototilled prior to seeding with a double-disc press drill with seven rows per plot and an 18 cm row spacing. The double-disc drill allowed for fertilizer placement with the seed or as a side-band application. For the side-band application the fertilizer was applied 2.54 cm to the side and 2.54 cm below the seed. Plot length was 4.6 meters.

The fertilizer treatments used are presented in Table 1.1.2. The phosphorus source utilized was monoammonium phosphate (11-55-0) for all treatments. No additional nitrogen was utilized for legume crops, but for flax and rapeseed an additional application of nitrogen of 112 kg N/ha was utilized for all treatments except Treatment 7. This nitrogen was applied as surface broadcast ammonium nitrate (34-0-0) at seeding time.

Trifluralin (Treflan) at 1.12 kg/ha in 110 l/ha of water was spring applied and incorporated preplant by rototilling for all crops except field beans and lentils. Post-emergent herbicides included Tok/RM (1.34 kg active/ha) for rapeseed and Buctril-M (0.56 kg active/ha) for flax.

Severe infestations of flea beetles on the rapeseed necessitated four sprayings with malathion.

At approximately three to four weeks after seeding stand counts were taken by counting the number of plants in the centre three rows of each individual plot over a distance of 2 meters.

Table 1.1.2 Treatments used in phosphate placement experiment:

A. For beans, fababeans, peas, lentils

Treatment number	P_2O_5 Applied (kg/ha)	Placement
1	0	--
2	17	with seed
3	34	with seed
4	50	with seed
5	67	with seed
6	101	with seed
7	0	--
8	17	side-band
9	34	side-band
10	50	side-band
11	67	side-band
12	101	side-band

B. For flax and rapeseed

Treatment number	N applied (kg/ha)	P_2O_5 applied (kg/ha)	Placement of P
1	112	0	--
2	112	17	with seed
3	112	34	with seed
4	112	50	with seed
5	112	67	with seed
6	112	101	with seed
7	0	0	--
8	112	17	side-band
9	112	34	side-band
10	112	50	side-band
11	112	67	side-band
12	112	101	side-band

Irrigation of the plot designated for this purpose was conducted using a specially designed sprinkler system for small plot work. The actual scheduling of irrigation was determined by tensiometers. Shallow tensiometers were installed at the 10 to 15 cm depth initially and then moved down to the 15 to 23 cm depth in late June. Deeper tensiometers were installed initially at the 25 to 30 cm depth and moved down to the 40 to 45 cm depth in late June. The shallow tensiometers were installed in fertility treatments 3 and 10 in all four replicates of each crop. The deeper tensiometers were installed in fertility treatment 10 in all four replicates of each crop.

The tensiometers were utilized to determine both the timing of irrigation and the amount to apply. Irrigation water was applied when the shallow tensiometers indicated a soil moisture tension of 0.5 atm. The amount of water to apply was determined by the readings obtained by the deep tensiometers as indicated in Table 1.1.3. The timing and amounts of irrigation water applied are presented in Table 1.1.4.

Table 1.1.3 Depth of water required to replenish soil moisture in the irrigated plot.

Deep tensiometer reading (atm)	Amount of water to apply (mm)
0.3	64
0.3 - 0.7	89
greater than 0.7	114

Table 1.1.4 Amounts and timing of irrigation applications for the phosphorus placement experiment.

Crop	Growing* season rainfall (mm)	Dates and amounts of irrigation applications	Total water (rainfall + irrigation) (mm)
Fababeans	172	May 15, 25 mm; June 26, 75 mm; July 9, 86 mm; July 30, 35 mm; Aug. 9, 89 mm.	482
Peas	172	May 15, 25 mm; June 26, 107 mm; July 9, 58 mm; July 30, 97 mm.	459
Beans	183	May 15, 25 mm; June 26, 58 mm; July 9, 51 mm; July 30, 34 mm; Aug. 10, 152 mm.	503
Lentils	166	May 15, 25 mm; June 26, 78 mm; July 9, 56 mm; July 23, 100 mm.	425
Flax	172	May 15, 25 mm; June 26, 56 mm; July 9, 66 mm; July 22, 48 mm; July 30, 30 mm; Aug. 9, 89 mm.	486
Rapeseed	166	May 15, 25 mm; June 26, 92 mm; July 9, 53 mm; July 20, 63 mm; July 30, 90 mm; Aug. 10, 152 mm.	641

*Growing season rainfall different for the various irrigated crops since the crops were harvested on different dates. Growing season rainfall for the dryland crops was 166 mm.

Neutron access tubes were installed to a depth of 120 cm in fertility treatment 10 of all replicates in all crops of the irrigated plot. Moisture monitoring was then conducted with the neutron probe at 15 cm intervals except for the 0-15 cm depth which was done gravimetrically. Moisture measurements were made at the time of installation at seeding time, at two week intervals until harvest and again at harvest time. At harvest time the moisture was also monitored with the neutron probe in fertility treatment 10 of all replicates in all crops of the dryland plot.

At harvest, yield samples were taken, for all crops except peas, from all treatments by hand cutting at the soil surface the three center rows of the seven-row plot over a length of 3 meters. The samples were then dried, weighed and threshed. The peas were harvested using a small plot Hege combine and the straw material was collected, dried and weighed. All grain samples were cleaned and weighed. Subsamples of both grain (replicates kept separate) and straw (replicates bulked except for peas) were ground in preparation for N and P analyses. Analyses were performed for nitrogen and phosphorus contents of the grain using a NeoTech Infrared Grain Quality Analyzer. Straw nitrogen and phosphorus contents were determined by wet digestion and colorimetric analyses using a Technicon AutoAnalyzer II System. In the case of flax and rapeseed the oil content of the seed was also determined.

After harvest soil samples were taken from each replicate of each crop to a depth of 60 cm by bulking two cores from Treatments 2, 3 and 4. The soil cores were taken midway between the crop rows to avoid the phosphorus that was placed with the seed at seeding time.

RESULTS AND DISCUSSION

The information obtained on stand counts is presented in Figure 1.1.1. The irrigated and dryland plots were averaged as the two moisture treatments had been handled identically up to the time that stand counts were taken.

For fababeans there was no effect of phosphorus by either placement method.

For peas, beans and lentils the side-band phosphate treatment resulted in little change in the crop stand. However, in all cases seed-placed phosphate reduced the stand, particularly at the higher rates.

For flax and rapeseed side-banded phosphorus had little or no effect on the stand, whereas seed placed phosphorus reduced the stand drastically.

Data on the effect of phosphate fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of the six crops and oil content of flax and rapeseed are presented in Tables 1.1.5 to 1.1.16. Grain and straw yields are also presented graphically in Figures 1.1.2 and 1.1.3, respectively.

Under dryland conditions, grain yields (Figure 1.1.2) for fababeans, beans, lentils and flax showed no significant

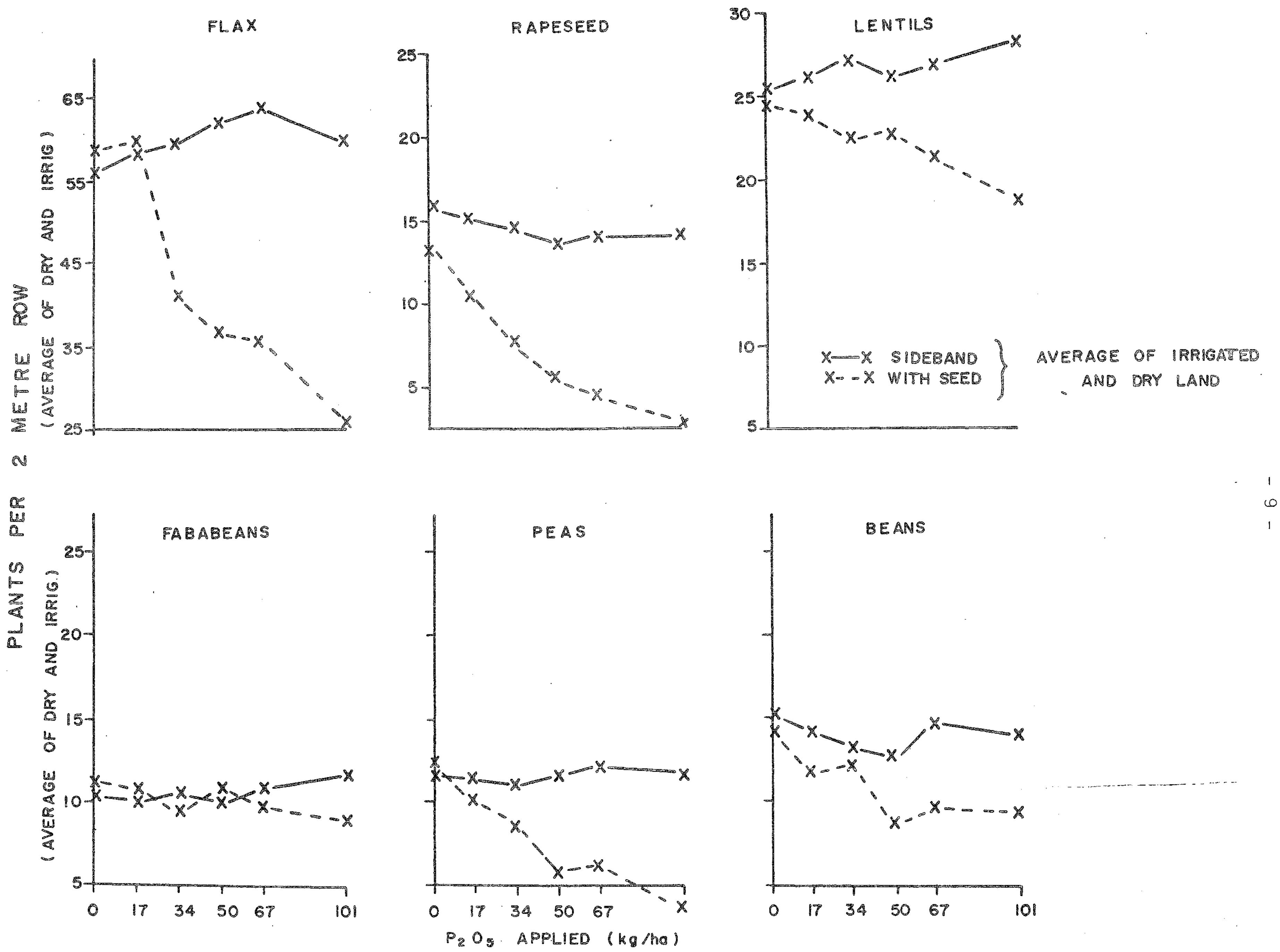

Fig. 1.1.1. The effect of phosphate rate and placement on stand of crops.

Table 1.1.5. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of irrigated fababeans.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Grain[2] % P	Straw % P
		Grain	Straw				Grain	Straw	Total		
0	Seed-placed	3707	3928	0.94	28.6	0.95	169.6	37.3	206.9	0.458	0.072
17	Seed-placed	4332	4458	0.98	28.5	0.92	197.5	41.0	238.5	0.480	0.054
34	Seed-placed	4546	4945	0.93	29.2	0.89	212.4	44.0	256.4	0.552	0.096
50	Seed-placed	5079	5323	0.96	28.0	0.62	227.5	33.0	260.5	0.498	0.060
67	Seed-placed	4898	5136	0.96	28.5	0.62	223.3	31.8	255.1	0.542	0.066
101	Seed-placed	4232	5023	0.85	28.5	0.89	193.0	44.7	237.7	0.592	0.117
0	Side-banded	4493	4477	0.99	28.6	0.74	205.6	33.1	238.7	0.475	0.048
17	Side-banded	4222	4576	0.92	28.7	0.74	193.9	33.9	227.8	0.492	0.078
34	Side-banded	4949	5026	0.98	28.4	0.65	224.9	32.7	257.6	0.508	0.045
50	Side-banded	5368	5596	0.96	28.0	0.74	240.5	41.4	281.9	0.522	0.051
67	Side-banded	5685	5898	0.96	29.1	0.74	264.7	43.6	308.3	0.522	0.066
101	Side-banded	5662	6273	0.90	29.0	0.74	262.7	46.4	309.1	0.578	0.075
L.S.D. (.05)		1233	1269	0.09							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

Table 1.1.6. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of dryland fababeans.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake			Grain[2] % P	Straw % P
		Grain (kg/ha)	Straw (kg/ha)				Grain (kg/ha)	Straw (kg/ha)	Total (kg/ha)		
0	Seed-placed	1398	2647	0.51	24.5	0.46	54.8	12.2	67.0	0.568	0.129
17	Seed-placed	1240	2658	0.45	25.8	0.49	51.2	13.0	64.2	0.552	0.099
34	Seed-placed	814	1837	0.43	24.4	0.55	31.8	10.1	41.9	0.578	0.246
50	Seed-placed	1140	3008	0.41	24.0	0.62	43.8	18.6	62.4	0.565	0.213
67	Seed-placed	1438	3223	0.44	23.0	0.46	52.9	14.8	67.7	0.570	0.183
101	Seed-placed	1040	2766	0.36	23.6	0.46	39.3	12.7	52.0	0.608	0.204
0	Side-banded	1549	2638	0.59	24.5	0.46	60.7	12.1	72.8	0.538	0.096
17	Side-banded	920	2272	0.41	23.3	0.43	34.3	9.8	44.1	0.562	0.186
34	Side-banded	1093	2166	0.49	24.4	0.52	42.7	11.3	54.0	0.545	0.165
50	Side-banded	914	2070	0.42	24.3	0.43	35.5	8.9	44.4	0.590	0.159
67	Side-banded	797	1912	0.40	24.2	0.65	30.9	12.4	43.3	0.605	0.159
101	Side-banded	1480	2729	0.54	24.7	0.46	38.5	12.6	71.1	0.562	0.171
L.S.D. (.05)		619	1045	0.14							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

Table 1.1.7. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of irrigated peas.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Grain[2] % P	Straw % P
		Grain	Straw				Grain	Straw	Total		
0	Seed-placed	1872	1958	0.96	20.8	1.16	62.3	22.7	85.0	0.370	0.123
17	Seed-placed	1769	1719	1.04	19.8	1.20	56.0	20.6	76.6	0.365	0.128
34	Seed-placed	1458	1686	0.91	19.9	1.18	46.4	19.9	66.3	0.398	0.131
50	Seed-placed	1422	1769	0.79	19.0	1.21	43.2	21.4	64.6	0.422	0.155
67	Seed-placed	1262	1343	0.96	19.2	1.16	38.8	15.6	54.4	0.438	0.138
101	Seed-placed	1369	1363	1.01	19.1	1.15	41.8	16.8	58.6	0.452	0.149
0	Side-banded	2079	1758	1.22	20.8	1.23	69.2	21.6	90.8	0.368	0.110
17	Side-banded	2023	2050	1.02	20.4	1.16	66.0	23.8	89.8	0.385	0.104
34	Side-banded	1626	1779	0.98	19.9	1.27	51.8	22.6	74.4	0.425	0.139
50	Side-banded	1712	2011	0.91	20.6	1.39	56.4	28.0	84.4	0.412	0.159
67	Side-banded	2274	2459	0.93	21.2	1.24	77.1	30.5	107.6	0.438	0.122
101	Side-banded	2305	2809	0.83	20.9	1.24	77.1	34.8	111.9	0.442	0.125
L.S.D. (.05)		526	632	0.27							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

Table 1.1.8. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of dryland peas.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Grain[2] % P	Straw % P
		Grain	Straw				Grain	Straw	Total		
0	Seed-placed	1827	1664	1.10	23.2	1.05	67.8	17.5	85.3	0.385	0.086
17	Seed-placed	1521	1293	1.20	21.7	0.99	52.8	12.8	65.6	0.390	0.091
34	Seed-placed	1482	1294	1.16	22.5	1.01	53.4	13.1	66.5	0.422	0.095
50	Seed-placed	1885	1770	1.06	21.3	0.98	64.2	17.3	81.5	0.450	0.088
67	Seed-placed	1515	1367	1.11	21.0	0.95	50.9	13.0	63.9	0.438	0.091
101	Seed-placed	1328	1178	1.20	20.1	0.91	42.7	10.7	53.4	0.440	0.100
0	Side-banded	2121	1569	1.36	23.2	0.98	78.7	15.4	94.1	0.378	0.070
17	Side-banded	2004	1665	1.22	22.4	1.02	71.8	17.0	88.8	0.415	0.083
34	Side-banded	2151	1800	1.22	22.6	0.96	77.8	17.3	95.1	0.408	0.077
50	Side-banded	2187	2021	1.09	22.9	1.18	80.1	23.8	103.9	0.390	0.093
67	Side-banded	2606	2297	1.14	23.4	0.99	97.6	22.7	120.3	0.430	0.081
101	Side-banded	1837	1976	0.94	22.8	1.01	67.0	20.0	87.0	0.432	0.116
L.S.D. (.05)		565	528	0.25							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

Table 1.1.9. The effect of phosphorus fertilizer rate and placement on the yield, protein content and nitrogen uptake of irrigated beans.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Straw[2] % P
		Grain	Straw				Grain	Straw	Total	
0	Seed-placed	1553	1119	1.30	16.7	0.75	41.5	8.4	49.9	0.186
17	Seed-placed	1457	1046	1.34	16.5	0.84	38.5	8.8	47.3	0.195
34	Seed-placed	1572	1150	1.36	15.4	0.69	38.7	7.9	46.6	0.126
50	Seed-placed	1832	1348	1.35	16.4	0.56	48.1	7.5	55.6	0.093
67	Seed-placed	1747	1267	1.34	17.3	0.65	48.4	8.2	56.6	0.126
101	Seed-placed	2035	1457	1.40	17.6	0.60	57.3	8.7	66.0	0.114
0	Side-banded	1509	1071	1.40	16.7	0.72	40.3	7.7	48.0	0.117
17	Side-banded	1691	1235	1.37	16.2	0.69	43.8	8.5	52.3	0.141
34	Side-banded	1653	1191	1.33	17.0	0.65	45.0	8.4	53.4	0.129
50	Side-banded	1640	1160	1.38	16.8	0.72	44.1	8.4	52.5	0.162
67	Side-banded	1400	1102	1.29	15.6	0.72	34.9	7.9	42.8	0.168
101	Side-banded	1936	2141	1.12	15.8	0.72	48.9	15.4	64.3	0.141
L.S.D. (.05)		620	512	0.29						

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Straw % P on oven-dry basis.

Table 1.1.10. The effect of phosphorus fertilizer rate and placement on the yield, protein content and nitrogen uptake of dryland beans.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Straw[2] % P
		Grain	Straw				Grain	Straw	Total	
0	Seed-placed	766	680	1.13	16.1	0.47	19.7	3.2	22.9	0.081
17	Seed-placed	844	736	1.15	16.2	0.44	21.9	3.2	25.1	0.063
34	Seed-placed	905	806	1.13	16.3	0.47	23.6	3.8	27.4	0.087
50	Seed-placed	763	700	1.08	16.7	0.44	20.4	3.1	23.4	0.066
67	Seed-placed	1008	919	1.11	17.0	0.47	27.4	4.3	31.7	0.078
101	Seed-placed	922	874	1.06	17.2	0.44	25.4	3.8	29.2	0.078
0	Side-banded	908	788	1.15	16.1	0.47	23.4	3.7	27.1	0.066
17	Side-banded	928	795	1.16	16.3	0.47	24.2	3.7	27.9	0.075
34	Side-banded	962	861	1.10	16.8	0.47	25.9	4.0	29.9	0.072
50	Side-banded	993	896	1.11	17.6	0.44	28.0	3.9	31.9	0.096
67	Side-banded	983	904	1.10	16.9	0.44	26.6	4.0	30.6	0.099
101	Side-banded	986	975	1.01	16.1	0.47	25.4	4.6	30.0	0.117
L.S.D. (.05)		268	230	0.08						

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Straw % P on oven-dry basis.

Table 1.1.11. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of irrigated lentils.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Grain[2] % P	Straw % P
		Grain	Straw				Grain	Straw	Total		
0	Seed-placed	1331	2158	0.60	21.3	1.14	45.4	24.6	70.0	0.520	0.150
17	Seed-placed	874	1779	0.49	20.8	1.08	29.1	19.2	48.3	0.528	0.168
34	Seed-placed	1172	2045	0.57	21.1	1.20	39.6	24.5	63.1	0.535	0.174
50	Seed-placed	773	1602	0.47	20.0	1.11	24.7	17.8	42.5	0.518	0.171
67	Seed-placed	1047	1899	0.55	21.2	1.05	35.5	19.9	55.4	0.530	0.168
101	Seed-placed	925	1818	0.50	21.0	1.11	31.1	20.2	51.3	0.528	0.174
0	Side-banded	837	1980	0.45	21.3	1.17	28.5	23.2	51.7	0.542	0.168
17	Side-banded	1055	2170	0.49	19.9	1.14	33.6	24.7	58.3	0.542	0.174
34	Side-banded	979	1946	0.49	19.9	1.02	31.2	19.8	51.0	0.532	0.156
50	Side-banded	741	1751	0.43	21.0	1.20	24.9	21.0	45.9	0.518	0.204
67	Side-banded	990	1960	0.50	19.9	1.32	31.5	25.9	57.4	0.540	0.192
101	Side-banded	1213	2278	0.53	20.6	1.26	40.0	28.7	68.7	0.525	0.192
L.S.D. (.05)		357	542	0.09							

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[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

Table 1.1.12. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and phosphorus content of dryland lentils.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Grain[2] % P	Straw % P
		Grain	Straw				Grain	Straw	Total		
0	Seed-placed	1382	1655	0.83	18.0	0.57	39.8	9.4	49.2	0.532	0.096
17	Seed-placed	1459	1771	0.82	19.0	0.57	44.4	10.1	54.5	0.520	0.084
34	Seed-placed	1338	2099	0.67	17.1	0.54	36.6	11.3	47.9	0.550	0.096
50	Seed-placed	1247	1604	0.77	19.2	0.69	38.3	11.1	49.4	0.545	0.108
67	Seed-placed	1440	1823	0.79	18.0	0.66	41.5	12.0	53.5	0.530	0.084
101	Seed-placed	1718	2133	0.80	17.8	0.63	48.9	13.4	62.3	0.545	0.102
0	Side-banded	1232	1919	0.66	18.0	0.60	35.5	11.5	47.0	0.562	0.075
17	Side-banded	1333	1736	0.76	16.6	0.63	35.4	10.9	46.3	0.542	0.090
34	Side-banded	1364	1840	0.74	16.4	0.57	35.8	10.5	46.3	0.540	0.108
50	Side-banded	1290	1618	0.78	18.4	0.60	38.0	9.7	47.7	0.558	0.093
67	Side-banded	1183	1808	0.69	18.2	0.57	34.4	10.3	44.7	0.565	0.117
101	Side-banded	1336	1758	0.76	17.5	0.63	37.4	11.1	48.5	0.570	0.114
L.S.D. (.05)		460	504	0.19							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

Table 1.1.13. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and oil content of irrigated flax.

P_2O_5[3] applied (kg/ha)	Fertilizer placement	Yield Grain (kg/ha)	Yield Straw (kg/ha)	Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake Grain (kg/ha)	Nitrogen uptake Straw (kg/ha)	Nitrogen uptake Total (kg/ha)	Straw[2] % P	Grain % oil
0	Seed-placed	2766	2390	0.52	21.6	0.32	95.6	7.6	103.2	0.036	49.9
17	Seed-placed	2679	4081	0.67	21.4	0.32	91.7	13.1	104.8	0.036	48.7
34	Seed-placed	2443	3856	0.63	22.2	0.32	86.8	12.3	99.1	0.026	47.2
50	Seed-placed	2311	3839	0.60	22.1	0.29	81.7	11.1	92.8	0.039	46.1
67	Seed-placed	2667	4287	0.63	21.3	0.35	90.9	15.0	105.9	0.036	46.2
101	Seed-placed	1855	3201	0.56	21.7	0.32	64.4	10.2	74.6	0.042	45.3
0	Side-banded	1788	2638	0.67	21.6	0.35	61.8	9.2	71.0	0.048	49.9
17	Side-banded	2833	3765	0.77	20.9	0.29	94.7	10.9	105.6	0.030	47.2
34	Side-banded	3218	4260	0.78	20.8	0.29	107.1	12.4	119.5	0.033	47.7
50	Side-banded	3184	4697	0.68	21.3	0.26	108.5	12.2	120.7	0.033	47.1
67	Side-banded	2940	4838	0.62	21.7	0.39	102.1	18.9	121.0	0.036	45.8
101	Side-banded	2501	4424	0.56	22.4	0.32	89.6	14.2	103.8	0.039	49.4
L.S.D. (.05)		632	1608	0.20							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Straw % P on oven-dry basis.

[3] All treatments except 0 side-band received an additional broadcast application of 112 kg N/ha.

Table 1.1.14. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and oil content of dryland flax.

P_2O_5[3] applied (kg/ha)	Fertilizer placement	Yield Grain (kg/ha)	Yield Straw (kg/ha)	Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake Grain (kg/ha)	Nitrogen uptake Straw (kg/ha)	Nitrogen uptake Total (kg/ha)	Straw[2] % P	Grain % oil
0	Seed-placed	1015	2875	0.35	24.0	0.37	39.0	10.6	49.6	0.009	38.4
17	Seed-placed	1231	3315	0.37	21.1	0.28	41.6	9.3	50.9	0.006	42.7
34	Seed-placed	1218	3380	0.36	22.7	0.37	44.2	12.5	56.7	0.009	39.9
50	Seed-placed	1144	3066	0.36	22.2	0.37	40.6	11.3	51.9	0.015	39.0
67	Seed-placed	807	2588	0.31	21.1	0.40	27.2	10.4	37.6	0.015	37.7
101	Seed-placed	1226	2909	0.42	22.6	0.35	44.3	10.2	54.5	0.018	39.9
0	Side-banded	1140	2903	0.39	24.0	0.25	43.8	7.3	51.1	0.009	39.5
17	Side-banded	1194	3329	0.36	22.0	0.37	42.0	12.3	54.3	0.006	39.0
34	Side-banded	1057	3015	0.35	22.4	0.34	37.9	10.3	48.2	0.009	39.6
50	Side-banded	1038	3134	0.33	23.2	0.40	38.5	12.5	51.0	0.012	37.8
67	Side-banded	1070	3046	0.35	21.4	0.45	36.6	13.7	50.3	0.030	37.6
101	Side-banded	1149	3289	0.34	23.5	0.45	43.2	14.8	58.0	0.036	40.2
L.S.D. (.05)		427	696	0.07							

[1] Grain protein based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Straw % P on oven-dry basis.

[3] All treatments except 0 side-band received an additional broadcast application of 112 kg N/ha.

Table 1.1.15. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and oil content of irrigated rapeseed.

P_2O_5[3] applied (kg/ha)	Fertilizer placement	Yield Grain (kg/ha)	Yield Straw (kg/ha)	Grain/straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake Grain (kg/ha)	Nitrogen uptake Straw (kg/ha)	Nitrogen uptake Total (kg/ha)	Straw[2] % P	Grain % oil
0	Seed-placed	1604	4658	0.36	19.1	0.48	49.0	22.4	71.4	0.054	44.6
17	Seed-placed	1896	4607	0.41	18.9	0.42	57.3	19.3	76.6	0.054	45.3
34	Seed-placed	1676	5286	0.33	18.7	0.58	50.1	30.7	80.8	0.081	44.8
50	Seed-placed	1368	3899	0.37	19.1	0.48	41.8	18.7	60.5	0.090	45.4
67	Seed-placed	1690	4087	0.40	21.0	0.55	56.8	22.5	79.3	0.096	43.5
101	Seed-placed	1324	3914	0.38	20.6	0.64	43.6	25.0	68.6	0.156	43.5
0	Side-banded	891	2080	0.43	19.1	0.42	27.2	8.7	35.9	0.075	45.6
17	Side-banded	2351	4949	0.48	20.3	0.45	76.4	22.3	98.7	0.051	45.0
34	Side-banded	1846	4426	0.42	20.2	0.55	59.7	24.3	84.0	0.066	45.9
50	Side-banded	1905	4532	0.42	19.7	0.39	60.0	17.7	77.7	0.057	44.4
67	Side-banded	2174	4418	0.49	20.2	0.48	70.3	21.2	91.5	0.090	43.3
101	Side-banded	1777	4600	0.40	19.6	0.45	55.7	20.7	76.4	0.105	44.2
L.S.D. (.05)		817	2066	0.12							

[1] Grain protein based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Straw % P on oven-dry basis.

[3] All treatments except 0 side-band received an additional broadcast application of 112 kg N/ha.

Table 1.1.16. The effect of phosphorus fertilizer rate and placement on the yield, protein content, nitrogen uptake and oil content of dryland rapeseed.

P_2O_5 applied (kg/ha)	Fertilizer placement	Yield		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake			Straw[2] % P	Grain % oil
		Grain (kg/ha)	Straw (kg/ha)				Grain (kg/ha)	Straw (kg/ha)	Total (kg/ha)		
0	Seed-placed	770	2039	0.38	29.0	0.96	35.7	19.6	55.3	0.048	37.5
17	Seed-placed	697	2313	0.31	29.4	1.00	32.3	23.1	55.4	0.063	37.8
34	Seed-placed	484	1380	0.43	30.0	1.09	23.2	15.0	38.2	0.078	36.9
50	Seed-placed	516	1647	0.30	30.5	0.87	25.2	14.3	39.5	0.096	36.5
67	Seed-placed	335	1112	0.30	29.8	1.25	16.0	13.9	29.9	0.126	37.4
101	Seed-placed	337	1194	0.29	28.4	1.41	15.3	16.8	32.1	0.150	39.1
0	Side-banded	859	2396	0.37	29.0	0.64	39.9	15.3	55.2	0.042	38.3
17	Side-banded	683	2299	0.31	29.9	1.00	32.7	23.0	55.7	0.060	36.8
34	Side-banded	726	2126	0.31	28.6	1.00	33.2	21.3	54.5	0.081	36.1
50	Side-banded	968	2776	0.35	29.3	1.00	45.4	27.8	73.2	0.096	36.8
67	Side-banded	930	2731	0.34	29.5	1.06	43.9	28.9	72.8	0.108	36.2
101	Side-banded	883	2634	0.33	29.4	1.16	41.5	30.6	72.1	0.117	36.8
L.S.D. (.05)		459	1331	0.11							

[1] Grain protein content based on % N at air-dry moisture content x 6.25; straw % N on oven-dry basis.

[2] Straw % P on oven-dry basis.

[3] All treatments except 0 side-band received an additional broadcast application of 112 kg N/ha.

responses to phosphorus fertilizer rates or placement. Peas and rapeseed appeared to show small responses with the side-band treatment which yielded higher than the seed-placed treatment for most of the phosphorus rates.

Under irrigated conditions grain yields for peas, flax and rapeseed showed small phosphate responses with the side-band treatment and a decline in yield for the seed-placed treatment. At all phosphorus fertilizer rates the side-band treatment out-yielded the seed-placed treatment.

Fababeans under irrigation responded strongly to both rates and placement of phosphorus. This response was much higher for the side-band treatment than the seed-placed treatment.

Beans and lentils under irrigation showed no response to phosphorus rates or placement.

The straw yield (Figure 1.1.3) showed similar trends to that for grain yield for all crops except flax. In the case of flax, straw yields indicated a very strong response to side-band phosphorus and some response to seed-placed phosphorus for the irrigated treatment.

The relative responses of the crops to irrigation can also be seen in Figures 1.1.2 and 1.1.3. Fababeans responded strongly to irrigation with grain yields increased by more than threefold over the dryland treatment. Flax and rapeseed grain yields also showed a strong response to irrigation. Bean yield showed a small response to irrigation while pea yield showed relatively little response to irrigation.

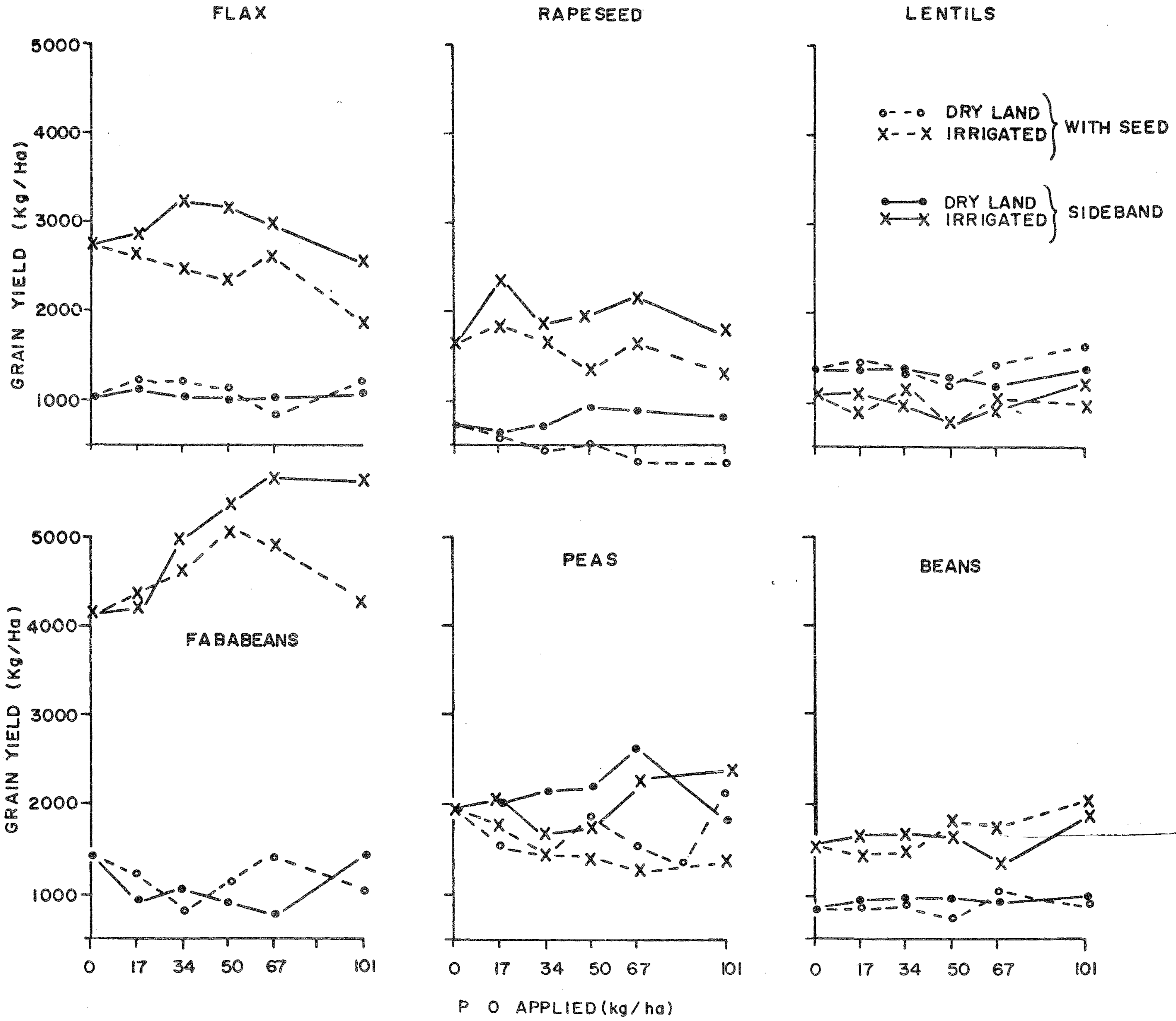

Fig. 1.1.2. The effect of phosphate rate and placement on grain yield of crops.

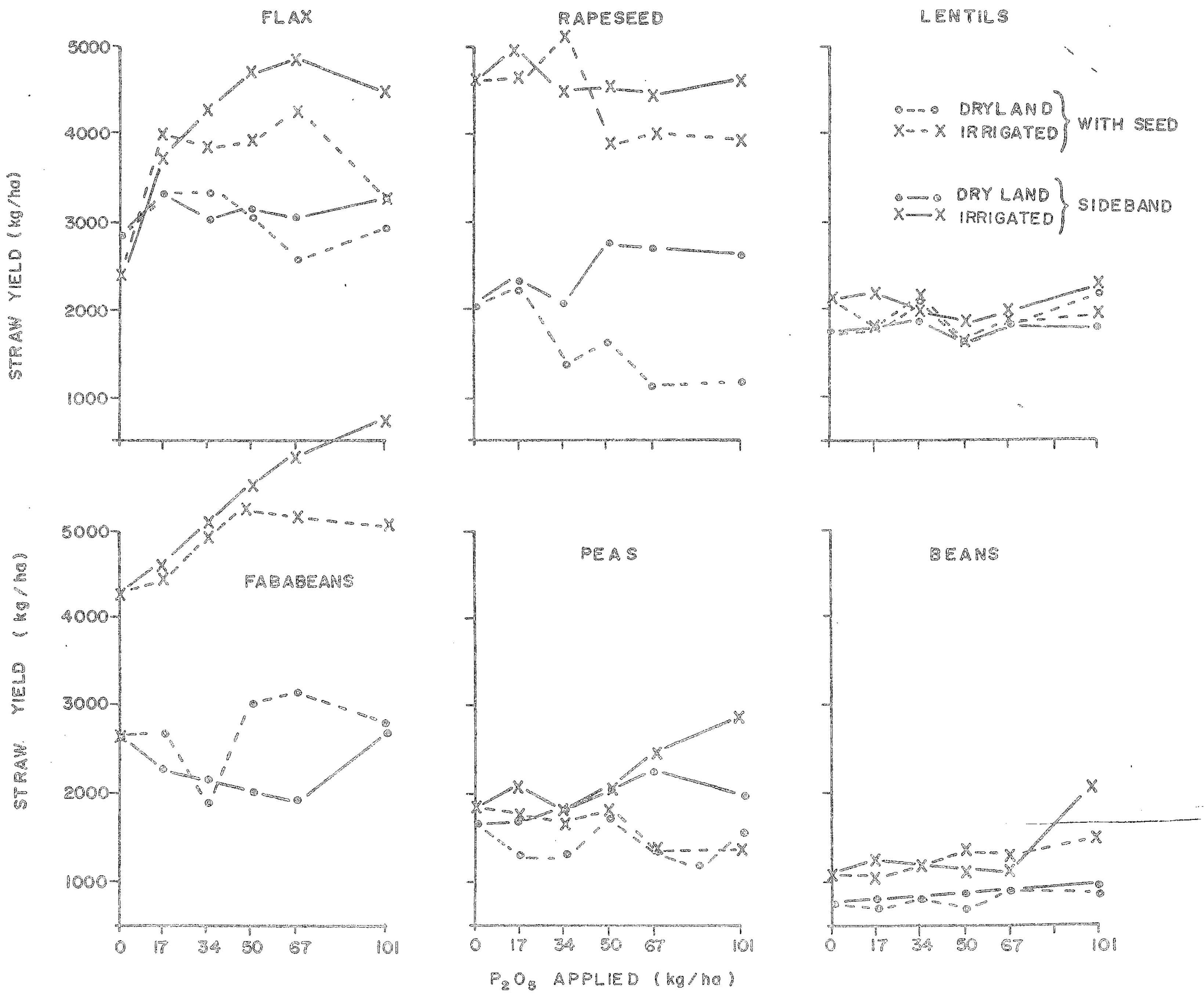

Fig. 1.1.3. The effect of phosphate rate and placement on straw yield of crops.

Lentils showed no response to irrigation with dryland yields being higher than the irrigated yields in some cases. As little is known about the water requirement of lentils, it may require further work to establish scheduling of water applications.

Previous work with rapeseed in the South Saskatchewan Irrigation Project has indicated that it responds strongly to irrigation with grain yields as high as 2400 to 2500 kg/ha being recorded with optimum levels of water and nitrogen. This work shows a response of both flax and rapeseed to irrigation and nitrogen. For rapeseed under irrigation the yield doubled in the presence of 112 kg N/ha in comparison to no nitrogen added (Treatment 7). No response to applied nitrogen was observed for the dryland treatment. This same trend was also observed for flax but not to as great an extent as for rapeseed.

Grain/straw ratios for all the crops showed no response to rates or placement of phosphorus under both dryland and irrigated conditions. Irrigated fababeans, beans, lentils and flax had grain/straw ratios higher than dryland with fababeans showing the greatest increase (double that of dryland). Peas and rapeseed showed little difference in grain/straw ratios between irrigated and dryland conditions and if anything were slightly lower under irrigation.

Grain protein content was not affected by rate or placement of phosphorus for any of the crops under study. Irrigation increased the protein content of fababeans by approximately 4%. Irrigation had relatively little effect on the protein content of the other crops except rapeseed, where irrigation reduced the protein content sharply. The protein content of 29 to 30% for the dryland rapeseed may be somewhat high as the samples contained some immature seeds. Previous work has shown protein content of 24 to 26% for dryland rapeseed at Outlook and irrigation frequently reduces this to approximately 18 to 20% as was also found in the present work.

Straw nitrogen content and grain and straw phosphorus content were not affected by rate or placement of phosphorus.

Irrigation increased straw nitrogen content for fababeans, peas, beans and lentils while it decreased for flax and rapeseed. This could possibly be due to a favourable influence of irrigation on *Rhizobium* sp. for the pulse crops. Phosphorus content of grain was determined for fababeans, peas and lentils and showed a decrease with irrigation for fababeans with little or no change for peas and lentils. Straw phosphorus content decreased for fababeans and increased for peas, beans, lentils and flax. No change was observed for the straw phosphorus content of rapeseed between the dryland and irrigated treatments.

The oil content of flax and rapeseed was not affected by rate or placement of phosphorus. Irrigation increased the oil content of both crops. Previous work at Outlook has shown oil content to increase with irrigation, the levels being similar to those found in the present work.

Seasonal Water Use

The seasonal water use of the six crops under both dryland and irrigated conditions is presented in Table 1.1.17. A greater total water use was found for each crop under irrigated than dryland conditions. However, only fababeans, flax and rapeseed showed an increase in grain yield when irrigated. Peas, beans and lentils showed little change in grain yield when irrigated indicating that these three crops are either not suited for production under irrigation or the wrong scheduling of irrigation applications was followed.

For the irrigated crops rapeseed had the greatest total water use followed closely by beans. These two crops received a large irrigation application on August 10/76 of 152 mm, some of which most likely was lost through deep percolation resulting in an erroneously high water use value for both crops.

The irrigated fababeans and flax had a lower total water use than the rapeseed yet showed the greatest response to the applied water in terms of grain yield. Thus, the fababeans and flax would appear to be more efficient in their water use patterns than was the rapeseed. However, as stated previously the water use value for the irrigated rapeseed may be in error due to percolation losses after a large water application late in the season.

Fall Soil Analyses

The results for the analyses of the fall soil samples

Table 1.1.17 Seasonal water use of irrigated and dryland crops for the phosphorus placement experiment.

Crop	Irrigated				Dryland		
	Rainfall	Irrigation	ΔS*	Total** water use	Rainfall	ΔS*	Total** water use
	mm						
Fababeans	172	310	35	517	166	130	296
Peas	172	287	1	460	166	77	243
Beans	183	320	48	551	166	70	236
Lentils	166	259	-81	344	166	51	217
Rapeseed	172	475	-74	573	166	53	219
Flax	166	314	-30	450	166	61	227

*ΔS = change in soil moisture content (spring - fall).

**Total water use = rainfall + irrigation + ΔS.

are presented in Table 1.1.18. No change was observed in the soil analyses from spring to fall except for the dryland flax and to some extent the dryland rapeseed where NO_3-N increased. This residual NO_3-N was not evident on the irrigated flax and rapeseed due to increased plant uptake and possibly leaching losses of the applied fertilizer nitrogen.

Table 1.1.18 Fall soil analyses for the P placement experiments.

Depth (cm)	pH	Conductivity (mmhos/cm)	NO_3-N	P	K	SO_4-S
			kg/ha*			
Irrigated Peas						
0-15	7.1	0.5	7	13	728	17
15-30	7.3	0.4	3	5	279	15
30-60	7.7	0.8	6	6	593	48+
Irrigated Fababeans						
0-15	7.4	0.5	4	10	713	22
15-30	7.5	0.4	3	4	281	18
30-60	7.9	0.9	4	6	590	48+
Irrigated Lentils						
0-15	7.5	0.4	4	13	618	17
15-30	7.7	0.5	2	5	233	13
30-60	8.0	1.1	6	6	508	48+
Irrigated Beans						
0-15	7.2	0.4	6	7	616	17
15-30	7.4	0.4	3	3	259	13
30-60	8.0	0.7	8	5	600	47
Irrigated Rapeseed						
0-15	7.3	0.5	6	12	621	12
15-30	7.5	0.4	4	5	255	10
30-60	7.9	0.6	8	6	490	32
Irrigated Flax						
0-15	7.1	0.4	2	13	729	17
15-30	7.3	0.4	2	6	273	14
30-60	7.9	0.6	8	6	600	44
Dry Peas						
0-15	7.0	0.5	8	20	514	20
15-30	7.3	0.5	2	7	208	24+
30-60	7.8	0.6	6	6	483	48+
Dry Fababeans						
0-15	7.3	0.4	6	12	623	20
15-30	7.4	0.4	2	5	241	24+
30-60	7.9	0.6	4	6	568	58+

Table 1.1.18 Con't.

Depth (cm)	pH	Conductivity (mmhos/cm)	NO_3-N	P	K	SO_4-S
			kg/ha*			
			Dry Lentils			
0-15	7.0	0.3	5	13	570	20
15-30	7.3	0.3	2	6	214	17
30-60	7.9	0.6	6	5	535	47
			Dry Beans			
0-15	7.2	0.5	9	10	626	21
15-30	7.3	0.4	2	4	241	21
30-60	7.8	0.7	5	4	573	48+
			Dry Rapeseed			
0-15	6.9	0.3	13	12	549	7
15-30	7.2	0.3	7	6	308	4
30-60	7.6	0.5	14	6	555	11
			Dry Flax			
0-15	6.8	0.4	35	12	676	19
15-30	7.2	0.3	11	5	244	17
30-60	7.8	0.7	14	4	613	48+

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

1.2 Phosphorus Requirements of Annual Crops Under Irrigation

Since the inception of irrigation in the South Saskatchewan Irrigation Project some farmers have applied large quantities of fertilizer to their irrigated land to ensure an adequate supply of nutrients for crop growth. Such large fertilizer applications have lead over the years to large accumulations of phosphate in the soil. The extent to which this residual phosphate meets the requirements of growing crops and thus whether there is a need for additional phosphorus fertilizer applications is not clear at this time. Therefore, it was considered necessary to carry out a research project to establish the extent to which this residual phosphate meets the demands of a growing crop and whether or not a response would be shown to applied phosphorus fertilizer. A research project of this nature would have to include a range in soil textures and annual crops. The results from several years research would then provide adequate information for making phosphorus fertilizer recommendations to irrigation farmers.

PURPOSE

To investigate the response of annual crops under irrigation to phosphorus fertilization on land with residual phosphate from previous high rates of application.

EXPERIMENTAL METHODS

Five sites were selected in 1976 for the initial year of this project. Due to poor stand establishment and wind erosion, three of these sites had to be abandoned part way through the growing season. The remaining two sites were located on Asquith sandy loam soil (Barrich Farms Ltd.). The fields on which the sites were located were both seeded to potatoes in 1975 and had a history of large fertilizer applications.

Soil analyses from samples taken at seeding time indicated a high level of $NaHCO_3$ extractable P (0-15 cm) for field no. 9 and a medium level for field no. 8 (Table 1.2.1). The soil analyses clearly indicates a high level of phosphate at depth for each of these sites. It is also interesting to note the high levels of nitrogen in the soil at both sites, the levels being higher at field no. 9 than field no. 8 (Table 1.2.1).

Small plots of randomized complete block design with four replicates and seven treatments were established at each site. The treatments included a range of phosphorus rates from 0-101 kg P_2O_5/ha (Table 1.2.2). Monoammonium phosphate was used as the phosphate source. The plots were rototilled then seeded to Neepawa wheat using a double-disc press drill with seven rows per plot and an eighteen cm row spacing over a length of 4.6 meters. The phosphorus fertilizer was seed-placed through a set of cones while the seed was applied through the seed box. The plots were situated within the co-operating farmers field and completely surrounded by his crop.

Table 1.2.1 Spring soil analyses for the P correlation experiment.

Depth (cm)	pH	Conductivity (mmhos/cm)	NO_3-N	P	K	SO_4-S
			kg/ha*			
		Asquith sandy loam (Barrich No. 8)				
0-15	7.3	0.5	54	28	646	17
15-30	7.1	0.5	61	57	459	17
30-60	7.8	0.4	89	22	490	36
60-90	8.0	0.6	38	11	528	48+
		Asquith sandy loam (Barrich No. 9)				
0-15	7.0	0.7	87	46	525	14
15-30	6.8	0.4	60	62	308	28
30-60	7.7	0.5	119	44	420	33
60-90	7.9	0.4	101	28	445	30

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

Table 1.2.2. Fertility treatments used in phosphorus correlation experiments.

Treatment No.	P_2O_5* applied (kg/ha)
1	0
2	17
3	34
4	50
5	67
6	84
7	101

*All phosphorus was seed-placed

Field no. 9 received a post-emergent application of Hoe grass to control a severe infestation of green foxtail. The control was excellent and no green foxtail was present at harvest.

All irrigation applications were as conducted by the co-operating farmer. The timing and amounts of irrigation water applied along with the total growing season rainfall are presented in Table 1.2.3 for both the plots.

Table 1.2.3 Amounts and timing of irrigation applications and growing season rainfall for the phosphorus correlation experiments.

Plot	Growing season rainfall (mm)	Dates and rates of irrigation applications	Total water (rainfall + irrigation) (mm)
Field 8	153	June 25, 33 mm; July 14, 25 mm; Aug. 3, 43 mm.	254
Field 9	152	May 19, 5 mm; May 20, 6 mm; May 24, 7 mm; June 25, 32 mm; July 2, 39 mm; July 11, 25 mm; July 23, 19 mm; Aug. 3, 5 mm.	290

At harvest, yield samples were taken from all treatments by clipping at the soil surface the three centre rows over a length of 3 meters. The samples were then dried, weighed and threshed. The grain samples were cleaned and weighed. Subsamples of both grain (replicates kept separate) and straw (replicates bulked) from each plot were mixed and ground. Analyses were performed for percent nitrogen content of the straw, percent protein content of the grain and percent phosphorus content of both grain and straw.

After harvest soil samples were collected from the check treatment of each of the four replicates and submitted for analyses.

RESULTS AND DISCUSSION

The results for the effect of phosphorus fertilization on the yield, nitrogen content and phosphorus content of the Neepawa wheat are presented in Table 1.2.4. These results indicate that there was no yield response to seed-placed phosphorus on field no. 8. The grain yield on field no. 9 showed a small decrease for the two highest phosphorus rates over that of the control treatment. However, no yield responses were observed for the straw on field no. 9. As well, phosphorus fertilization had no effect on grain/straw ratios, grain protein content, straw nitrogen content, grain phosphorus content or straw phosphorus content.

The yields of both grain and straw were high with those from field no. 9 larger than those from field no. 8.

Table 1.2.4. The effect of phosphorus fertilization on the yield, nitrogen content, nitrogen uptake, phosphorus content and phosphorus uptake of Neepawa wheat grown on irrigated soil.

P_2O_5 applied (kg/ha)	Yield (kg/ha)		Grain/ straw ratio	Grain[1] % protein	Straw % N	Nitrogen uptake (kg/ha)			Grain[2] % P	Straw % P	Phosphorus uptake (kg/ha)		
	Grain	Straw				Grain	Straw	Total			Grain	Straw	Total
Asquith sandy loam (Barrich No. 8)													
0	3620	6096	0.59	15.3	0.50	112.2	30.5	142.7	0.512	0.066	18.5	4.0	22.5
17	3345	5335	0.63	16.2	0.53	110.1	28.3	138.4	0.495	0.048	16.6	2.6	19.2
34	3545	6044	0.59	16.7	0.44	119.8	26.6	146.4	0.520	0.048	18.4	2.9	21.3
50	3642	6068	0.60	16.8	0.56	124.6	34.0	158.6	0.527	0.075	19.2	4.6	23.8
67	3465	5632	0.63	16.7	0.50	117.1	28.2	145.3	0.528	0.054	18.3	3.0	21.3
84	4079	6413	0.64	16.7	0.56	138.3	35.9	174.2	0.518	0.060	21.1	3.9	25.0
101	3147	5848	0.51	14.4	0.62	91.9	36.3	128.2	0.524	0.093	16.5	5.4	21.9
L.S.D. (.05)	1114	1671	0.11										
Asquith sandy loam (Barrich No. 9)													
0	4205	8055	0.52	16.5	0.69	139.2	55.6	194.8	0.517	0.045	21.7	3.6	25.3
17	3880	7717	0.50	17.2	0.72	102.8	55.6	158.4	0.521	0.075	20.2	5.8	26.0
34	4221	7958	0.53	17.4	0.69	149.0	54.0	203.9	0.512	0.051	21.6	4.1	25.7
50	4127	8352	0.50	16.8	0.72	140.7	60.1	200.8	0.530	0.075	21.9	6.3	28.2
67	4066	7908	0.51	15.9	0.72	130.5	56.9	187.4	0.527	0.072	21.4	5.7	27.1
84	3690	7874	0.47	17.4	0.72	130.3	56.7	187.0	0.545	0.093	20.1	7.3	27.4
101	3744	7583	0.50	17.4	0.84	132.2	63.7	195.9	0.542	0.090	20.3	6.8	27.1
L.S.D. (.05)	405	457	0.04										

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[1] Grain % protein based on % N at 13.5% moisture x 5.7; straw % N on oven-dry basis.

[2] Grain % P and Straw % P on oven-dry basis.

The small grain/straw ratios are in agreement with those obtained from previous research plots in the irrigation district for soft wheat and barley where large fertilizer N applications were made to N deficient soils. The high grain and straw yields could be due in part to the large quantities of residual nitrogen in these two fields.

An interesting outcome of this research was the high protein content of the hard wheat in combination with the high yields. This too was probably due to the large quantities of residual nitrogen in these soils. Interestingly enough, the highest protein contents (16% to 17%) and straw nitrogen contents were found on field no. 9 which also had the highest yield. This in turn lead to a higher nitrogen uptake on field no. 9 than on field no. 8.

The phosphorus content of the grain and straw from both plots were similar with those from field no. 9 slightly larger than those from field no. 8. This in combination with the highest yields from field no. 9 lead to a greater phosphorus uptake on field no. 9 than on field no. 8.

The results for the analyses of the fall soil samples are presented in Table 1.2.5. These results indicate, as did the spring soil analyses, that there was still a large quantity of residual phosphate in the soils. The nitrogen levels were reduced due to crop removal and possibly leaching in the light textured soils but still were relatively high in field no. 9.

The data obtained from this research indicates that

Table 1.2.5 Fall soil analyses for the P correlation experiment.

Depth (cm)	pH	Conductivity (mmhos/cm)	NO_3-N	P	K	SO_4-S
			kg/ha*			
		Asquith sandy loam (Barrich No. 8)				
0-15	7.3	0.4	6	29	645	14
15-30	6.9	0.4	8	45	490	21
30-60	7.6	0.5	44	22	494	35
60-90	7.8	0.9	30	10	545	30
		Asquith sandy loam (Barrich No. 9)				
0-15	7.0	0.5	35	28	394	19
15-30	6.6	0.5	54	62	290	31
30-60	7.5	0.5	91	36	298	17
60-90	7.9	0.5	82	18	293	14

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

farms under irrigation and using higher levels of fertility must utilize soil testing to determine the residual nutrients present. A further application to the soil test information may in some cases even be the selection of crops. For soils with very high levels of residual nitrogen the production of hard wheat could lead to high protein levels which is desirable. However, the production of soft wheat or malting barley would lead to protein levels that would make the product unmarketable or at best marketable at a reduced price.

1.3 Phosphorus Requirements of Alfalfa

Previous research on the nutrient requirments of irrigated alfalfa by the Department of Soil Science, University of Saskatchewan, in the South Saskatchewan Irrigation Project indicated no response to applied nitrogen, potassium, sulfur or boron. However, a response to applied phosphorus occurred for soils with very low soil test phosphorus levels, particularly where the A horizon had been removed by levelling operations. A single large application of phosphorus (225 kg P_2O_5/ha or greater) was found to be preferable to small annual applications (84 to 112 kg P_2O_5/ha) for increasing yields of such low phosphorus areas.

This research has provided valuable information on the response of alfalfa to applied phosphorus for soils testing in the very low range. However, information for soils testing in higher ranges is required before soil test benchmarks can be refined. Therefore, it was considered necessary to continue this research on phosphorus soil test benchmark calibration for irrigated alfalfa.

PURPOSE

Continuation of phosphorus soil test benchmark calibration for irrigated alfala.

EXPERIMENTAL METHODS

Sites for investigation were selected in 1976 within the South Saskatchewan Irrigation Project on three established alfalfa fields. The sites (Table 1.3.1) were selected to give

Table 1.3.1. Site characteristics of soils selected for irrigated alfalfa study.

	Site 1	Site 2	Site 3
Legal location	NE20-28-7-W3	NE30-28-7-W3	SW31-30-7-W3
Co-operator	Pederson	Gross	Wudel
Year seeded	1971	1975	1973
Irrigation type	Border-dyke	Border-dyke	Border-dyke
Soil association	Elstow	Bradwell	Bradwell
Texture	Loam	Loam	Very fine sandy loam

some range in soil characteristics and phosphorus soil test levels as indicated by the analyses of soil samples taken prior to plot establishment. The Pederson site (Table 1.3.2)

Table 1.3.2. Spring soil analyses for irrigated alfalfa experiments (Pederson site).

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha*			
1	0-15	8.0	0.7	15	8	210	24+
	15-30	8.2	0.6	8	3	240	24+
	30-60	7.9	3.1	4	8	580	48+
2	0-15	7.9	0.4	16	7	190	24+
	15-30	8.0	0.4	7	3	180	24+
	30-60	8.3	0.4	8	4	420	48+
3	0-15	7.8	0.4	17	4	195	22
	15-30	8.0	0.4	7	2	195	18
	30-60	8.2	0.4	6	4	430	48
4	0-15	8.0	0.7	8	6	285	24+
	15-30	8.3	0.6	3	3	310	24+
	30-60	8.0	0.6	8	8	770	48+

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth and the Gross site (Table 1.3.3) both had a low phosphorus soil test level. The soil potassium level at the Pederson site was just above the currently accepted sufficiency level. The Wudel site (Table 1.3.3) had a medium phosphorus

Table 1.3.3. Spring soil analyses for irrigated alfalfa experiments (Gross and Wudel sites).

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha*			
			Gross site				
1	0-15	7.7	0.3	9	11	680	10
	15-30	7.7	0.3	9	6	300	10
	30-60	7.9	0.3	12	10	440	26
2	0-15	7.8	0.3	7	10	465	14
	15-30	7.9	0.3	5	6	210	12
	30-60	8.0	0.3	10	8	380	34
3	0-15	7.8	0.3	5	7	425	9
	15-30	7.9	0.3	5	4	225	9
	30-60	8.0	0.3	10	4	400	22
4	0-15	7.7	0.3	8	8	475	9
	15-30	7.8	0.3	7	4	230	10
	30-60	8.0	0.3	10	4	430	24
			Wudel site				
1	0-15	8.5	0.3	9	27	270	24+
	15-30	8.7	0.3	8	10	220	18
	30-60	8.1	0.3	10	16	400	32
2	0-15	7.5	0.3	19	20	440	13
	15-30	7.5	0.3	13	10	585	21
	30-60	7.8	0.4	34	18	1000	42
3	0-15	7.5	0.3	17	15	475	13
	15-30	7.6	0.3	17	11	640	24+
	30-60	7.7	0.4	48	24	1160	44
4	0-15	7.3	0.4	14	15	420	24+
	15-30	7.7	0.4	10	8	320	24+
	30-60	8.3	0.4	36	10	500	48+

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth soil test level. The Pederson and Gross sites were located in the southern part of the Irrigation Project while the Wudel site was located in the northern part of the Irrigation Project.

The experiments were established in April of 1976. The fertilizer treatments were arranged in a randomized complete block design with four replicates. Border-dyke irrigation was used at all locations and two of the replicates were placed on each of two border strips. All fertilizer material was hand broadcast. Triple superphosphate (0-45-0) was the source of phosphorus, potassium chloride (fine) (0-0-60) the source of potassium and granulated elemental sulfur (0-0-0-90) (Agri-Sul) the source of sulfur. The various treatments used for the Pederson site are presented in Table 1.3.4 and for the Gross and Wudel sites in Table 1.3.5.

Table 1.3.4. Fertility treatments for the irrigated alfalfa experiments (Pederson site).

Treatment No.	Application	P_2O_5	K_2O	S	Other
		kg/ha			
1		0	0	0	0
2	Annual	28	0	0	0
3	Annual	56	0	0	0
4	Annual	84	0	0	0
5	Annual	112	0	0	0
6	Once only	168	0	0	0
7	Once only	336	0	0	0
8	Annual	0	28	0	0
9	Annual	0	56	0	0
10	Annual	0	112	0	0
11	Annual	0	224	0	0
12	Annual	0	0	28	0
13	Annual	0	0	56	0
14	Annual	0	0	112	0
15	Annual	0	0	224	0
16	Spare				
17	Spare				
18	Spare				

Table 1.3.5. Fertility treatments for the irrigated alfalfa experiments (Gross and Wudel sites).

Treatment No.	Application	P_2O_5 (kg/ha)
1		0
2	Annual	28
3	Annual	56
4	Annual	84
5	Annual	112
6	Once only	84
7	Once only	168
8	Once only	252
9	Once only	336
10	Spare	0

Each plot was 1.5 meters by 6 meters. Samples were cut at a height of approximately 7.5 cm with a 60 cm Mott forage plot harvester over a 5 meter length of the plot. A wet weight of the samples was taken in the field immediately after cutting. A 500 g subsample of each treatment was taken and returned to the laboratory for drying. A dry weight of the subsamples was taken and the four replicates of each treatment bulked and ground in preparation for analyses.

All irrigation applications were as applied by the co-operating farmer.

RESULTS AND DISCUSSION

The yield results are presented in Table 1.3.6 for the Pederson site and Table 1.3.7 for the Gross and Wudel sites. The yield results were variable and showed no consistent trends for the phosphorus fertilizer treatments to indicate

Table 1.3.6. Yield results for irrigated alfalfa (Pederson site).

Treatment No.	Application (kg/ha)	Dry matter yield (kg/ha)		
		Pederson site		
		Cut 1	Cut 2	Total
		(June 28/76)	(Aug. 5/76)	
1	0	5593	2338	7931
2	28 P_2O_5 Annual	5333	2647	7980
3	56 P_2O_5 Annual	5578	2764	8342
4	84 P_2O_5 Annual	4879	2706	7585
5	112 P_2O_5 Annual	5584	2471	8055
6	168 P_2O_5 Once	4961	2520	7481
7	336 P_2O_5 Once	5795	2024	7819
8	28 K_2O Annual	5451	2405	7856
9	56 K_2O Annual	4266	2359	6625
10	112 K_2O Annual	4825	2313	7138
11	224 K_2O Annual	5041	2391	7432
12	28 S Annual	4928	2404	7332
13	56 S Annual	4920	2275	7195
14	112 S Annual	5130	2523	7653
15	224 S Annual	5092	2775	7867
16	Spare	5832	2346	8178
17	Spare	4983	2360	7343
18	Spare	5154	2450	7604
L.S.D. ($P = 0.05$)		921	398	

Table 1.3.7. Yield results for irrigated alfalfa (Gross and Wudel sites).

Treatment No.	P_2O_5	Dry matter yield (kg/ha)					
		Gross site			Wudel site		
		Cut 1	Cut 2	Total	Cut 1	Cut 2	Total
		(June 29/76)	(Aug. 6/76)		(June 29/76)	(Aug. 6/76)	
1	0	4476	2621	7097	3964	2528	6492
2	28 Annual	4681	2398	7079	3791	2655	6446
3	56 Annual	4817	2571	7388	3928	2794	6722
4	84 Annual	4366	2582	6948	4862	2712	7574
5	112 Annual	5770	2482	8252	3240	2549	5789
6	84 Once	5077	2479	7556	3880	2643	6523
7	168 Once	6478	2640	9118	4284	2510	6794
8	252 Once	4678	2981	7659	3864	2698	6562
9	336 Once	5254	2591	7845	4443	2495	6938
10	Spare	5046	2415	7461	4200	2591	6791
L.S.D. (P = 0.05)		1329	339		1336	429	

that a phosphorus response had occurred. At the Pederson site where potassium and sulfur treatments were also applied no response was observed for these treatments. Overall yields at the three sites were possibly somewhat low for irrigated alfalfa, however, they were generally higher than those obtained from previous research in the South Saskatchewan Irrigation Project.

The results for protein and phosphorus content of the alfalfa are presented in Table 1.3.8 for the Pederson site and Table 1.3.9 for the Gross and Wudel sites. The results indicate that phosphorus fertilization had no effect on the protein content of the alfalfa at the three sites. Likewise, potassium and sulfur fertilization at the Pederson site had no effect on the protein content. The protein content of the alfalfa from the Wudel site was higher than that from either the Pederson or Gross sites for the first cut. The reason for this could have possibly been due to differences in the extent of flowering at the three sites since highest protein yields are obtained when approximately one-tenth of the plants have open flowers. Protein contents for the three sites were similar by the second cut.

The results also indicate that the phosphorus content of the alfalfa was not affected by phosphorus fertilization at the Pederson site. However, at the Gross site phosphorus content of the alfalfa increased with an increase in the rate of phosphorus fertilization. This same trend was observed to some extent at the Wudel site. Potassium and sulfur fertili-

Table 1.3.8. The effect of phosphorus, potassium and sulfur fertilization on the protein and phosphorus content of irrigated alfalfa (Pederson site).

Treatment No.	Fertilizer application (kg/ha)	% protein[1]		% P	
		Cut 1	Cut 2	Cut 1	Cut 2
		(June 28/76)	(Aug. 5/76)		
1	0	18.75	18.75	0.225	0.220
2	28 P_2O_5 Annual	18.75	19.69	0.240	0.225
3	56 P_2O_5 Annual	13.13	16.69	0.180	0.240
4	84 P_2O_5 Annual	14.06	18.19	0.210	0.255
5	112 P_2O_5 Annual	15.00	17.81	0.210	0.255
6	168 P_2O_5 Once	15.94	18.94	0.250	0.270
7	336 P_2O_5 Once	15.00	17.63	0.250	0.285
8	28 K_2O Annual	15.00	17.44	0.195	0.215
9	56 K_2O Annual	15.00	16.31	0.190	0.210
10	112 K_2O Annual	13.13	16.13	0.180	0.210
11	224 K_2O Annual	15.00	18.19	0.195	0.245
12	28 S Annual	15.00	17.63	0.205	0.225
13	56 S Annual	14.06	17.63	0.190	0.220
14	112 S Annual	15.00	18.19	0.210	0.240
15	224 S Annual	15.00	17.06	0.195	0.210
16	Spare	15.00	18.56	0.190	0.240
17	Spare	15.00	18.94	0.205	0.240
18	Spare	14.06	17.63	0.185	0.225

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[1] Protein content based on % N at oven-dry moisture x 6.25; % P on oven-dry basis.

Table 1.3.9. The effect of phosphorus fertilization on the protein and phosphorus content of irrigated alfalfa (Gross and Wudel sites).

Treatment No.	P_2O_5 applied (kg/ha)	% protein[1]		% P	
		Cut 1	Cut 2	Cut 1	Cut 2
		(June 29/76)	(Aug. 6/76)		
		Gross site			
1	0	15.00	15.94	0.170	0.225
2	28 Annual	15.00	17.06	0.190	0.255
3	56 Annual	15.00	18.19	0.200	0.270
4	84 Annual	16.88	18.38	0.225	0.290
5	112 Annual	15.00	19.31	0.230	0.310
6	84 Once	16.88	17.44	0.210	0.260
7	168 Once	15.94	18.56	0.255	0.295
8	252 Once	15.00	19.31	0.255	0.315
9	336 Once	16.88	18.56	0.300	0.315
10	Spare	15.94	20.06	0.175	0.240
		Wudel site			
1	0	21.56	19.31	0.330	0.310
2	28 Annual	21.56	18.00	0.330	0.300
3	56 Annual	21.56	18.19	0.345	0.285
4	84 Annual	23.44	17.44	0.375	0.285
5	112 Annual	23.44	17.44	0.360	0.290
6	84 Once	22.50	18.19	0.355	0.300
7	168 Once	23.44	17.81	0.360	0.310
8	252 Once	24.38	18.75	0.390	0.345
9	336 Once	22.50	18.00	0.390	0.340
10	Spare	23.44	18.19	0.315	0.280

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[1] Protein content based on % N at oven-dry moisture x 6.25; % P on oven-dry basis

zation had no effect on the phosphorus content of the alfalfa at the Pederson site.

2. THE EFFECT OF THE NITRIFICATION INHIBITOR ATC ON SOIL MINERAL NITROGEN STATUS AND WHEAT YIELDS

The objectives of this research, which was conducted during the 1976 growing season, were:

(1) To evaluate the effectiveness of the nitrification inhibitor ATC (4-amino-1,2,4-triazole) in controlling the oxidation of ammonium to nitrate by the nitrifying organisms in the soil under Saskatchewan environmental conditions, and

(2) To evaluate ATC coated urea as a source of nitrogen for wheat in selected Saskatchewan soils.

EXPERIMENTAL METHODS

In the spring of 1976 three sites were selected for field trials to test the nitrification inhibitor ATC. These sites were located on stubble fields of a Bradwell very fine sandy loam (University of Saskatchewan Goodale Farm, Floral, Sask.), an Elstow loam (Carlson farm, Outlook, Sask.) and a Melfort silty clay loam (Nielson Bros. farm, Melfort, Sask.). Composite soil samples were taken to a depth of 60 cm for each replicate from each site and submitted to the Saskatchewan Soil Testing Laboratory for routine analysis prior to plot establishment. Results of the analyses for each site are presented in Table 2.1.

Small plots of randomized complete block design were established at each of the three sites. Treatments on the Bradwell soil included 200 kg N/ha urea, 200 kg N/ha urea

Table 2.1 Results of analyses of soils from areas selected for the nitrification inhibitor trials.

Co-operator/ location	Soil type/ texture	Depth (cm)	NO_3-N	$NaHCO_3$ Ext.-P	$NaHCO_3$ Ext.-K	SO_4-S	pH	Cond. (mmhos/cm)
			kg/ha*					
University	Bradwell:	0-7	9	23	564	4	7.7	0.3
Goodale Farm	vfsl	7-15	9	12	326	4	7.6	0.3
NE33-35-4W3		15-30	16	19	395	9	7.9	0.3
		30-60	10	15	385	6	8.1	0.2
			44					
Carlson	Elstow:	0-15	17	29	450	15	8.1	0.4
NE14-27-7W3	l	15-30	16	13	255	24	8.2	0.6
		30-60	28	28	620	48	8.4	0.6
			61					
Nielson	Melfort:	0-15	20	23	565	24	7.3	0.9
NE32-43-19W2	SiCl	15-30	12	10	393	24	7.4	0.8
		30-60	19	10	650	48	7.6	0.9
			41					

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

coated with 0.5% ATC (w/w) and 2.0% ATC (w/w) and 1.0 and 4.0 kg ATC/ha (Table 2.2). Treatments on the Elstow and Melfort soils included urea, urea coated 0.3% ATC and 1.0% ATC all at four rates: 25, 50, 100 and 200 kg N/ha (Tables 2.3 and 2.4). The 200 kg N/ha urea at both sites and the 200 kg N/ha urea coated with 1.0% ATC at the Elstow site and 0.3% ATC at the Melfort site were duplicated within each replicate to facilitate plant and soil sampling of these treatments throughout the growing season.

The Bradwell and Melfort soils were rotovated prior to broadcasting and incorporation of the treatments. All pre-seeding tillage operations were conducted by the co-operating farmer at the Outlook site. Incorporation of the treatments at this site consisted of two harrowing operations at right angles by the co-operating farmer after the application of granular Avadex B.W. The Bradwell soil was left fallow while the Elstow and Melfort soils were seeded to Neepawa wheat. At the Melfort site seeding was conducted with a seven row (18 cm spacing) experimental plot seeder and a blanket application of 11-55-0 was applied to give 40 kg P_2O_5/ha with the seed to all treatments. The Outlook site was seeded with a hoe-press drill by the co-operating farmer and received a blanket application of 11-55-0 with the seed to give 30 kg P_2O_5/ha.

The Goodale site was cultivated throughout the summer as required to control weed growth. The Melfort site received a post emergent wild oat spray in the form of Endaven.

Table 2.2 Treatments used to investigate the effect of the nitrification inhibitor ATC on Soil NO_3^--N and NH_4^+-N levels in a summerfallowed plot.

Treatment No.	kg/ha	Source
1	0	-
2	200 N	Urea with 0.5% ATC
3	200 N	Urea with 2.0% ATC
4	200 N	Urea
5	1.0 ATC	ATC
6	4.0 ATC	ATC

Plot size:	1m x 2m
Design:	Randomized complete block with 4 reps
Location:	NE 33-35-4 W3, University Goodale Farm
Soil type:	Bradwell very fine sandy loam
Date established:	May 13, 1976

Table 2.3 Treatments used to investigate the effect of the nitrification inhibitor ATC on the uptake of fertilizer nitrogen and the yield of wheat under irrigated conditions.

Treatment No.	kg N/ha	Source
0	0	-
1	0	-
2	25	Urea
3	50	Urea
4	100	Urea
5	200	Urea
6	200*	Urea
7	25	Urea with 0.3% ATC
8	50	Urea with 0.3% ATC
9	100	Urea with 0.3% ATC
10	200	Urea with 0.3% ATC
11	25	Urea with 1.0% ATC
12	50	Urea with 1.0% ATC
13	100	Urea with 1.0% ATC
14	200	Urea with 1.0% ATC
15	200*	Urea with 1.0% ATC

*Treatments 0,6 and 15 were for destructive sampling throughout the growing season.

Plot size:	1.5m x 6.1m
Irrigation type:	Border dike
Design:	Randomized complete block with 4 reps
Location:	NE 14-27-7 W3 (A. Carlson farm, Cutbank)
Soil type:	Elstow loam
Date established:	May 14, 1976 (Neepawa wheat)

Table 2.4 Treatments used to investigate the effect of the nitrification inhibitor ATC on the uptake of fertilizer nitrogen and the yield of wheat under dryland conditions.

Treatment No.	kg N/ha	Source
0	0	-
1	0	0
2	25	Urea
3	50	Urea
4	100	Urea
5	200	Urea
6	200*	Urea
7	25	Urea with 0.3% ATC
8	50	Urea with 0.3% ATC
9	100	Urea with 0.3% ATC
10	200	Urea with 0.3% ATC
11	25	Urea with 1.0% ATC
12	50	Urea with 1.0% ATC
13	100	Urea with 1.0% ATC
14	200	Urea with 1.0% ATC
15	200*	Urea with 0.3% ATC

*Treatments 0,6 and 15 were for destructive sampling throughout the growing season.

Plot size:	1.5m x 6.1m
Design:	Randomized complete block with 4 reps
Location:	NE 32-43-19 W2 (Nielson farm, Melfort)
Soil type:	Melfort silty clay loam
Date established:	May 19, 1976 (Neepawa wheat)

Unfortunately a heavy infestation of wild oats was still encountered at this site. Wild oats were controlled at the Outlook site by the pre-plant Avadex BW treatment. No problem was encountered with broadleaf weeds at either site.

Soil samples (0-7 cm, 7-15 cm, 15-30 cm and 30-60 cm) were collected from the Goodale site at two week intervals after its establishment. Three cores from each treatment were bulked per sample. The samples were air-dried (% moisture air-dry basis determined (Appendix Table B1)) and ground prior to exchangeable NH_4^+ and NO_3^--N analysis.

At the Outlook and Melfort sites total above ground plant (3 centre rows x 0.9 m) and soil (0-7 cm, 7-15 cm, 15-30 cm and 30-60 cm) samples were collected at five different growth stages (tillering, flagleaf, heading, softdough and maturity) throughout the growing season from three selected treatments which were duplicated for this purpose (Tables 2.3and 2.4). The three treatments sampled were: control*, 200 kg N/ha urea, and 200 kg N/ha urea coated with ATC (1.0% ATC at the Elstow site and 0.3% ATC at the Melfort site). The plant samples were dried, weighed for yield estimations and ground for total N and P analysis. The soil samples were treated in the same manner as those collected from the Goodale site. Air-dry moisture is presented

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*Samples were collected from guard rows surrounding plot since the control treatment was not duplicated within the plot.

in Appendix Tables B2 and B3.

At maturity the plots were harvested by taking the middle three rows 3 m long from each treatment (cut at soil surface), dried, weighed and threshed. The grain was cleaned and weighed. Grain samples and subsamples of straw (replicates from one treatment were bulked) were ground for total N and P analysis.

After each plot was harvested a composite soil sample was collected from each treatment (0-7 cm, 7-15 cm, 15-30 cm and 30-60 cm) by bulking replicates and treated in the same manner as all other soil samples collected.

Results

I. Goodale fallow plot

The NO_3^- and NH_4^+ concentrations of soil samples collected at two week intervals from the Goodale site to a depth of 60 cm are presented in Tables 2.5 and 2.6. The results for the individual depths are presented in Appendix Tables B4.1 to B4.6.

There were no significant differences in NO_3^- and NH_4^+ concentrations to a depth of 60 cm for the check, 1.0 kg ATC/ha and 4.0 kg ATC/ha treatments at any one sampling date (Tables 2.5 and 2.6). NO_3^- contents for these three treatments generally increased up to 14 weeks (Aug. 19) after plot establishment and then levelled off. NO_3^- levels at the last sampling date (Sept. 16) were higher than those at the initial sampling date (May 13) by 14-19 kg NO_3^--N/ha

Table 2.5 NO_3-N levels (kg/ha - 60 cm) at two week intervals for the Goodale summerfallowed plot (Bradwell soil).

Sampling Date	Check	1.0 kg ATC/ha	4.0 kg ATC/ha	200 kg N/ha	200 kg N/ha	200 kg N/ha	L.S.D.
				Urea	Urea + 0.5% ATC	Urea + 2.0% ATC	
May 22	14.6	13.5	11.5	29.3	22.3	15.9	3.7
June 10	15.8	16.2	12.8	145.5	57.2	32.2	10.8
June 24	20.8	25.2	20.1	141.9	101.8	48.9	13.5
July 8	23.8	25.5	29.7	172.0	135.3	74.4	6.6
July 22	26.0	25.8	26.3	174.8	137.3	119.0	14.6
Aug. 5	29.5	37.4	50.7	207.5	166.6	145.2	23.8
Aug. 19	34.0	40.5	37.8	232.4	163.7	131.9	22.4
Sept. 2	30.9	35.0	38.2	169.1	137.9	154.2	24.8
Sept. 16	28.7	33.5	28.6	195.0	137.3	119.9	14.8

Table 2.6 NH_4-N levels (kg/ha - 60 cm) at two week intervals for the Goodale summerfallowed plot (Bradwell soil).

Sampling Date	Check	1.0 kg ATC/ha	4.0 kg ATC/ha	200 kg N/ha	200 kg N/ha	200 kg N/ha	L.S.D.
				Urea	Urea + 0.5% ATC	Urea + 2.0% ATC	
May 22	33.0	34.0	31.3	160.3	137.6	129.7	24.7
June 10	15.2	18.3	21.0	44.3	58.1	139.8	20.0
June 24	21.7	21.2	18.8	28.7	91.6	94.5	17.0
July 8	19.7	21.4	21.1	25.4	36.5	111.7	5.7
July 22	22.3	21.0	20.4	25.0	37.1	69.4	11.8
Aug. 5	24.3	24.1	30.4	29.7	27.0	80.9	31.6
Aug. 19	22.5	24.6	26.5	25.8	25.8	69.1	15.7
Sept. 2	22.9	24.7	33.0	24.3	25.3	80.0	15.5
Sept. 19	22.4	22.1	21.1	22.4	21.5	34.1	4.4

indicating that nitrification did take place. NH_4^+ content showed an initial increase before rapidly decreasing and leveling off. At the last sampling date the NH_4^+ contents were slightly lower than those at the initial sampling date indicating that NH_4^+ did not build up but instead was nitrified.

Significant differences in NO_3^- and NH_4^+ levels were observed for the 200 kg N/ha urea, urea with 0.5% ATC and urea with 2.0% ATC treatments at the different sampling dates (Tables2.5 and 2.6). At the first sampling date (2 weeks) NO_3^- levels were relatively low for the three treatments whereas NH_4^+ levels were relatively high (Figures 2.1 and 2.2) indicating that hydrolysis of the urea had taken place but the NH_4^+ formed had not yet been nitrified. As time progressed, NO_3^- levels increased and were in the order urea $>$ 0.5% ATC coated urea $>$ 2.0% ATC coated urea while NH_4^+ levels decreased and were in the order 2.0% ATC coated urea $>$ 0.5% ATC coated urea $\geq$ urea. This indicated that the NH_4^+ formed from the hydrolysis of the urea was being nitrified but at a faster rate for the untreated urea than the ATC treated urea. Furthermore, the higher the concentration of ATC the greater the inhibition of nitrification as indicated by NO_3^- and NH_4^+ levels.

The distribution of NO_3^--N down to a depth of 60 cm at the last sampling date indicates that there is a difference between the urea and urea + ATC treatments (Figure 2.3). A

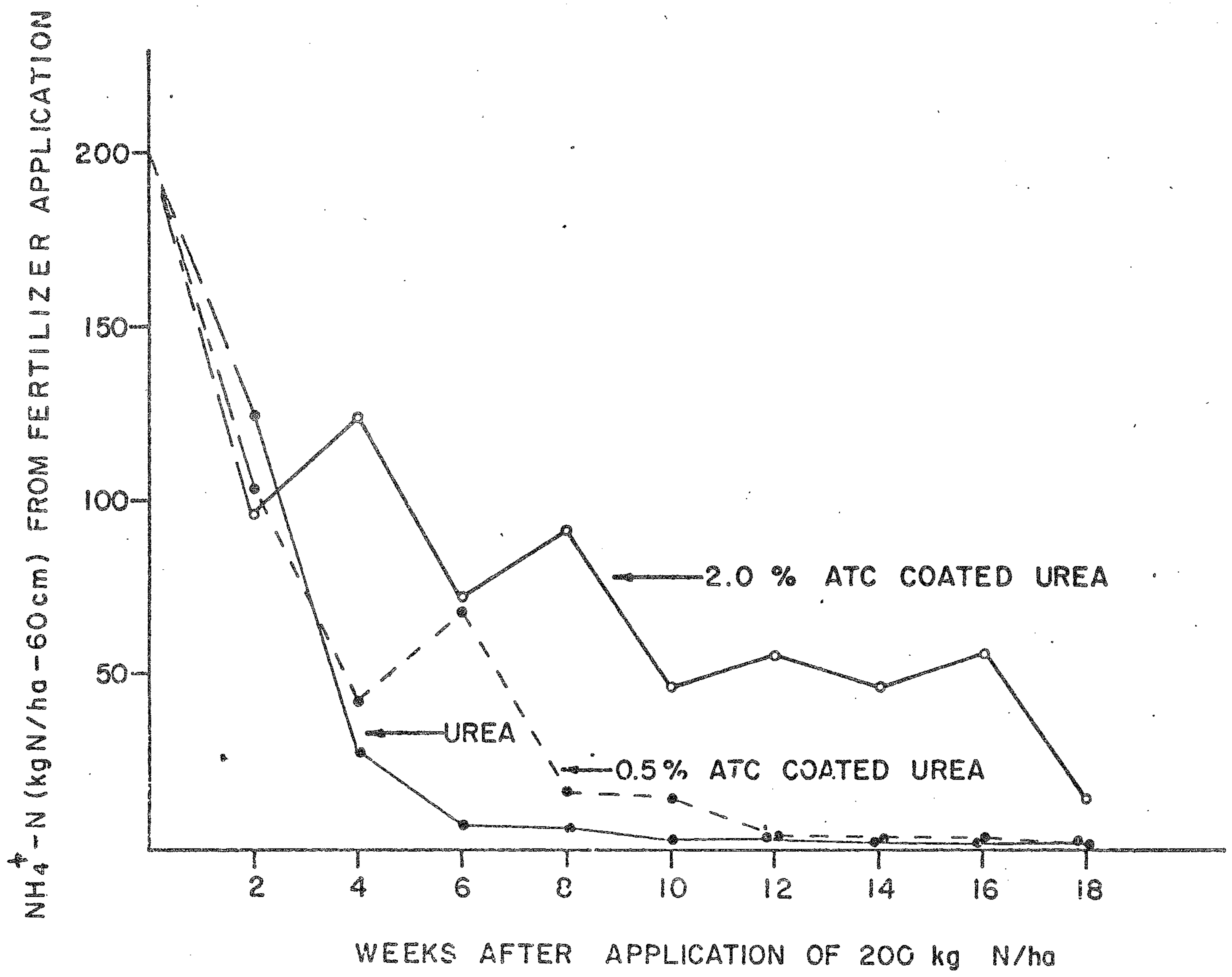

Figure 2.1 NH_4^+-N levels (kg/ha - 60 cm) above the check treatment at two-week intervals for the urea and ATC coated urea treatments on the Goodale plot (Bradwell soil).

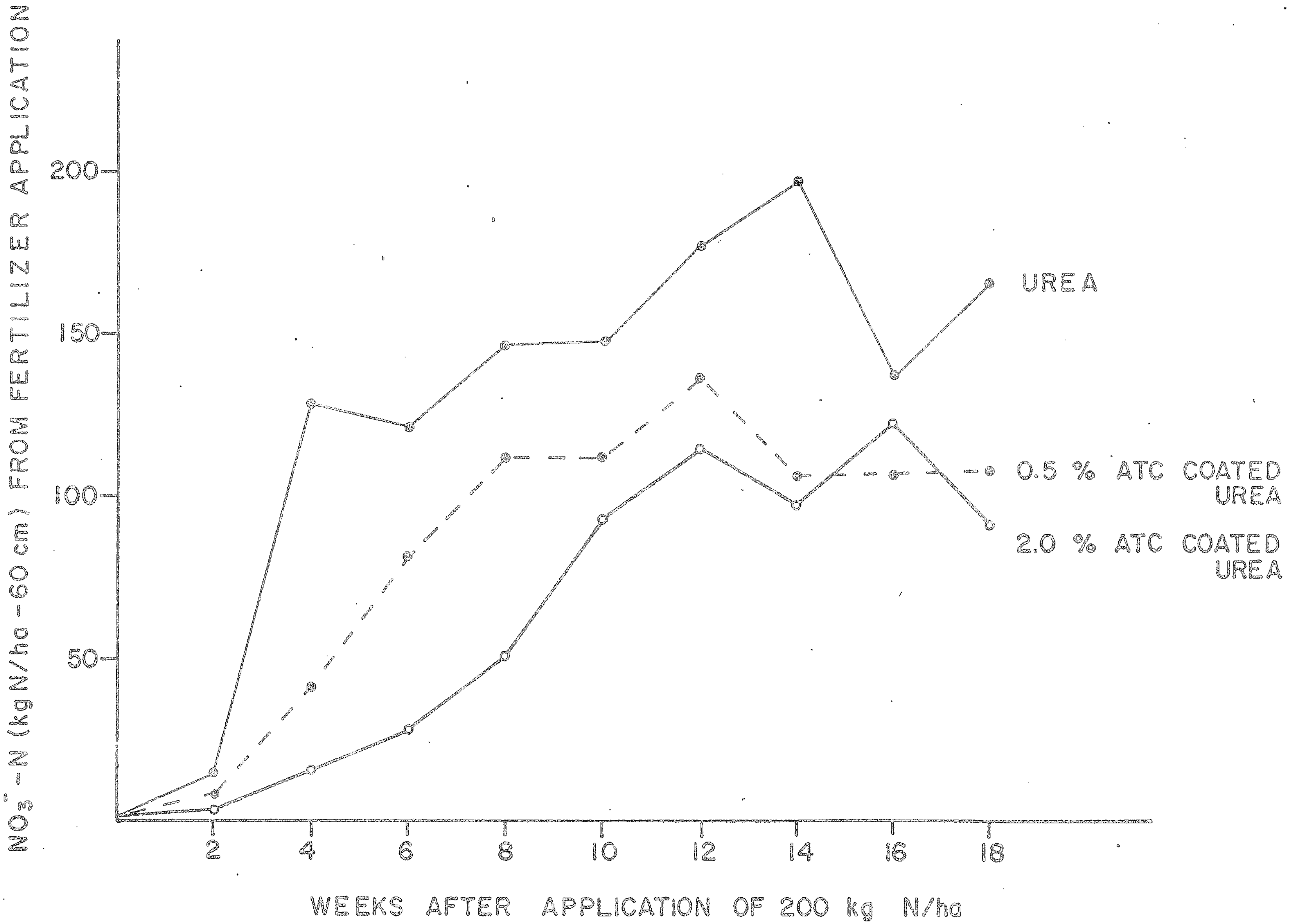

Figure 2.2 NO$_3^-$-N levels (kg/ha - 60 cm) above the check treatment at two-week intervals for the urea and ATC coated urea treatments on the Goodale plot (Bradwell soil).

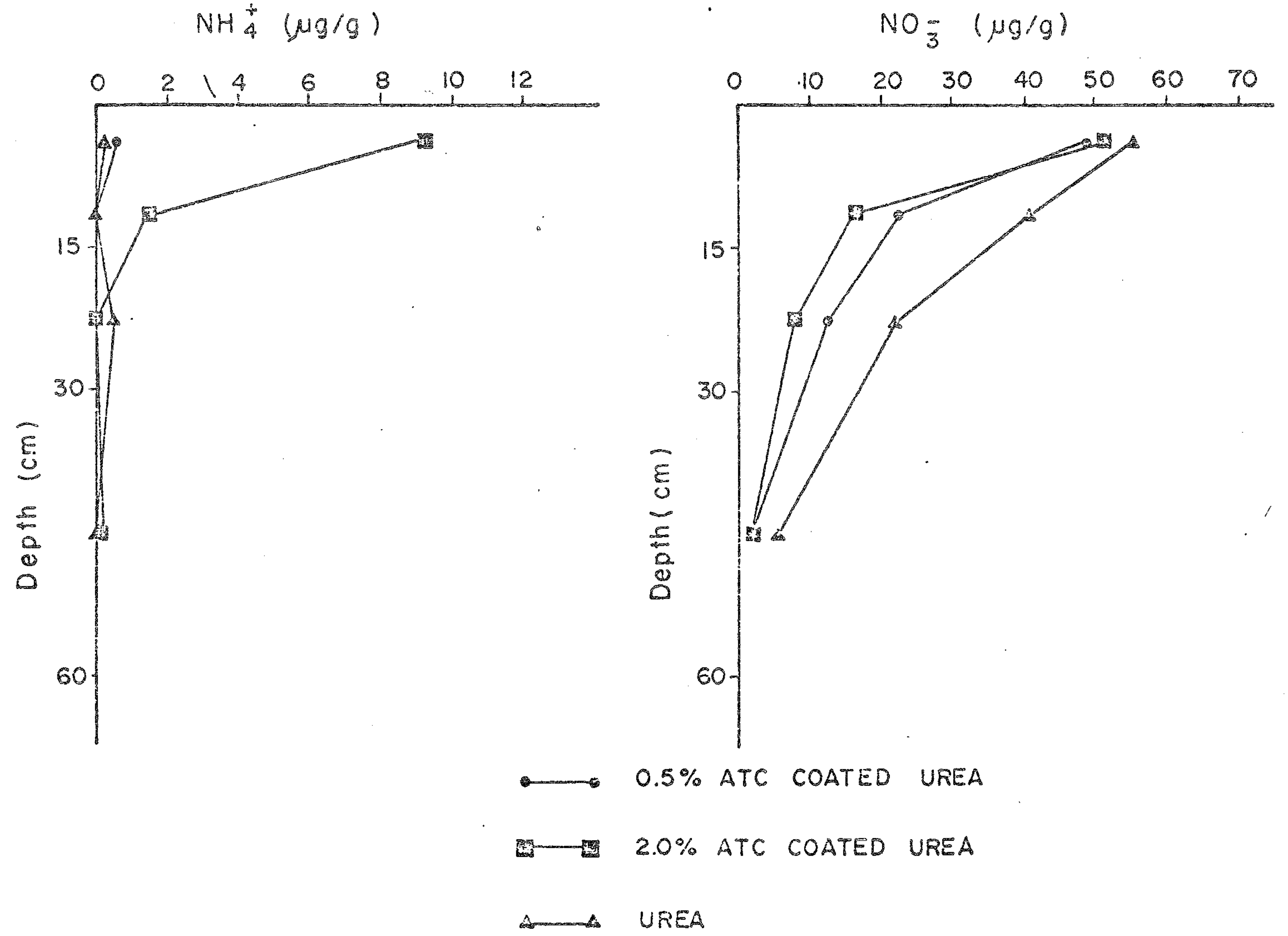

Figure 2.3 NH$_4^+$ and NO$_3^-$ concentrations (ug/g) with depth at the last sampling date (18 weeks after treatment application) for the 200 kg N/ha applied as urea and ATC coated urea on the Goodale plot (Bradwell soil).

greater amount of NO_3^--N was found with depth for the urea than either the urea + 0.5% ATC or urea + 2.0% ATC. However, downward movement would appear to have been limited since the NO_3^--N levels at the lowest depth (30-60 cm) showed only a small difference. This limited downward movement could be due in part to the low rainfall received at the Goodale site (Appendix Table B5).

The recovery of the applied N as $NO_3^- + NH_4^+$ for each treatment fluctuated irratically from one sampling date to the other and cannot be explained (Table2.7; Figure 2.4). A general trend was observed for the recovery of the applied N at any one sampling date: urea $\gg$ 2% ATC coated urea $\gg$ 0.5% ATC coated urea. A possible explanation for the trend could be that for the ATC coated urea more N was kept in the NH_4^+ form and for a longer period than for the urea and the NH_4^+ could have been lost through volatilization or fixed by clay minerals. However, the urea coated with 2.0% ATC showed a higher recovery than the urea coated with 0.5% ATC.

II. Outlook and Melfort plots

1. Wheat yields throughout the growing season

Total aboveground wheat yields at various growth stages indicated that there was a response to applied fertilizer nitrogen at both the Outlook and Melfort sites (Tables 2.8 and 2.9) as both the 200 kg N/ha urea and 200 kg N/ha urea coated with ATC were significantly greater than the control. The yields increased throughout the growing season with the

Table 2.7 Recovery of applied urea N in 0-60 cm soil depth at two week intervals for the Goodale summerfallowed plot. (200 kg N/ha applied as standard urea, 0.5% ATC coated and 2.0% ATC coated.)

Sampling Date	Percent Recovery		
	0.5% ATC	2.0% ATC	Urea
May 22	56	49	71
June 10	42	71	79
June 24	76	51	64
July 8	64	71	77
July 22	63	70	76
Aug. 5	70	86	92
Aug. 19	55	73	101
Sept. 2	55	90	70
Sept. 16	54	52	84

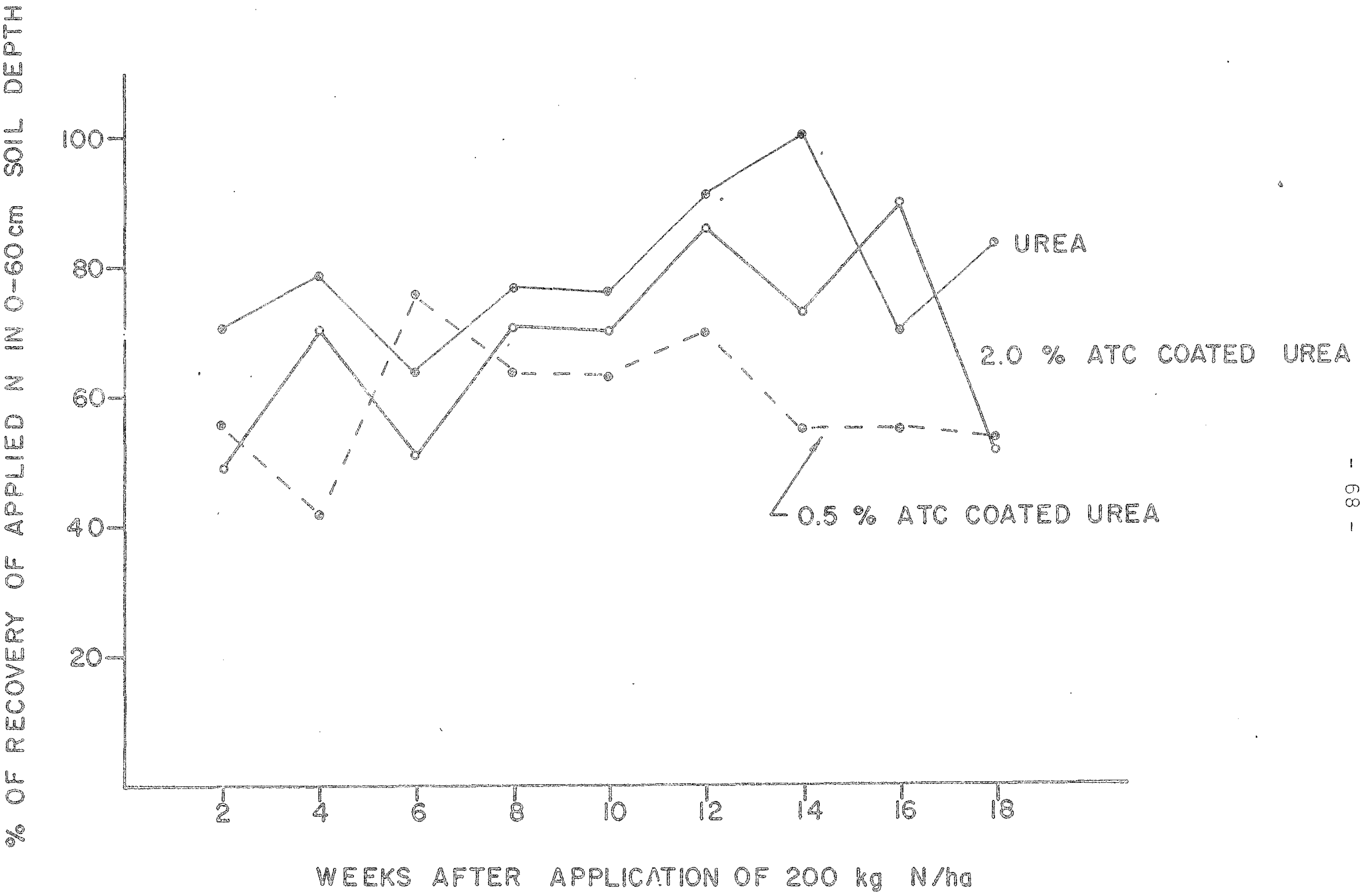

Figure 2.4 Percentage recovery of applied N in the 0-60 cm soil depth at two-week intervals for the urea and ATC coated urea treatments on the Goodale plot (Bradwell soil).

Table 2.8 The effect of urea and urea coated with ATC on dry matter production, N content, N uptake and P content at five growth stages throughout the growing season for the irrigated wheat plot (Elstow soil).

Sampling* Date	Growth Stage	Treatment**	Total wt. (kg/ha)	% N	N uptake (kg/ha)	% P
June 1(18)	Tillering	Control	118	4.79	5.65	0.464
		Urea	142	4.91	6.97	0.472
		Urea + 1.0% ATC	172	4.90	8.43	0.434
		L.S.D.	N.S.	0.26	--	N.S.
June 18(35)	Flagleaf	Control	640	3.43	21.95	0.402
		Urea	978	4.74	46.36	0.481
		Urea + 1.0% ATC	1015	4.75	48.21	0.502
		L.S.D.	337	0.18	--	0.02
July 5(52)	Heading	Control	1527	1.65	25.20	0.261
		Urea	4178	2.68	111.97	0.296
		Urea + 1.0% ATC	3994	2.84	113.43	0.305
		L.S.D.	477	0.17	--	0.04
July 22(69)	Soft dough	Control	3433	1.05	36.05	0.228
		Urea	6960	2.20	153.12	0.248
		Urea + 1.0% ATC	6883	1.88	129.40	0.216
		L.S.D.	654	0.19	--	0.03
Aug. 18(96)	Maturity	Control	4152	0.64	26.57	0.199
		Urea	9714	1.01	98.11	0.150
		Urea + 1.0% ATC	10954	1.00	109.54	0.128
		L.S.D.	942	0.11	--	0.02

*Numbers in parenthesis represents number of days after seeding.

**Urea and urea + 1.0% ATC applied at a rate of 200 kg N/ha.

Table 2.9 The effect of urea and urea coated with ATC on dry matter production, N content, N uptake and P content at four growth stages throughout the growing season for the dryland wheat plot (Melfort site).

Sampling* Date	Growth Stage	Treatment**	Total wt. (kg/ha)	% N	N uptake (kg/ha)	% P
June 30(42)	Flagleaf	Control	1390	2.21	30.72	0.308
		Urea	1467	4.31	63.23	0.424
		Urea + 0.3% ATC	1247	4.51	56.24	0.407
		L.S.D.	N.S.	0.30	--	0.02
July 16(58)	Heading	Control	2440	1.46	35.62	0.265
		Urea	3527	3.03	106.87	0.343
		Urea + 0.3% ATC	3603	3.22	116.02	0.367
		L.S.D.	514	0.08	--	0.03
Aug. 13(86)	Soft dough	Control	4362	0.79	34.46	0.256
		Urea	6879	1.33	91.49	0.158
		Urea + 0.3% ATC	6197	1.63	101.01	0.177
		L.S.D.	1431	0.21	--	0.02
Sept. 1(105)	Maturity	Control	5111	0.70	35.78	0.185
		Urea	8186	0.94	76.95	0.126
		Urea + 0.3% ATC	7684	1.06	81.45	0.133
		L.S.D.	1621	0.21	--	N.S.

*Numbers in parentheses represents number of days after seeding.

**Urea and urea + 0.3% ATC applied at a rate of 200 kg N/ha.

urea and urea coated with ATC treatments following the same trend at both sites (Figures 2.5 and 2.6). There was no significant difference in yield between the urea and urea coated with ATC treatments for each sampling date at each site. The overall yields were generally greater at the Outlook site than the Melfort site. The yields of the control were as high or higher at the Melfort site as the Outlook site possibly due to the greater nitrogen supplying power of the Melfort soil.

2. N content, P content, and N uptake by wheat throughout the growing season

The nitrogen content of the wheat decreased with time throughout the growing season (Tables 2.8 and 2.9). Where nitrogen was applied to the soil the nitrogen content of the wheat was significantly greater than where no nitrogen was applied. There was no significant difference between the urea and urea coated with ATC treatments for the nitrogen content of the wheat samples collected from the Outlook site at any of the growth stages. However, nitrogen content of the wheat samples from the Melfort site was significantly greater for the urea coated with ATC than the urea at the heading (58 days from seeding) and softdough (86 days from seeding) growth stages.

Nitrogen uptake by the wheat increased throughout the growing season and either peaked and decreased or levelled off by the time the plants reached maturity (Tables 2.8 and 2.9;

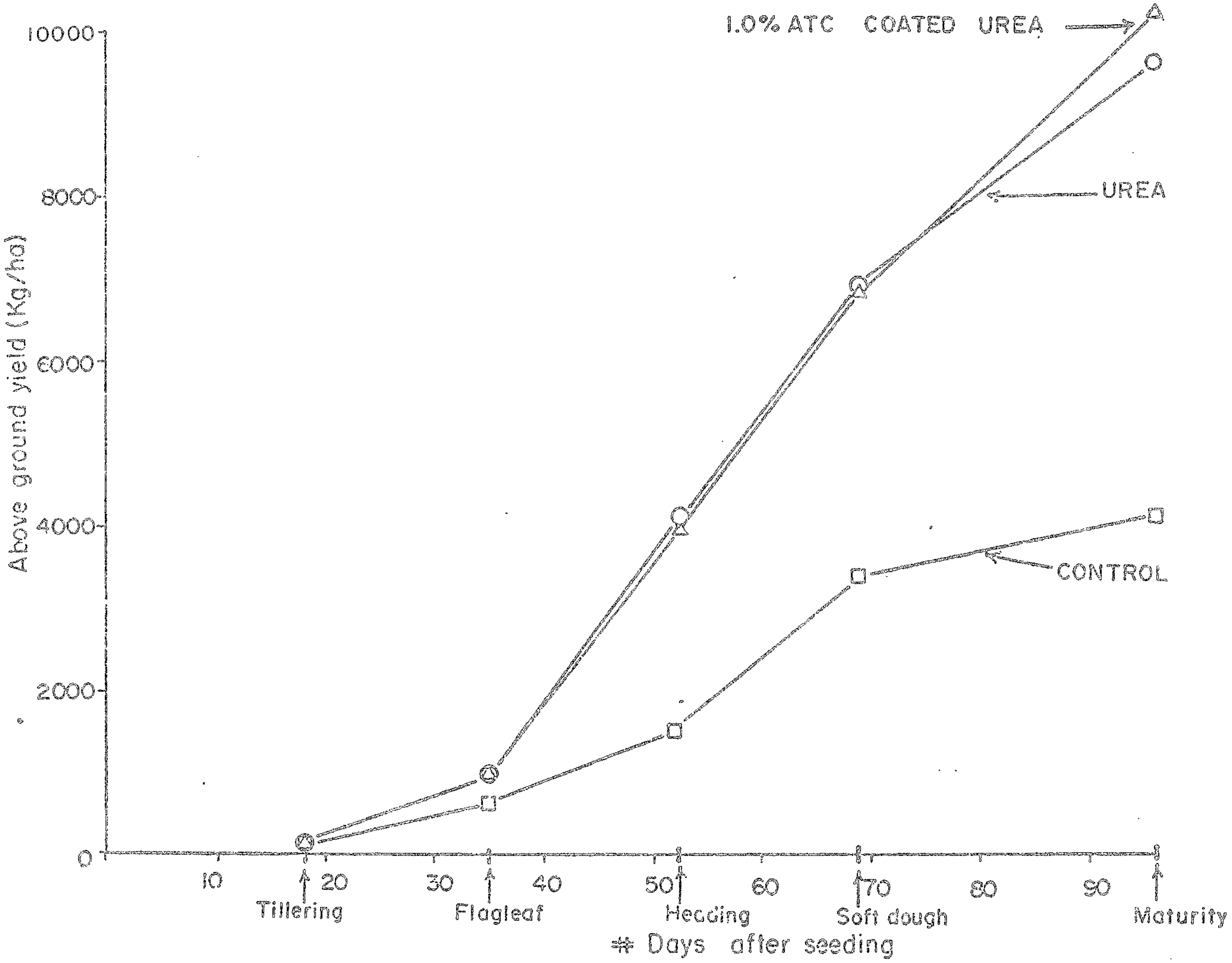

Figure 2.5 The change in aboveground yield (kg/ha) of irrigated Neepawa wheat throughout the growing season for the control, urea and ATC coated urea treatments on the Outlook plot (Elstow soil). The urea and ATC coated urea applied at a rate of 200 kg N/ha.

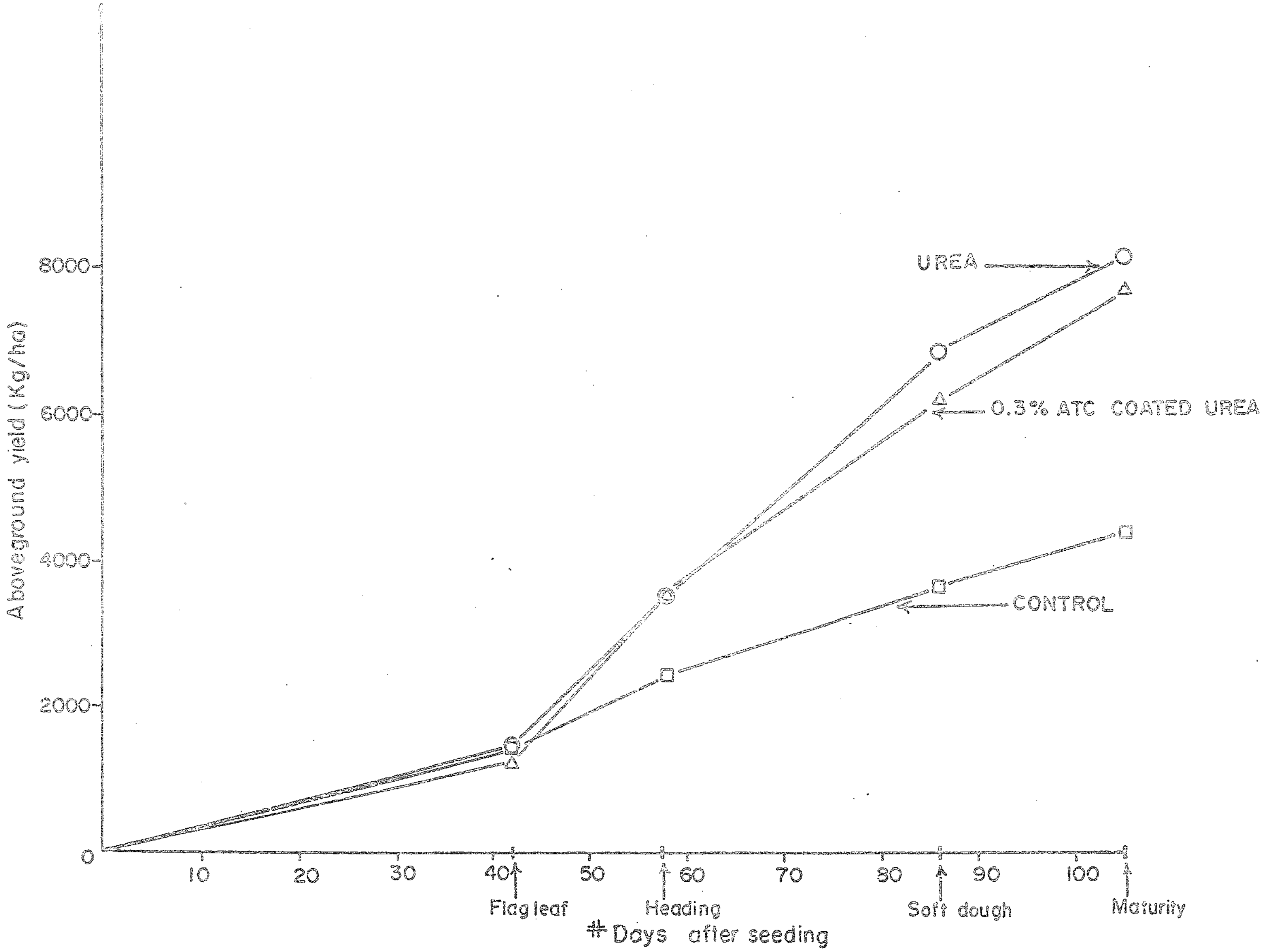

Figure 2.6 The change in aboveground yield (kg/ha) of dryland Neepawa wheat throughout the growing season for the control, urea and ATC coated urea treatments on the Melfort plot (Melfort soil). The urea and ATC coated urea applied at a rate of 200 kg N/ha.

Figures 2.7 and 2.8) at both sites. The urea and urea coated with ATC treatments followed the same nitrogen uptake pattern with little difference between the two treatments. Nitrogen uptake for the control treatment was much reduced compared to the treatment receiving nitrogen applications.

The phosphorus content of the plant samples decreased throughout the growing season at both the Outlook and Melfort sites. No significant trends were observed. The phosphorus content for the three treatments sampled was similar at any one sampling date.

3. NO_3^- and NH_4^+ contents in soil throughout the growing season

The NO_3^- and NH_4^+ contents down to a depth of 60 cm for the Outlook site at the various sampling times throughout the growing season are presented in Table 2.10 and Figure 2.9. The results for the individual depths are presented in Appendix Table B6. For the control both the NO_3^- and NH_4^+ contents increased from the initial sampling to the first growth stage (tillering - 18 days from seeding) after which the NO_3^- decreased to the low content found at the last sampling date (maturity - 96 days from seeding) and the NH_4^+ content levelled off. For the urea and urea coated with 1.0% ATC treatments, NO_3^- content increased up to the second growth stage (flagleaf - 35 days from seeding) and then decreased with contents slightly higher for the urea coated with 1.0% ATC than the urea.

The NH_4^+ contents for the urea and urea coated with 1.0%

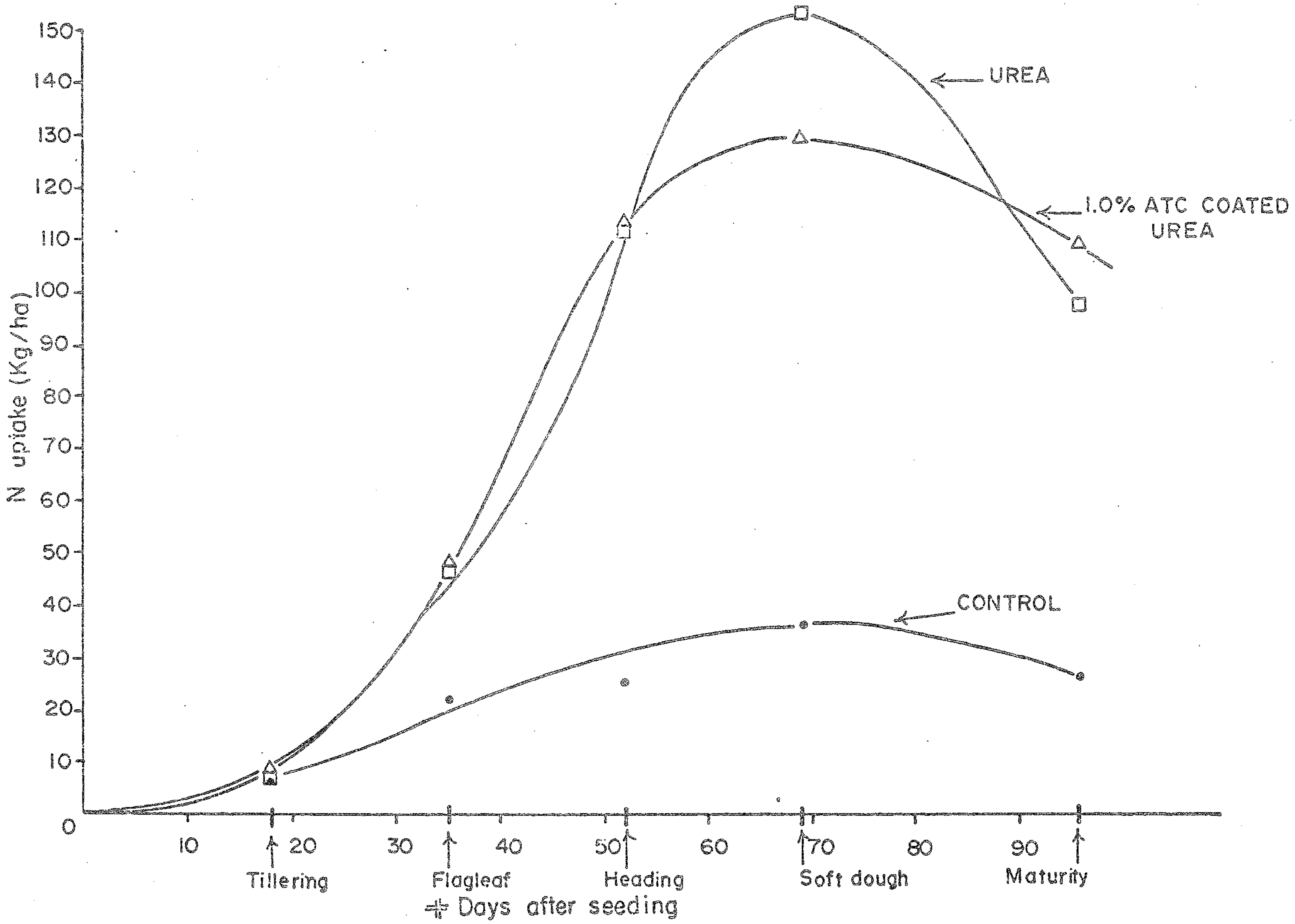

Figure 2.7 The nitrogen uptake (kg/ha) of irrigated Neepawa wheat throughout the growing season for the control, urea and ATC coated urea treatments on the Outlook plot (Elstow soil). The urea and ATC coated urea applied at a rate of 200 kg N/ha.

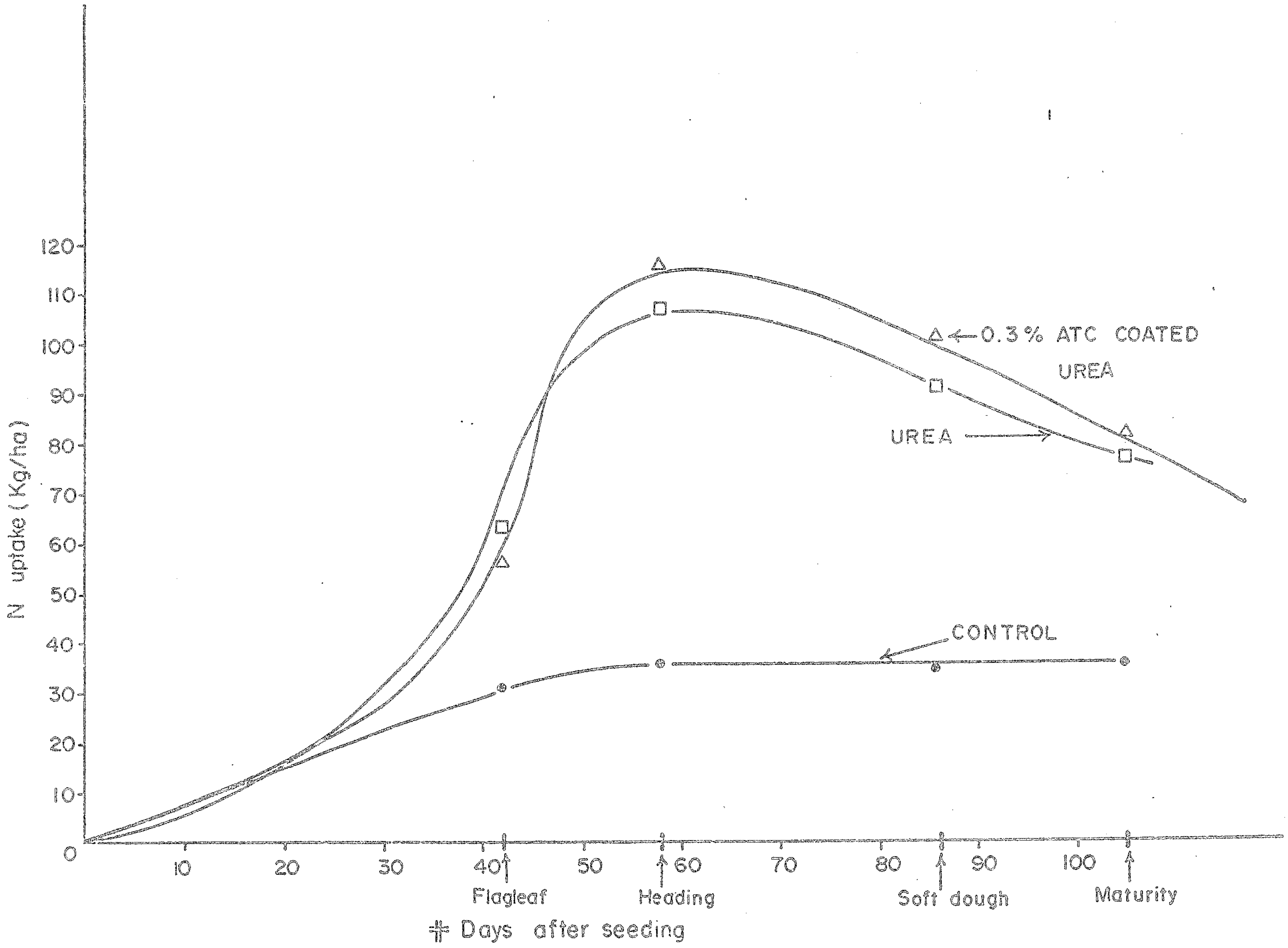

Figure 2.8 The nitrogen uptake (kg/ha) of dryland Neepawa wheat throughout the growing season for the control, urea and ATC coated urea treatments on the Melfort plot (Melfort soil). The urea and ATC coated urea applied at a rate of 200 kg N/ha.

Table 2.10 Soil NO_3^- and NH_4^+ levels (kg/ha - 60 cm) and percent recovery of applied fertilizer (NO_3^- + NH_4^+) throughout the growing season for the irrigated wheat plot (Elstow soil).

Sampling Date	Treatment*	NO_3^-	NH_4^+	Total	% Recovery from soil
	Check	63.8	74.2	138.0	--
	Urea	150.9	151.2	302.4	82.2
	Urea + 1.0% ATC	126.6	347.1	473.1	167.9
	L.S.D.	21.7	73.1	--	--
	Check	18.0	40.3	58.3	--
	Urea	235.8	75.4	311.2	126.5
	Urea + 1.0% ATC	188.0	155.5	343.5	142.6
	L.S.D.	18.5	33.0	--	--
	Check	8.2	46.8	55.0	--
	Urea	107.2	47.8	155.0	50.0
	Urea + 1.0% ATC	129.9	119.4	249.3	97.2
	L.S.D.	37.7	33.8	--	--
	Check	3.0	44.1	47.1	--
	Urea	58.4	46.5	104.9	28.9
	Urea + 1.0% ATC	69.7	50.5	120.2	36.6
	L.S.D.	24.3	N.S.**	--	--
	Check	5.2	43.1	48.3	--
	Urea	36.2	48.5	84.7	18.2
	Urea + 1.0% ATC	83.4	54.8	138.2	45.0
	L.S.D.	23.8	N.S.	--	--

*Urea and urea + 1.0% ATC applied at a rate of 200 kg N/ha.

**Not significant.

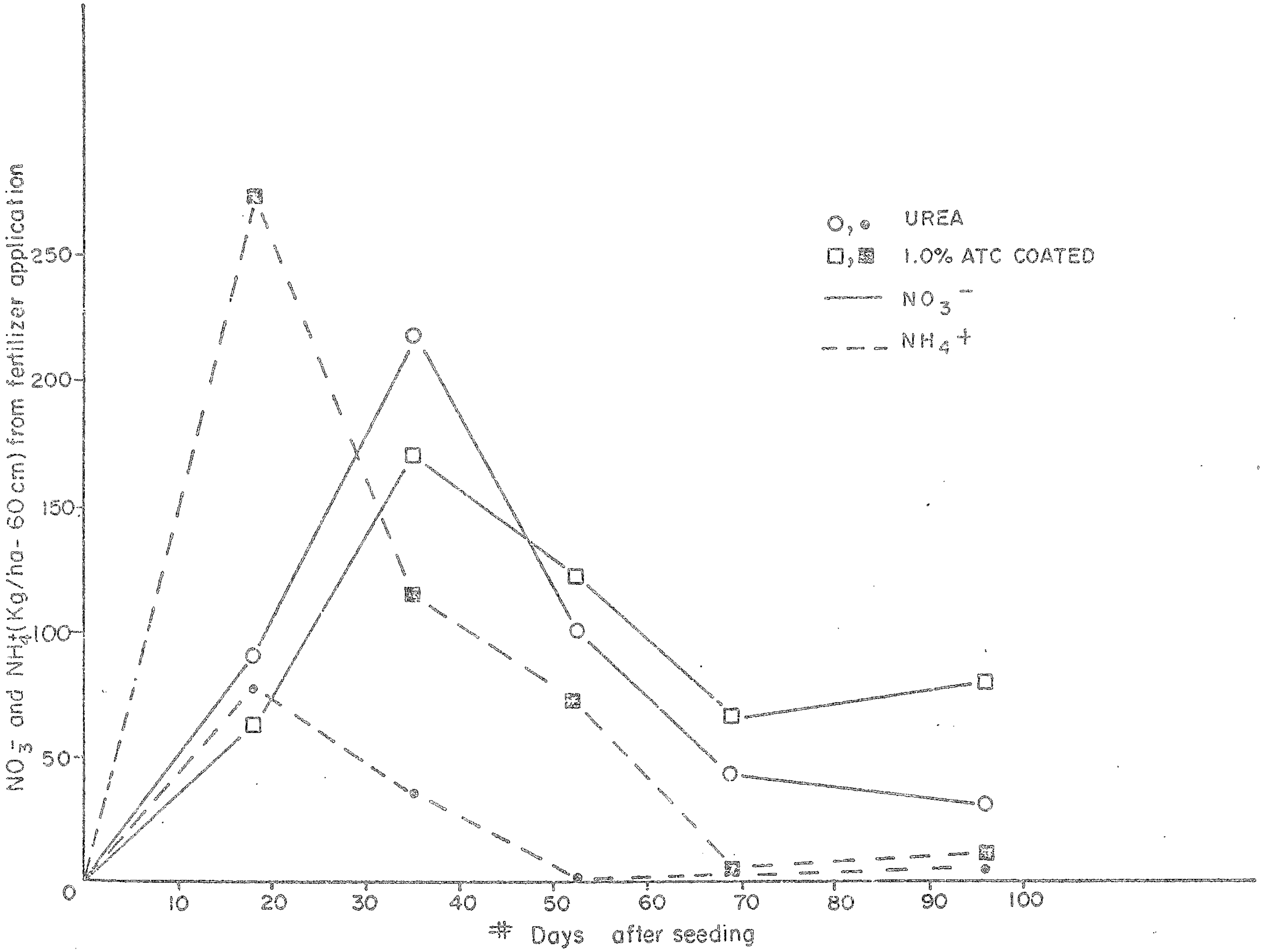

Figure 2.9 NO_3^- and NH_4^+ levels (kg/ha - 60 cm) above the check treatment throughout the growing season for the urea and ATC coated urea treatments on the Outlook plot (Elstow soil). The urea and ATC coated urea applied at a rate of 200 kg N/ha.

ATC treatments increased up to the first sampling date (tillering - 18 days after seeding) with contents much higher for the urea coated with ATC than the urea. The NH_4^+ contents decreased after the first sampling date (18 days after seeding) with the urea treatment remaining at lower levels than the urea coated with 1.0% ATC up to and including the last sampling date (96 days from seeding). The higher contents of NH_4^+ for the urea coated with 1.0% ATC than for the urea would indicate that the ATC did inhibit the nitrification of the NH_4^+ released from the hydrolysis of the urea to some extent. However, this did not affect total yield or nitrogen uptake of the wheat as indicated previously.

The NO_3^- and NH_4^+ contents down to a depth of 60 cm for the Melfort site are presented in Table 2.11and Figure 2.10 with results for the individual depth presented in Appendix Table B7.

For the control treatment at the Melfort site both NO_3^- and NH_4^+ contents showed little change from one sampling date to another but were lower than the content at the initial sampling. NO_3^- content for the urea and urea coated with 0.3% ATC treatments decreased from the first sampling date (flagleaf - 42 days from seeding) to the last sampling date (maturity - 105 days from seeding) and were significantly greater than the control. NH_4^+ contents showed little change with time being only significantly greater than the control at the first sampling date (42 days after seeding). No

Table 2.11 Soil NO_3^- and NH_4^+ levels (kg/ha - 60 cm) and percent recovery of applied fertilizer (NO_3^- + NH_4^+) throughout the growing season for the dryland wheat plot (Melfort soil).

Sampling Date	Treatment[*]	NO_3^-	NH_4^+	Total	% Recovery from soil
	Check	10.1	39.1	49.2	--
	Urea	133.3	44.6	177.9	64.4
	Urea + 0.3% ATC	140.1	48.1	188.2	69.5
	L.S.D.	32.5	N.S.[**]	--	--
	Check	7.1	39.1	46.2	--
	Urea	77.1	43.1	120.2	37.0
	Urea + 0.3% ATC	121.2	46.1	167.3	60.6
	L.S.D.	35.2	N.S.	--	--
	Check	6.6	36.3	42.9	--
	Urea	82.9	38.9	121.8	39.5
	Urea + 0.3% ATC	58.3	39.4	97.7	27.4
	L.S.D.	30.5	N.S.	--	--
	Check	11.3	36.3	47.6	--
	Urea	50.6	46.2	96.8	24.6
	Urea + 0.3% ATC	40.6	42.3	82.9	17.7
	L.S.D.	11.2	N.S.	--	--

[*] Urea and urea + 0.3% ATC applied at a rate of 200 kg N/ha.

[**] Not significant.

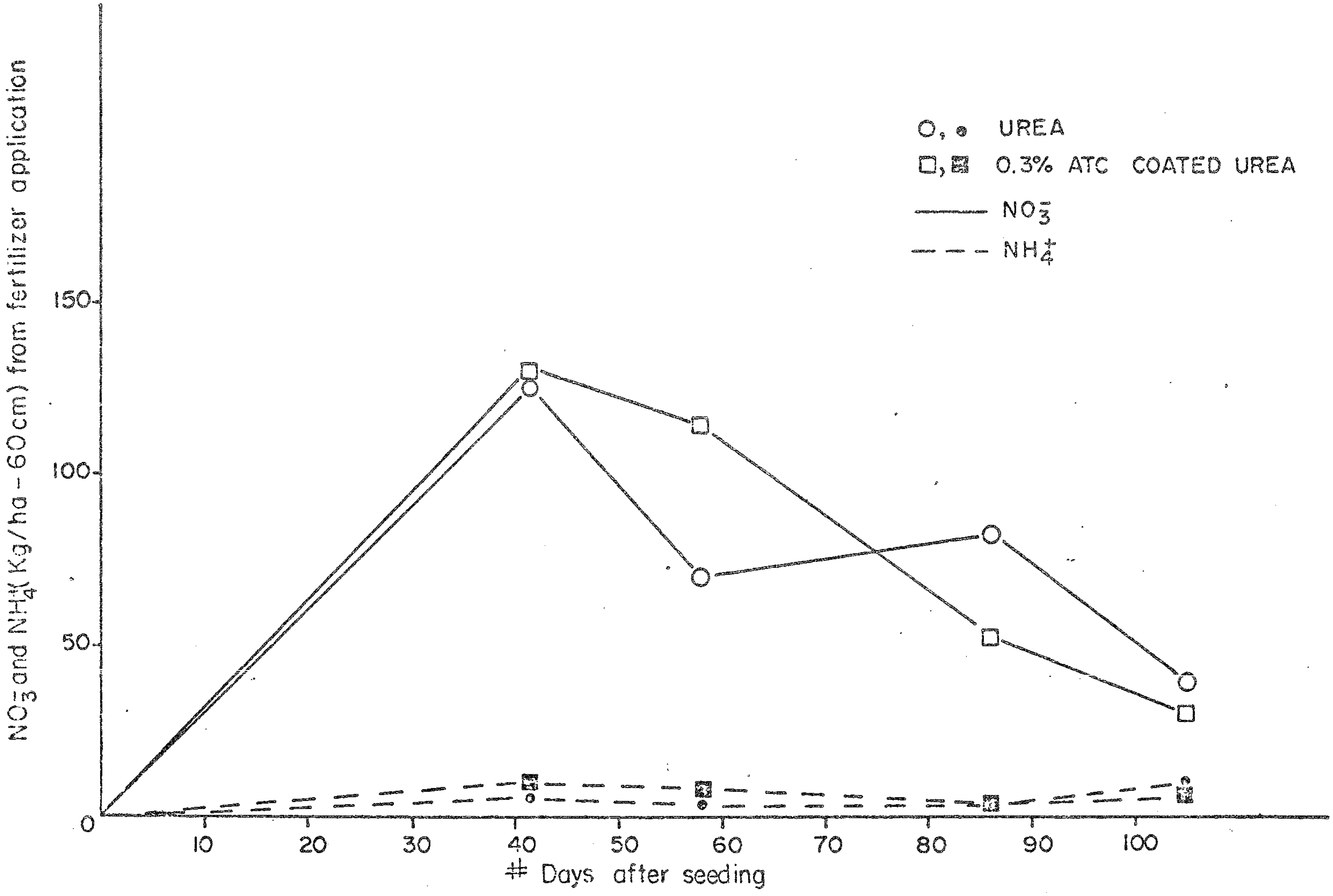

Figure 2.10 NO$_3^-$ and NH$_4^+$ levels (kg/ha - 60 cm) above the check treatment throughout the growing season for the urea and ATC coated urea treatments on the Melfort plot (Melfort soil). The urea and ATC coated urea applied at a rate of 200 kg N/ha.

significant differences between the urea and urea coated with 0.3% ATC treatments for both NO_3^- and NH_4^+ contents at any of the sampling dates. There are three possible reasons for no differences being observed between the urea and urea coated with ATC for both NO_3^- and NH_4^+ contents at the Melfort site:

(a) first sampling date was late (42 days). Most differences were observed soon after application of fertilizer at both the Goodale and Outlook sites,

(b) only 0.3% ATC used at Melfort site which could have been too low of a concentration to inhibit the nitrification of NH_4^+, and

(c) high nitrifying power of the Melfort soil.

4. Yield, N content, P content, and N uptake at final harvest

The yield of both grain and straw for the Outlook and Melfort sites increased with an increase in nitrogen fertilizer applications (Tables 2.12 and 2.13). However, there was no significant difference in the yield of either grain or straw for the urea, urea coated with 0.3% ATC and urea coated with 1.0% ATC treatments at any one nitrogen level at either site. Yields were generally highest at the Outlook site compared to the Melfort site. The Melfort site was infested with wild oats even though it received a post emergent application of Endaven and as a result the grain yields were probably reduced.

At both sites grain protein and straw nitrogen content increased with increasing rates of nitrogen application. On the irrigated Elstow soil the grain protein content at the

Table 2.12 The effect of urea and urea coated with ATC on the yield, N content, P content, and N uptake of irrigated wheat for the Outlook plot (Elstow soil).

Treatment (kg N/ha)	Yield (kg/ha)		Grain* Protein (%)	Grain†		Straw†		N uptake (kg/ha)		
	Grain	Straw		N (%)	P (%)	N (%)	P (%)	Grain	Straw	Total
0	2090	3086	10.41	2.11	0.50	0.20	0.05	44.1	6.2	50.3
25 Urea	2843	3856	10.87	2.21	0.48	0.23	0.03	62.8	8.9	71.7
50 Urea	3067	4276	11.27	2.29	0.48	0.29	0.04	70.2	12.4	82.6
100 Urea	3729	5229	12.83	2.60	0.47	0.32	0.03	97.0	16.7	113.7
200 Urea	3995	5819	13.58	2.76	0.46	0.41	0.03	110.3	23.9	134.2
25 Urea with 0.3% ATC	2761	4026	10.91	2.21	0.50	0.23	0.05	61.0	9.3	70.3
50 Urea with 0.3% ATC	3131	4758	10.80	2.19	0.49	0.26	0.05	68.6	12.4	81.0
100 Urea with 0.3% ATC	3645	5063	12.43	2.52	0.48	0.32	0.03	91.9	16.2	108.1
200 Urea with 0.3% ATC	3998	5670	14.18	2.88	0.46	0.44	0.03	115.1	24.9	140.0
25 Urea with 1.0% ATC	2360	3441	10.34	2.10	0.50	0.23	0.04	49.6	7.9	57.5
50 Urea with 1.0% ATC	3077	4248	11.12	2.26	0.49	0.23	0.03	69.5	9.8	79.3
100 Urea with 1.0% ATC	3792	5525	12.27	2.49	0.48	0.29	0.01	94.4	16.0	110.4
200 Urea with 1.0% ATC	4043	5507	15.00	3.04	0.48	0.43	0.03	122.9	23.7	146.6
L.S.D.	735	1043	0.17	0.12	0.04	--	--	--	--	--

*Grain protein based on % N at 13.5% moisture x 5.7.

†Straw and grain % N and % P on oven-dry basis.

Table 2.13 The effect of urea and urea coated with ATC on the yield, N content, P content, and N uptake of wheat for the Melfort plot (Melfort soil).

Treatment (kg N/ha)	Yield (kg/ha)		Grain* Protein (%)	Grain†		Straw†		N uptake (kg/ha)		
	Grain	Straw		N (%)	P (%)	N (%)	P (%)	Grain	Straw	Total
0	1026	2146	12.97	2.63	0.37	0.41	0.12	27.0	8.8	35.8
25 Urea	1311	3256	11.22	2.28	0.36	0.35	0.09	33.4	8.5	41.9
50 Urea	1788	3995	12.56	2.55	0.37	0.26	0.07	40.8	14.0	54.8
100 Urea	1941	4499	12.31	2.50	0.36	0.41	0.08	48.5	18.4	66.9
200 Urea	2686	5859	14.70	2.98	0.30	0.53	0.05	80.0	31.1	111.1
25 Urea with 0.3% ATC	1408	3465	12.09	2.45	0.38	0.35	0.09	34.5	12.1	46.6
50 Urea with 0.3% ATC	1659	3986	13.01	2.64	0.38	0.41	0.10	43.8	16.3	60.1
100 Urea with 0.3% ATC	1791	4403	13.58	2.76	0.36	0.58	0.08	49.4	25.5	73.9
200 Urea with 0.3% ATC	2686	5866	15.08	3.06	0.32	0.64	0.05	82.2	37.5	119.7
25 Urea with 1.0% ATC	1591	3563	12.04	2.44	0.49	0.38	0.09	38.8	13.5	52.3
50 Urea with 1.0% ATC	1564	4252	11.77	2.39	0.47	0.44	0.11	37.4	18.7	56.1
100 Urea with 1.0% ATC	2123	4853	11.98	2.43	0.47	0.35	0.05	51.6	17.0	68.6
200 Urea with 1.0% ATC	2157	5565	13.98	2.84	0.42	0.79	0.07	61.3	44.0	105.3
L.S.D.	686	1247	0.69	0.14	0.04	--	--	--	--	--

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*Grain protein based on % N at 13.5% moisture x 5.7.

†Straw and grain % N and % P on oven-dry basis.

200 kg N/ha rate was significantly higher for the ATC coated urea than the urea. However, no other general trends were observed in the data which indicate greater nitrogen uptake by wheat from either urea or urea coated with ATC.

Nitrogen uptake also increased with increasing rates of nitrogen application which follows since both yield and nitrogen content of the wheat increased with increasing rates of nitrogen application.

There were no observed differences in the phosphorus content of both grain and straw for the urea and ATC coated urea on the Outlook plot. However, the phosphorus content of grain for the urea coated with 1.0% ATC on the Melfort plot was significantly greater than the urea or urea coated with 0.3% ATC. No such differences could be noted for the phosphorus content of the straw at this plot.

Nitrogen uptake also increased with an increased in nitrogen fertilizer application which follows since both yield and nitrogen content of the wheat increased with nitrogen fertilizer application.

5. Soil NO_3^- and NH_4^+ contents after final harvest

The NO_3^- and NH_4^+ contents in the soil after the final harvest at both the Outlook and Melfort sites down to a depth of 60 cm are presented in Tables 2.14 and 2.15 with results for individual depths presented in Appendix Tables B8 and B9. Generally, NH_4^+ contents were similar for all treatments and nitrogen application rates at both sites. This trend was

Table 2.14 Soil NO_3^- and NH_4^+ levels (kg/ha - 60 cm) and percent recovery of applied fertilizer (NO_3^- + NH_4^+) at harvest for the irrigated wheat plot (Elstow soil).

Treatment (kg N/ha)	NO_3^-	NH_4^+ kg/ha	Total	% Recovery from soil
Check	11.3	34.0	45.3	-
25 Urea	9.9	35.5	45.4	0.4
50 Urea	17.2	32.0	49.2	7.8
100 Urea	22.2	36.0	58.2	12.9
200 Urea	58.6	39.0	97.6	26.2
25 Urea + 0.3% ATC	11.5	39.0	50.5	20.8
50 Urea + 0.3% ATC	7.8	38.0	45.8	1.0
100 Urea + 0.3% ATC	8.3	37.5	45.8	0.5
200 Urea + 0.3% ATC	36.3	34.5	70.8	12.8
25 Urea + 1.0% ATC	9.1	40.0	49.1	15.2
50 Urea + 1.0% ATC	12.8	33.0	45.8	1.0
100 Urea + 1.0% ATC	13.1	33.0	46.1	0.8
200 Urea + 1.0% ATC	29.9	30.0	59.9	7.3

Table 2.15 Soil NO_3^- and NH_4^+ levels (kg/ha - 60 cm) and percent recovery of applied fertilizer (NO_3^- + NH_4^+) at harvest for the dryland wheat plot (Melfort soil).

Treatment (kg N/ha)	NO_3^-	NH_4^+ kg/ha	Total	% Recovery from soil
Check	13.5	39.5	53.0	-
25 Urea	11.0	40.0	51.0	-12.5
50 Urea	11.2	39.5	50.7	-21.7
100 Urea	16.6	38.0	54.6	1.6
200 Urea	39.7	36.5	76.2	11.6
25 Urea + 0.3% ATC	19.4	39.5	58.9	23.6
50 Urea + 0.3% ATC	17.1	40.0	57.1	8.2
100 Urea + 0.3% ATC	24.9	33.0	57.9	4.9
200 Urea + 0.3% ATC	48.0	33.0	81.0	14.0
25 Urea + 1.0% ATC	9.7	33.0	42.7	-2.4
50 Urea + 1.0% ATC	10.6	38.0	48.6	-11.4
100 Urea + 1.0% ATC	12.8	35.0	47.8	-5.2
200 Urea + 1.0% ATC	111.8	33.5	145.3	46.2

observed previously for the time sampling data where the soil NH_4^+ contents had levelled off by the end of the growing season regardless of treatment.

The NO_3^- contents were highest for the highest nitrogen fertilizer application rate (200 kg N/ha) regardless of whether the nitrogen was applied as urea or urea coated with ATC. At the Elstow site NO_3^- contents for the highest nitrogen fertilizer application rate were in the order urea $\gg$ 0.3% ATC coated urea $\gg$ 1.0% ATC coated urea. But at the Melfort site NO_3^- contents were in the order 1.0% ATC coated urea $\gg$ 0.3% ATC coated urea $\gg$ urea.

SUMMARY

The effectiveness of the nitrification inhibitor ATC on soil mineral nitrogen status and wheat yields was studied in three Saskatchewan soils: a Bradwell very fine sandy loam, an Elstow loam and a Melfort silty clay loam.

The Bradwell soil, which was left fallow, was used to follow the time course of exchangeable NH_4^+ and NO_3^--N content of the soil after the application of urea and ATC coated urea. This soil analysis indicated that the ATC delayed but did not completely stop the nitrification of NH_4^+ released from the hydrolysis of the applied urea. It was also observed that the effect of the ATC to delay nitrification increased with concentration at the levels used in this study.

Recovery of the applied nitrogen as NO_3^- and NH_4^+ was generally greater for the urea than the ATC coated urea. Since the effect of the ATC was to delay the nitrification of the NH_4^+, the NH_4^+ could have been subject to loss through volatilization or fixation, thus giving a lower recovery for the ATC coated urea.

Neepawa wheat grown on the irrigated Elstow soil and dryland Melfort soil showed a strong response to applied nitrogen for both urea and ATC coated urea. Above ground dry matter production and nitrogen uptake of plant samples collected at five growth stages on the Elstow soil and four growth stages on the Melfort soil increased throughout the growing season reaching a maximum at the mature and soft dough growth stages, respectively, for each site. However, no significant differences in aboveground dry matter production and nitrogen uptake were observed between the urea and ATC coated urea treatments at each of the growth stages.

Final harvest of the wheat plots indicated that grain yield, straw yield, grain protein and straw nitrogen content increased with increasing rates of nitrogen application but showed no general trends to indicate greater nitrogen uptake by wheat from either urea or ATC coated urea. One exception was found for grain protein content grown on the irrigated Elstow soil at the 200 kg N/ha rate where the ATC coated urea treatment was significantly greater than the urea treatment.

Soil NO_3^- and NH_4^+ levels for the irrigated Elstow soil showed similar trends to those observed for the Bradwell soil in that NH_4^+ levels peaked before NO_3^- levels and that NH_4^+ levels were higher for the ATC coated urea than the urea. For the dryland Melfort soil, NH_4^+ levels showed little change with time being close to the control while NO_3^- levels decreased with time. After the final harvest soil NH_4^+ levels for both soils were similar for all treatments and application rates while NO_3^- levels were highest for the highest fertilizer nitrogen application rate (200 kg N/ha) regardless of whether the nitrogen was applied as urea or ATC coated urea.

3. PRODUCTIVITY STUDIES ON SOLONETZIC SOILS IN THE WEYBURN AREA

A PROGRESS REPORT

D.W. Anderson and D.B. Wilkinson

INTRODUCTION

The Saskatchewan Institute of Pedology is currently re-surveying the soils of the Weyburn and Virden map areas in southeastern Saskatchewan. To assess the significance of the greater detail, finer separations and longer time inputs of the new maps, a study comparing productivity levels of various soil series and map units was begun. This study included Solonetzic and Chernozemic soils, the most commonly occurring soils over much of this area. Additional objectives of this study were to assess the practicability of extending crop rotations on these Dark Brown soils and to gather basic data on soil properties and yield that could be used in the development of predictive models of crop production.

This study was initiated in 1975, when 5 sites were selected, experimental plots established and soil, weather and yield data gathered. The first year's results were for wheat grown on fallow and indicated that yields were greatest on Orthic Dark Brown and intergrade Solonetzic or Solodic Dark Brown soils at 2312 kg/ha. Almost equivalent yields of 1981 kg/ha were observed for Dark Brown Solod soils. Yields on Dark Brown Solonetz and Dark Brown Solodized-Solonetz profiles were less, at 1750 kg/ha and 1297 kg/ha respectively (Anderson and Wilkinson, 1976). Yields were significantly correlated with soil factors indicative of Solonetzic qualities, for example yield and soluble sodium levels of Bnt horizon had a correlation coefficient of -0.53. Surprisingly, yield was negatively correlated with nitrate nitrogen in the 0-60 cm depth, demonstrating the importance of other factors in determining yield.

MATERIALS AND METHODS

The experimental design was described in an earlier report (Anderson and Wilkinson, 1976). In summary, representative fields were selected, transects established across them and plots selected along the transects. Plots, replicated 3 to 5 times were selected on the 3 or 4 most commonly occurring series or subgroup profiles. At seeding, pH, salinity and nutrient levels were measured at each site. Soil moisture levels were measured at seeding and during the season using the neutron moisture probe. Crop growth was monitored. At harvest, square meter estimates of yields were obtained and soil profile described.

Soil analyses were by current techniques of the Saskatchewan Soil Testing Laboratory and included measurement of pH and conductivity on 1:1 soil-water suspensions.

Table 3.1 The subgroup profiles or series included in the study.

Symbol	Association	Subgroup
AMA	Amulet	Orthic Dark Brown
BKW	Brooking	Solonetzic Dark Brown
BKY	Brooking	Solodic Dark Brown
TCS	Trossachs	Dark Brown Solonetz
TCT	Trossachs	Dark Brown Solodized-Solonetz
TCU	Trossachs	Dark Brown Solod

The 1976 data was for wheat grown on land cropped to wheat in 1975 and summerfallowed in 1974. Fertilizer was applied according to soil test recommendations except for one site where additional N was supplied. Except for the Schnell site good control of weeds was accomplished.

RESULTS AND DISCUSSIONS

Yields - The yields of the 1976 wheat crop, grown on stubble, ranged from 1254 to 1984 kg/ha (Table 3.2). At the Flaten site yields were 212% of the 1975 fallow yield, largely a result of the 1975 drought in that area. Yields were reduced substantially at the Schnell site because of a wild oat infestation not treated with herbicide. The three normal fields, Halvorson, Lievaart and Memory, yielded about 82% of the 1975 fallow crop yield. Nitrate-N levels were substantially lower than the levels encountered after fallow, except at the Flaten site where more NO_3-N was available for the 1976 crop than the 1975 crop on fallow. Protein contents were lower for the 1976 crop, except for Flaten where the 1976 level was higher.

Yields were lowest on Dark Brown Solonetz (TCS) profiles at 1385 kg/ha (Table 3.3). Somewhat higher yields of 1397 to 1525 kg/ha were observed for the Chernozemic and intergrade profiles, the AMA, BKW and BKY soils. The best yields were realized on the deep Dark Brown Solod (TCU) profiles at a mean of 2052 kg/ha, with the Solodized-Solonetz profiles (TCT) at 1916 kg/ha. The good yields on the TCT soils were surprising, but perhaps explained by the fact that deep TCT soils with thick Ap and Ae horizons were selected and these soils generally had high NO_3-N levels. The relatively poor yields of the Chernozemic (AMA, BKY, BKW) soils may be explained by the low levels of N as compared to the Solonetzic soils although other factors may be involved. Six of the eight AMA profiles were at the Schnell site where weed problems reduced yield (Table 3.4).

Table 3.2 Yields, protein contents and N levels, 1975 fallow and 1976 stubble crops.

	1975		1976		NO_3-N	NO_3-N	NO_3-N	Growing
					0-60	0-60	0-60	Season
Co-operator	Yield kg/ha	Protein %	Yield kg/ha	Protein %	May 75 kg/ha	May 76 kg/ha	Oct. 76 kg/ha	Rainfall 1976 (mm)
Flaten	935	15.5	1984	18.0	128	170	111	229
Halvorson	2177	14.1	1800	13.0	121	65	29	220
Lievaart	2016	13.7	1691	11.8	110	78	29	180
Memory	1982	14.7	1603	14.4	104	78	60	196
Schnell	2331	12.9	1254	10.9	87	60	25	177

Table 3.3 A comparison of mean yields and protein contents among subgroup profiles.

Subgroup Profiles	Replicates	Total Yield kg/ha	Grain Yield kg/ha	Protein %
TCS	13	4971 ± 183	1385 ± 70	14.9
TCU	13	6786 ± 341	2052 ± 110	15.1
TCT	22	6447 ± 268	1916 ± 105	15.4
BKW	11	5242 ± 169	1397 ± 80	11.4
BKY	10	6122 ± 440	1525 ± 206	13.1
AMA	8	5492 ± 256	1439 ± 114	12.9

Table 3.4 Yields and protein contents for the subgroup profiles at each site

Co-operator	Series	No. of Replicates	Total Yield kg/ha		Grain Yield kg/ha		Protein %
Halvorson	TCS	1	520		1705		21.4
	TCU	5	6865	671	2022	233	13.1
	TCT	4	6436	995	1776	400	13.5
	BKY	2	7705	505	1885	35	13.9
	BKW	2	5320	211	1438	87	11.1
Flaten	TCS	3	5257	498	1542	167	18.7
	TCU	4	6906	710	2039	199	17.5
	TCT	10	6676	380	2096	134	18.0
Lievaart	AMA	2	5368	18	1533	173	10.6
	BKW	2	5205	280	1583	123	11.3
	TCS	5	5000	355	1368	100	12.1
	TCU	2	6643	408	2068	88	12.2
	TCT	4	6893	401	2040	152	12.1
Memory	BKW	2	4845	895	1365	280	9.6
	BKY	4	5851	904	1911	366	14.2
	TCS	4	4650	193	1210	93	14.0
	TCU	2	6495	1100	2138	368	15.9
	TCT	3	5173	7515	1518	58	14.6
Schnell	AMA	6	5534	347	1408	347	13.3
	BKY	4	5400	236	1290	173	13.1
	BKW	4	5601	240	958	87	12.1
	TCT	1	6225		1380		12.7

Soil Properties - Nitrate-N contents were greatest in the more strongly Solonetzic soils, the TCU, TCT and TCS series (Table 3.5). Much of the nitrate was in the subsoils, often in association with soluble salts. Available phosphorus (P) was slightly higher in the Solonetzic soils, but differences were not great. The data for soluble and exchangeable sodium (Na) and soluble salts (EC) indicate that the Solonetzic TCT and TCS soils had the highest Na contents and their subsoils were the most saline. Salt and Na contents of the intergrade and Chernozemic soils were lower. This indicates a general, but not always consistent, relationship between soil morphology and several chemical indices for Solonetzic soils. All soils were neutral to slightly alkaline, except for the surface horizon of the TCU soils which were acidic.

Correlations Between Yield and Soil Properties - The strongest correlations between yield and soil properties were between yield and depth of friable A horizon (Ap + Ae + AB horizon thickness, $r = 0.37$) and depth to lime carbonate ($r = 0.40$, Table 3.6). This was expected in that it has generally been recognized that the thickness of soil above the tough Solonetzic B was important in determining yield, and that deep soils occur in sites where moisture and nutrient supply are relatively favorable and natural productivity is high. NO_3-N levels in the 0-90 or 0-120 cm depths were correlated with yield, although R^2 values were quite low. The only significant correlation between yield and properties related to the salt or sodium content of the soils was between yield and the salinity level of the 0-15 cm depth. This is in contrast to 1975 data where strong correlations between yield and soluble and exchangeable sodium percentages were noted. However, the relatively good yields on the sodium affected

Table 3.5 Properties of the 6 subgroup profiles studied, mean values.

Number of replicates	TCU 13	TCT 22	TCS 13	BKY 10	BKW 11	AMA 8
NO_3-N, 0-15 cm, lbs/ac	24 ± 3	24 ± 2	27 ± 4	19 ± 3	17 ± 1	16 ± 1
NO_3-N, 0-60 cm, lbs/ac	92 ± 17	104 ± 14	87 ± 12	66 ± 7	62 ± 4	53 ± 3
NO_3-N 0-90 cm, lbs/ac	136 ± 14	155 ± 18	120 ± 15	107 ± 24	88 ± 1	75 ± 3
NO_3-N 0-120 cm, lbs/ac	161 ± 27	187 ± 21	139 ± 18	131 ± 30	106 ± 8	95 ± 5
NO_3-N, 30-120 cm, lbs/ac	116 ± 21	136 ± 16	89 ± 12	98 ± 30	74 ± 7	66 ± 5
P, 0-15 cm. lbs/ac	22 ± 2	22 ± 2	21 ± 3	17 ± 1	17 ± 2	18 ± 2
B horizon water sol. Na+ me/l	3.4 ± 1.2	9.3 ± 2.1	10 ± 3.2	1.05 ± 0.3	1.8 ± 0.7	
B horizon exch Na^+, me/100g	351 ± 126	3.4 ± 0.7	3.7 ± 0.8	0.50 ± 0.2	0.5 ± 0.2	0.4 ± 0.2
SAR Bnt	4.4 ± 1.4	8.4 ± 1.6	7.9 ± 1.5	1.8 ± 0.6	1.6 ± 0.6	1.1 ± 0.8
pH, 0-15 cm	6.5 ± 0.1	6.7 ± 0.1	7.2 ± 0.1	7.2 ± 0.2	7.2 ± 0.1	7.6 ± 0.1
pH, 15-30 cm	6.9 ± 0.1	7.3 ± 0.1	7.7 ± 0.1	7.5 ± 0.1	7.6 ± 0.1	7.8 ± 0.1
pH, 30-60 cm	7.7 ± 0.2	7.9 ± 0.1	8.3 ± 0.1	8.0 ± 0.1	8.3 ± 0.1	8.2 ± 0.1
EC, 0-15 (mmhos/cm)	0.37 ± 0.06	0.42 ± 0.05	0.75 ± 0.05	0.44 ± 0.03	0.64 ± 0.08	0.49 ± 0.04
EC, 15-30 (mmhos/cm)	0.53 ± 0.07	0.76 ± 0.13	1.26 ± 0.45	0.54 ± 0.05	0.55 ± 0.05	0.40 ± 0.03
EC, 30-60 (mmhos/cm)	1.17 ± 0.43	2.26 ± 0.60	2.77 ± 1.23	0.61 ± 0.20	0.56 ± 0.13	0.34 ± 0.02
EC, 60-90 (mmhos/cm)	2.10 ± 0.73	3.91 ± 0.83	3.78 ± 1.38	1.42 ± 0.78	2.24 ± 0.87	0.43 ± 0.03
EC, 90-120 (mmhos/cm)	2.94 ± 0.75	5.04 ± 0.92	4.84 ± 1.52	1.93 ± 0.51	3.26 ± 0.98	0.96 ± 0.27

Table 3.6 Simple correlation coefficients between soil properties and yield, protein content and protein yield.

Soil Property	Grain Yield kg/ha	Protein (%)	Protein Yield kg/ha
NO_3-N, 0-15 cm	0.14	0.56	0.34
NO_3-N, 0-60 cm	0.18	0.72	0.46
NO_3-N, 0-90 cm	0.24	0.78	0.53
NO_3-N, 0-120 cm	0.27	0.78	0.55
Salinity, 0-15 cm	-0.29		
Ap + Ae + AB thickness	0.37		
Depth to $CaCO_3$, cm	0.40		

Significance levels, 5% level, r = 0.22, 1% level, r = 0.29.
Only most significant correlations shown.

TCU and TCT profiles in 1976 disrupted this relationship.

Available N supplies in the 0-15, 0-60 and 0-90 cm depths were strongly correlated with the protein content of the grain, with best correlations obtained with NO_3-N in the 0-90 cm depth. This indicates the importance of subsoil N in determining protein content of grain. Somewhat poorer correlations were noted between protein yield and NO_3-N reflecting the poor correlations between NO_3-N and grain yield and inverse yield-protein relationships.

Multiple Regression Equations - Stepwise multiple regression between yield and soil properties yielded the following regression equation:

Grain yield (g/m^2) = 112 + 2.53 (Ap + Ae + AB cm) with a R^2 value of 22.2%.

Additional soil properties which were added to the equation step-wise but did not make a statistically significant contribution were:

Depth to $CaCO_3$ - 4% increase in R^2

Phosphorus, 0-15 cm - 1.8% increase in R^2

NO_3-N, 0-120 cm - 0.9% increase in R^2.

Relationships between protein yield and soil properties were described by the equation:

Protein yield (g/m^2) = 77.0 + 0.054 (NO_3-N, 0-120 cm) + 0.59 (Depth to $CaCO_3$) . (R^2 = 36.5%).

This equation includes the effect of A horizon thickness on yield and NO_3-N supplies in percent protein.

This short report is a summary of some of the data gathered in this study. Complete data for the 1975 and 1976 has been stored by computer methods and is available for use. This includes data for soil moisture at seeding and through the growing season. Further discussion of the data can be found in the 1976 and 1977 proceedings of the Soil Fertility Workshop.

REFERENCES

Anderson, D.W. and D.B. Wilkinson, 1977. Productivity studies on Solonetzic soils in the Weyburn area, a progress report. Proc. 1977 Soil Fertility Workshop, University of Saskatchewan.

4. APPENDICES

Appendix Table A. Selected tables of data for the 1976 irrigation experiments.

Appendix Table A1. Fall soil analyses P placement experiment, Elstow loam (Pederson site).

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha*			
			Irrigated Peas				
1	0-15	7.1	0.4	7	16	755	16
	15-30	7.2	0.4	2	5	270	17
	30-60	7.6	0.6	4	4	630	48+
2	0-15	7.1	0.4	4	11	730	18
	15-30	7.2	0.3	4	6	305	15
	30-60	7.7	1.1	6	8	640	48+
3	0-15	7.1	0.4	10	14	700	15
	15-30	7.3	0.4	3	5	290	13
	30-60	7.8	0.6	6	6	600	48+
4	0-15	7.2	0.6	6	12	725	18
	15-30	7.3	0.4	3	5	250	13
	30-60	7.8	0.7	6	6	500	48+
			Irrigated Fababeans				
1	0-15	7.2	0.6	5	7	685	24+
	15-30	7.4	0.3	3	4	285	24+
	30-60	7.8	1.5	4	6	610	48+
2	0-15	7.4	0.4	3	19	680	19
	15-30	7.5	0.4	2	6	280	15
	30-60	8.0	0.6	4	8	560	48+
3	0-15	7.4	0.6	4	8	785	21
	15-30	7.7	0.4	3	4	310	15
	30-60	8.0	0.7	4	4	610	48+
4	0-15	7.4	0.4	3	6	700	24+
	15-30	7.5	0.4	3	3	250	16
	30-60	7.9	0.7	4	4	580	48+
			Irrigated Lentils				
1	0-15	7.3	0.4	4	21	685	20
	15-30	7.5	0.4	2	7	240	18
	30-60	7.7	1.9	4	12	580	48+
2	0-15	7.6	0.4	4	10	600	15
	15-30	7.8	0.6	3	5	215	15
	30-60	8.1	0.6	6	6	410	24

Appendix
Table A1. Con't.

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha			
3	0-15	7.6	0.4	4	11	580	10
	15-30	7.8	0.6	2	4	230	8
	30-60	8.1	0.9	6	6	520	48+
4	0-15	7.6	0.4	4	11	605	24+
	15-30	7.8	0.4	2	3	245	11
	30-60	8.1	0.8	6	4	520	48+
			Irrigated Beans				
1	0-15	7.0	0.3	11	8	590	17
	15-30	7.2	0.3	3	3	260	16
	30-60	7.9	0.8	12	6	630	48+
2	0-15	7.3	0.4	5	7	665	18
	15-30	7.5	0.4	3	3	255	10
	30-60	8.0	0.6	6	4	580	42
3	0-15	7.3	0.4	4	5	680	14
	15-30	7.4	0.4	3	3	280	13
	30-60	7.9	0.6	6	6	580	48+
4	0-15	7.3	0.4	4	6	530	18
	15-30	7.5	0.4	3	3	240	12
	30-60	8.0	0.6	6	4	610	48+
			Irrigated Rapeseed				
1	0-15	7.2	0.4	5	12	640	12
	15-30	7.3	0.3	2	5	215	12
	30-60	7.8	0.4	6	6	460	32
2	0-15	7.3	0.4	5	9	480	11
	15-30	7.6	0.4	3	4	235	9
	30-60	7.9	0.6	6	6	480	30
3	0-15	7.3	0.6	6	13	720	11
	15-30	7.6	0.4	5	5	300	8
	30-60	7.9	0.6	10	6	540	32
4	0-15	7.3	0.6	7	13	645	15
	15-30	7.6	0.4	4	5	270	12
	30-60	7.9	0.6	8	6	480	34

Appendix
Table A1. Con't.

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha			
			Irrigated Flax				
1	0-15	7.0	0.4	2	15	725	18
	15-30	7.4	0.4	2	6	255	13
	30-60	7.9	0.6	14	6	560	48+
2	0-15	7.0	0.4	2	13	650	16
	15-30	7.2	0.3	2	6	250	8
	30-60	7.8	0.6	6	6	660	32
3	0-15	7.2	0.4	2	15	825	14
	15-30	7.3	0.4	2	6	320	11
	30-60	8.0	0.7	4	6	580	48+
4	0-15	7.1	0.4	3	10	715	19
	15-30	7.4	0.4	2	5	265	24+
	30-60	7.8	0.6	8	6	600	48+
			Dry Peas				
1	0-15	7.0	0.6	9	20	465	24+
	15-30	7.2	0.4	2	7	200	24+
	30-60	7.7	0.6	8	6	480	48+
2	0-15	7.1	0.4	7	13	495	21
	15-30	7.4	0.4	2	5	225	24+
	30-60	7.8	0.6	6	6	540	48+
3	0-15	6.9	0.4	9	26	560	17
	15-30	7.1	0.4	2	8	200	24+
	30-60	7.8	0.6	4	6	470	48+
4	0-15	7.0	0.4	8	21	535	18
	15-30	7.5	0.6	3	6	205	24+
	30-60	7.7	0.6	4	6	440	48+
			Dry Fababeans				
1	0-15	7.2	0.4	5	11	630	24+
	15-30	7.4	0.4	2	4	230	24+
	30-60	8.0	0.9	4	4	560	48+
2	0-15	7.4	0.4	5	12	590	24+
	15-30	7.7	0.4	2	4	265	24+
	30-60	8.0	0.1	4	8	630	48+

Appendix
Table A1. Con't.

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha			
3	0-15	7.1	0.4	7	16	620	20
	15-30	7.3	0.4	2	6	220	24+
	30-60	7.9	0.6	4	8	540	48+
4	0-15	7.3	0.4	6	10	650	13
	15-30	7.3	0.4	2	4	250	24+
	30-60	7.8	0.6	4	4	540	48+
			Dry Lentils				
1	0-15	7.0	0.3	4	12	480	15
	15-30	7.4	0.3	2	4	210	8
	30-60	8.0	0.7	8	4	500	48+
2	0-15	7.1	0.3	5	11	535	18
	15-30	7.3	0.3	2	5	205	24+
	30-60	7.8	0.7	4	4	520	48+
3	0-15	7.0	0.4	5	15	670	24+
	15-30	7.3	0.3	2	6	210	17
	30-60	8.1	0.6	6	4	540	48+
4	0-15	6.9	0.3	5	14	595	24+
	15-30	7.1	0.3	2	6	230	19
	30-60	7.7	0.4	4	6	580	42
			Dry Beans				
1	0-15	6.9	0.6	8	10	670	24+
	15-30	7.1	0.4	2	4	260	21
	30-60	7.8	0.7	4	4	630	48+
2	0-15	7.3	0.4	7	7	565	20
	15-30	7.5	0.4	2	2	250	23
	30-60	7.9	0.6	4	4	560	48+
3	0-15	7.2	0.4	11	11	680	21
	15-30	7.5	0.4	2	3	240	24+
	30-60	8.0	0.7	6	4	600	48+
4	0-15	7.0	0.4	8	12	590	20
	15-30	7.1	0.3	1	4	215	17
	30-60	7.6	0.6	4	4	500	48+

Appendix
Table A1. Con't.

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha			
			Dry Rapeseed				
1	0-15	7.1	0.4	10	11	560	9
	15-30	7.3	0.3	3	5	200	4
	30-60	7.6	0.4	6	6	520	7
2	0-15	6.9	0.3	9	10	530	6
	15-30	7.1	0.3	4	5	540	4
	30-60	7.6	0.4	6	4	560	6
3	0-15	6.8	0.3	15	14	560	6
	15-30	7.1	0.3	9	7	260	4
	30-60	7.6	0.4	18	6	560	8
4	0-15	6.8	0.3	18	14	540	6
	15-30	7.1	0.3	11	6	230	4
	30-60	7.6	0.6	24	6	580	22
			Dry Flax				
1	0-15	6.7	0.4	52	14	665	15
	15-30	7.1	0.3	17	6	240	17
	30-60	7.8	0.6	10	4	540	48+
2	0-15	6.8	0.4	36	12	724	18
	15-30	7.2	0.3	10	5	245	17
	30-60	7.8	1.0	32	4	630	48+
3	0-15	7.0	0.4	25	10	580	24+
	15-30	7.4	0.4	6	4	240	15
	30-60	7.8	0.6	10	4	650	48+
4	0-15	7.0	0.4	26	11	735	18
	15-30	7.2	0.3	9	5	250	18
	30-60	7.8	0.7	22	4	630	48+

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*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

Appendix
Table A2. Spring soil analyses P correlation experiments.

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha*			
			Asquith sandy loam (Barrich No. 8)				
1	0-15	7.2	0.6	64	24	750	9
	15-30	7.0	0.6	83	49	460	12
	30-60	7.9	0.4	94	20	490	32
	60-90	8.0	0.9	40	10	480	48
2	0-15	7.2	0.6	61	46	625	24
	15-30	7.3	0.4	57	22	350	22
	30-60	7.8	0.4	98	22	490	48
	60-90	8.0	0.8	28	12	560	48
3	0-15	7.4	0.4	55	23	630	22
	15-30	6.8	0.6	65	120	580	20
	30-60	7.7	0.4	84	22	540	28
	60-90	8.0	0.4	30	10	590	48
4	0-15	7.4	0.4	34	20	580	11
	15-30	7.2	0.4	40	38	445	15
	30-60	7.9	0.4	80	24	440	34
	60-90	8.1	0.3	54	12	480	48
			Asquith sandy loam (Barrich No. 9)				
1	0-15	7.0	0.7	120	38	605	20
	15-30	6.7	0.4	67	58	330	23
	30-60	7.6	0.6	152	48	400	42
	60-90	7.8	0.4	124	30	440	32
2	0-15	6.9	0.7	93	39	465	12
	15-30	6.6	0.4	63	54	300	19
	30-60	7.5	0.6	122	58	470	34
	60-90	7.8	0.4	122	36	470	26
3	0-15	7.2	0.6	55	51	520	12
	15-30	7.1	0.4	40	94	320	48
	30-60	7.9	0.4	80	40	370	32
	60-90	8.0	0.3	60	24	430	34
4	0-15	7.0	0.6	78	57	510	12
	15-30	6.9	0.4	70	40	280	21
	30-60	7.8	0.4	120	28	380	24
	60-90	8.1	0.3	96	20	440	26

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*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

Appendix
Table A3. Fall soil analyses P correlation experiments.

Rep.	Depth (cm)	pH	Cond. (mmhos/cm)	NO_3-N	P	K	SO_4-S
				kg/ha*			
		Asquith sandy loam (Barrich No. 8)					
1	0-15	7.2	0.4	8	38	725	12
	15-30	6.8	0.4	11	43	550	20
	30-60	7.5	0.7	68	22	460	48+
	60-90	7.8	1.2	42	8	500	24+
2	0-15	7.3	0.4	6	27	605	13
	15-30	7.0	0.4	8	34	430	30
	30-60	7.6	0.4	30	20	460	24+
	60-90	7.8	1.1	20	8	500	24+
3	0-15	7.3	0.4	5	23	570	18
	15-30	7.0	0.3	7	32	455	16
	30-60	7.6	0.6	52	16	530	19
	60-90	7.7	0.6	42	8	600	48+
4	0-15	7.3	0.4	4	26	680	13
	15-30	6.9	0.3	4	72	525	18
	30-60	7.5	0.4	26	30	500	48+
	60-90	7.8	0.8	16	16	580	24+
		Asquith sandy loam (Barrich No. 9)					
1	0-15	7.0	0.6	41	26	495	22
	15-30	6.4	0.6	67	49	360	48+
	30-60	7.6	0.4	78	34	320	18
	60-90	7.9	0.4	86	16	320	9
2	0-15	7.3	0.4	30	27	380	22
	15-30	7.1	0.4	35	61	295	20
	30-60	7.5	0.6	68	30	300	18
	60-90	7.8	0.4	42	18	290	22
3	0-15	6.9	0.4	31	29	310	19
	15-30	6.3	0.4	45	80	240	24+
	30-60	7.4	0.6	152	50	290	22
	60-90	7.8	0.6	116	20	280	10
4	0-15	6.8	0.4	36	31	390	12
	15-30	6.5	0.6	69	58	265	32
	30-60	7.6	0.4	64	30	280	11
	60-90	7.9	0.4	84	16	280	16

*kg/ha = ppm x 2 for 15 cm depth and ppm x 4 for 30 cm depth.

Appendix Table A4. Legal location and soil type of experimental field plots for 1976 irrigation trials.

Farmer co-operator	Crop investigated	Legal location	Soil type
A. Pederson	Fababeans Peas Beans Lentils Rapeseed Flax	NW21-28-7-W3	Elstow loam
Barrich Farms Ltd.	Hard wheat	SW24-29-8-W3	Asquith sandy loam
	Hard wheat	NW24-29-8-W3	Asquith sandy loam
A. Pederson	Alfalfa	NE20-28-7-W3	Elstow loam
G. Gross	Alfalfa	NE30-28-7-W3	Bradwell loam
M. Wudel	Alfalfa	SW31-30-7-W3	Bradwell very fine sandy loam

Appendix B. Selected tables of data from the nitrification inhibitor experiment (Section 2).

Appendix Table B1. Soil moisture content (air-dry basis) of samples collected at two-week intervals for the Goodale summerfallow plot (Bradwell soil). Average moisture content (% air-dry basis).

Date	0-7 cm		7-15 cm		15-30 cm		30-60 cm	
	$\overline{X}$	S.E.	$\overline{X}$	S.E.	$\overline{X}$	S.E.	$\overline{X}$	S.E.
May 27	14.75	± 0.49	15.73	± 0.24	13.97	± 0.42	9.49	± 0.28
June 10	13.70	± 0.31	12.46	± 0.62	12.22	± 0.93	12.69	± 0.35
June 24	15.45	± 0.11	15.39	± 0.85	14.29	± 0.23	12.58	± 0.19
July 8	15.79	± 0.41	15.04	± 0.18	14.16	± 0.42	13.80	± 0.39
July 22	8.15	± 0.46	11.30	± 0.28	12.60	± 0.28	12.40	± 0.30
Aug. 5	6.58	± 0.42	11.99	± 0.20	12.26	± 0.28	11.88	± 0.32
Aug. 19	13.19	± 1.80	14.11	± 1.12	13.51	± 0.55	12.41	± 0.32
Sept. 3	8.29	± 1.55	17.03	± 4.88	12.97	± 0.54	12.03	± 0.34
Sept. 16	9.25	± 0.35	12.28	± 0.65	12.38	± 0.35	12.33	± 0.27

Appendix Table B2. Soil moisture content (air-dry basis) of samples collected throughout the growing season for the irrigated wheat plot (Elstow soil).

Date	Sampling Treatment*	0-7 cm		7-15 cm		15-30 cm		30-60 cm	
		$\overline{X}$	S.E.	$\overline{X}$	S.E.	$\overline{X}$	S.E.	$\overline{X}$	S.E.
May 28	Control	7.9	± 2.2	15.9	± 2.7	18.2	± 1.5	20.0	± 0.7
	Urea	7.2	± 1.7	16.3	± 2.6	18.9	± 0.7	19.2	± 0.6
	Urea + 1.0% ATC	7.8	± 0.5	17.8	± 1.8	18.2	± 1.3	19.4	± 1.6
June 18	Control	12.6	± 2.5	12.6	± 0.5	22.2	± 5.6	21.8	± 0.8
	Urea	8.4	± 1.9	13.9	± 0.9	16.4	± 0.9	20.3	± 0.6
	Urea + 1.0% ATC	10.0	± 0.6	10.2	± 2.1	17.1	± 1.7	19.7	± 0.7
July 5	Control	11.2	± 0.5	16.4	± 2.5	10.5	± 3.7	18.9	± 0.7
	Urea	7.9	± 0.6	7.7	± 1.0	12.0	± 1.1	16.5	± 1.0
	Urea + 1.0% ATC	10.6	± 2.7	9.1	± 2.4	11.6	± 0.9	11.4	± 3.4
July 22	Control	12.5	± 3.6	14.4	± 2.4	20.2	± 1.2	22.6	± 0.5
	Urea	11.9	± 0.9	7.8	± 1.7	17.4	± 0.9	23.0	± 0.8
	Urea + 1.0% ATC	10.7	± 1.5	9.8	± 3.0	16.9	± 1.3	21.0	± 0.8
Aug. 18	Control	8.1	± 1.9	8.5	± 2.1	15.3	± 0.8	19.7	± 0.9
	Urea	5.8	± 0.5	6.7	± 1.7	14.8	± 2.2	16.5	± 0.9
	Urea + 1.0% ATC	6.1	± 1.0	7.1	± 1.2	11.9	± 2.3	17.4	± 1.7

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*Urea and urea + 1.0% ATC applied at a rate of 200 kg N/ha.

Appendix Table B3. Soil moisture content (air-dry basis) of samples collected throughout the growing season for the dryland what plot (Melfort soil). Average moisture content (% air-dry basis).

Date	Sampling Treatment*	0-7 cm		7-15 cm		15-30 cm		30-60 cm	
		$\bar{X}$	S.E.	$\bar{X}$	S.E.	$\bar{X}$	S.E.	$\bar{X}$	S.E.
June 30	Control	31.5	± 0.7	27.5	± 1.0	21.1	± 0.6	20.9	± 0.8
	Urea	28.4	± 1.7	28.2	± 2.0	22.9	± 1.3	20.8	± 0.7
	Urea + 0.3% ATC	30.2	± 1.2	29.6	± 1.2	22.2	± 1.2	21.5	± 0.8
July 16	Control	40.1	± 2.1	31.8	± 1.1	24.3	± 0.2	24.2	± 0.7
	Urea	34.8	± 1.1	39.8	± 1.2	31.6	± 6.0	24.5	± 0.6
	Urea + 0.3% ATC	30.8	± 5.3	33.0	± 2.7	24.0	± 1.0	24.6	± 0.8
Aug. 13	Control	30.3	± 1.3	25.2	± 1.5	20.3	± 0.4	20.3	± 0.6
	Urea	26.0	± 2.3	20.3	± 1.1	17.7	± 0.9	19.1	± 0.5
	Urea + 0.3% ATC	25.2	± 1.1	19.9	± 0.6	17.7	± 0.6	19.7	± 0.6
Sept. 1	Control	32.7	± 2.4	25.9	± 2.2	20.6	± 1.8	19.6	± 1.4
	Urea	24.0	± 3.8	16.8	± 2.2	17.3	± 2.1	18.8	± 0.8
	Urea + 0.3% ATC	25.5	± 1.4	15.7	± 4.0	17.1	± 1.3	19.3	± 1.2

*Urea and urea + 0.3% ATC applied at a rate of 200 kg N/ha.

Appendix

Table B4. Average NO_3^--N and NH_4^+-N content by treatment of soil samples from four soil depths for ten sampling dates (µg N/g). Data is average of four replicates. Goodale summerfallow site.

Table 4.1. Check Treatment

Sampling Date	Sample Depth (cm)							
	0-7		7-15		15-30		30-60	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
May 13*	2.9	3.0	2.7	2.8	2.6	3.5	1.0	3.5
May 22	2.8	4.8	2.2	4.4	2.8	3.9	1.0	4.0
June 10	1.8	2.4	2.0	2.0	3.2	1.6	1.4	1.9
June 24	3.5	2.8	3.7	2.9	3.3	2.8	1.7	2.6
July 8	4.4	3.1	4.8	2.6	2.9	2.0	2.2	2.5
July 22	4.6	2.9	4.6	3.4	4.2	3.0	2.1	2.5
August 5	6.0	3.4	4.7	3.1	4.0	3.3	2.7	2.8
August 19	8.6	4.0	5.8	2.5	4.0	3.0	2.9	2.5
September 2	9.3	3.9	5.2	2.6	3.4	2.6	2.4	2.8
September 16	7.5	2.4	4.6	3.0	3.7	2.9	2.3	2.8

Table 4.2. 200 kg N/ha 0.5% ATC Coated Urea

Sampling Date	Sample Depth (cm)							
	0-7		7-15		15-30		30-60	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
May 13*	2.9	3.0	2.7	2.8	2.6	3.5	1.0	3.5
May 22	6.3	53.8	5.4	50.8	3.3	6.5	1.0	5.0
June 10	19.2	39.0	15.4	8.1	7.9	1.9	1.7	1.8
June 24	41.5	49.3	26.9	18.3	10.5	4.4	3.1	3.8
July 8	52.1	12.3	35.6	6.6	15.2	3.0	4.3	2.9
July 22	28.1	6.3	38.0	9.8	23.4	3.3	6.1	3.6
August 5	38.2	3.8	52.0	3.0	21.4	3.1	8.4	3.5
August 19	51.0	4.0	41.3	3.0	17.3	2.8	9.2	3.3
September 2	50.0	4.8	35.5	4.1	15.0	2.6	5.6	2.8
September 16	55.3	2.9	29.0	2.4	18.3	2.5	4.1	2.8

Table 4.3. 200 kg N/ha 2.0% ATC Coated Urea

Sampling Date	Sample Depth (cm)							
	0-7		7-15		15-30		30-60	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
May 13*	2.9	3.0	2.7	2.8	2.6	3.5	1.0	3.5
May 22	3.7	81.8	4.6	17.1	2.6	5.6	0.6	4.9
June 10	6.8	93.6	6.8	25.8	5.9	4.6	1.7	2.8
June 24	16.5	58.5	10.8	13.8	6.8	4.5	2.0	3.3
July 8	27.3	54.3	18.9	29.6	7.5	5.3	3.3	4.3
July 22	41.7	25.4	29.5	23.0	12.7	3.9	5.6	3.3
August 5	41.8	24.8	30.0	15.3	17.9	9.0	9.4	5.7
August 19	38.1	25.1	36.0	13.8	13.1	3.5	7.9	5.8
September 2	61.5	36.8	37.3	14.0	11.9	3.4	7.9	5.6
September 16	59.0	11.6	21.1	4.5	11.5	3.0	4.2	3.0

Table 4.4. 200 Kg N/ha Urea

Sampling Date	Sample Depth (cm)							
	0-7		7-15		15-30		30-60	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
May 13*	2.9	3.0	2.7	2.8	2.6	3.5	1.0	3.5
May 22	6.9	93.8	11.2	30.5	3.8	9.8	0.9	4.1
June 10	48.3	11.0	47.0	20.1	18.5	2.8	3.3	1.9
June 24	45.9	8.0	43.6	4.5	20.0	2.9	3.1	2.6
July 8	44.2	5.3	51.2	3.9	27.5	2.9	5.4	2.6
July 22	18.6	2.9	45.4	3.3	31.6	3.6	11.9	2.9
August 5	30.2	4.4	48.5	3.5	32.2	3.1	16.1	3.9
August 19	57.3	5.3	55.3	2.5	39.3	2.8	10.3	3.1
September 2	44.3	4.4	43.0	2.5	26.7	2.5	7.1	3.1
September 16	63.0	2.6	45.8	2.6	28.3	3.4	7.4	2.6

Table 4.5. 1.0 kg ATC/ha

Sampling Date	Sample Depth (cm) 0-7		7-15		15-30		30-60	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
May 13*	2.9	3.0	2.7	2.8	2.6	3.5	1.0	3.5
May 22	2.4	4.8	2.9	4.6	2.5	4.1	0.8	4.1
June 10	2.2	2.6	2.0	2.5	3.0	2.6	1.5	2.0
June 24	4.6	3.9	3.2	2.9	3.7	2.6	2.4	2.3
July 8	5.5	3.0	5.2	2.8	3.6	2.6	1.9	2.6
July 22	4.9	1.9	4.3	2.9	3.7	3.1	2.3	2.5
August 5	6.5	3.1	4.7	2.6	4.3	2.6	4.4	3.3
August 19	9.9	3.4	7.4	3.0	4.8	2.9	3.4	3.1
September 2	9.6	4.0	7.0	2.5	3.8	2.9	2.7	3.1
September 16	9.8	2.8	5.1	2.3	4.1	2.5	2.6	3.0

Table 4.6. 4.0 kg ATC/ha

Sampling Date	Samplg Depth (cm) 0-7		7-15		15-30		30-60	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
May 13*	2.9	3.0	2.7	2.8	2.6	3.5	1.0	3.5
May 22	2.5	3.9	3.0	4.6	1.8	3.6	0.6	3.9
June 10	1.6	3.5	2.2	3.5	2.5	2.8	1.0	2.1
June 24	4.2	2.6	3.5	2.4	3.0	2.1	1.6	2.4
July 8	5.6	3.0	5.1	3.1	3.7	2.5	2.9	2.5
July 22	5.7	2.1	4.2	3.3	4.0	2.3	2.1	2.6
August 5	8.3	3.4	6.4	3.8	5.6	2.8	6.2	4.4
August 19	11.4	4.0	7.0	3.3	4.8	3.0	3.4	3.3
September 2	11.8	6.6	7.2	4.4	4.2	4.8	2.7	3.1
September 16	8.4	2.0	4.2	2.5	3.4	2.3	2.3	3.0

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* Levels of NO_3^--N and NH_4^+-N prior to urea and ATC application.

Appendix Table B5. Seasonal precipitation at the Goodale summer-fallow plot (Bradwell soil).

Date	Rainfall (mm)
June 8	33.0
June 21	15.2
July 1	20.9
July 6	9.9
July 12	24.9
July 19	5.2
Aug. 3	4.8
Aug. 30	8.7
Sept. 14	2.8
Sept. 21	1.6
TOTAL	127.0

Appendix Table B6. Soil NO_3^- and NH_4^+ levels (kg/ha) at four depths throughout the growing season for the irrigated wheat plot (Elstow soil).

Sampling Date	0-7 cm		7-15 cm		15-30 cm		30-60 cm		Total (0-60 cm)	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
	kg/ha									
May 11*	8.1	4.0	8.1	4.0	11.8	7.0	20.8	17.2	48.8	32.2
Control										
May 28	22.7	16.8	6.7	7.6	10.0	14.6	24.4	35.2	63.8	74.2
June 18	3.0	5.3	1.4	4.8	3.6	9.8	10.0	20.4	18.0	40.3
July 5	2.2	4.9	1.2	4.3	1.6	12.0	3.2	25.6	8.2	46.8
July 22	0.9	7.0	0.5	4.5	0.4	8.2	1.2	24.4	3.0	44.1
Aug. 18	2.4	7.6	1.4	6.1	1.0	8.2	0.4	21.2	5.2	43.1
200 kg N/ha Urea										
May 28	83.0	54.4	16.5	16.9	13.8	25.8	37.6	54.4	150.9	151.5
June 18	68.8	31.4	62.8	12.4	68.6	9.2	35.6	22.4	235.8	75.4
July 5	7.4	6.6	47.2	4.8	38.2	11.2	14.4	25.2	107.2	47.8
July 22	1.6	8.7	1.8	4.8	14.6	9.8	40.4	23.2	58.4	46.5
Aug. 18	1.4	7.5	1.4	8.8	10.6	10.2	22.8	22.0	36.2	48.5
200 kg N/ha Urea with 1.0% ATC										
May 28	40.8	185.1	15.0	27.6	16.8	50.8	54.0	83.6	126.6	347.1
June 18	62.5	102.1	30.3	14.8	40.0	12.6	55.2	26.0	188.0	155.5
July 5	33.8	48.0	47.5	34.6	25.8	11.6	22.8	25.2	129.9	119.4
July 22	8.8	11.1	2.9	8.0	10.0	8.2	48.0	23.2	69.7	50.5
Aug. 18	15.3	11.0	27.7	14.0	8.8	8.2	31.6	21.6	83.4	54.8

*Initial sampling before treatment application.

Appendix Table B7. Soil NO_3^- and NH_4^+ levels (kg/ha) at four depths throughout the growing season for the dryland wheat plot (Melfort soil).

Sampling Date	0-7 cm		7-15 cm		15-30 cm		30-60 cm		Total (0-60 cm)	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
	kg/ha									
May 18*	8.6	7.6	8.6	7.6	8.6	13.6	10.4	22.0	36.2	50.8
					Control					
June 30	3.4	5.4	1.9	6.1	1.6	10.0	3.2	17.6	10.1	39.1
July 17	2.6	5.8	1.5	5.5	1.4	10.6	1.6	17.2	7.1	39.1
Aug. 13	2.6	4.1	1.6	4.8	1.2	9.8	1.2	17.6	6.6	36.3
Sept. 1	7.1	3.9	2.2	5.0	0.8	9.8	1.2	17.6	11.3	36.3
					200 kg N/ha Urea					
June 30	52.3	7.3	48.2	6.3	17.6	11.0	15.2	20.0	133.3	44.6
July 17	23.2	5.9	12.5	6.4	21.8	11.2	19.6	19.6	77.1	43.1
Aug. 13	20.4	6.0	23.9	5.1	29.8	10.2	8.8	17.6	89.9	38.9
Sept. 1	21.2	9.5	10.6	5.9	8.8	10.8	10.0	20.0	50.6	46.2
					200 kg N/ha Urea with 0.3% ATC					
June 30	58.3	6.8	38.2	8.5	26.0	11.2	17.6	21.6	140.1	48.1
July 17	30.5	9.5	47.1	6.0	28.0	10.6	15.6	20.0	121.2	46.1
Aug. 13	17.1	4.8	21.2	4.8	9.6	10.2	10.4	19.6	58.3	39.4
Sept. 1	25.4	5.1	7.6	5.6	3.2	11.2	4.4	20.4	40.6	42.3

*Initial sampling before treatment application.

Appendix Table B8. Soil NO_3^- and NH_4^+ levels (kg/ha) at four depths at harvest for the irrigated wheat plot (Elstow soil).

Treatment (kg N/ha)	0-7 cm		7-15 cm		15-30 cm		30-60 cm		Total (0-60 cm)	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
	kg/ha									
0	3.7	3.5	2.4	3.5	2.0	7.0	3.2	20.0	11.3	34.0
25 Urea	2.9	3.5	2.2	4.0	2.0	8.0	2.8	20.0	9.9	35.5
50 Urea	2.1	3.0	1.1	3.0	2.0	6.0	12.0	20.0	17.2	32.0
100 Urea	2.1	4.5	1.5	3.5	2.6	8.0	16.0	20.0	22.2	36.0
200 Urea	9.2	4.0	13.6	3.0	22.2	8.0	13.6	24.0	58.6	39.0
25 Urea + 0.3% ATC	5.8	3.0	1.3	4.0	1.2	8.0	3.2	24.0	11.8	39.0
50 Urea + 0.3% ATC	2.1	3.5	1.7	3.5	1.6	7.0	2.4	24.0	7.8	38.0
100 Urea + 0.3% ATC	1.3	3.5	1.2	4.0	1.8	8.0	4.0	22.0	8.3	37.5
200 Urea + 0.3% ATC	4.5	3.5	16.2	3.0	7.6	6.0	8.0	22.0	36.3	34.5
25 Urea + 1.0% ATC	2.5	4.0	1.4	4.0	1.6	8.0	3.6	24.0	9.1	40.0
50 Urea + 1.0% ATC	2.5	3.0	1.5	3.0	1.6	7.0	7.2	20.0	12.8	33.0
100 Urea + 1.0% ATC	2.1	3.0	2.8	3.0	3.8	7.0	4.4	20.0	13.1	33.0
200 Urea + 1.0% ATC	4.2	3.0	3.7	2.0	6.4	7.0	15.6	18.0	29.9	30.0

Appendix Table B9. Soil NO_3^- and NH_4^+ levels (kg/ha) at four depths at harvest for the dryland wheat plot (Melfort soil).

Treatment (kg N/ha)	0-7 cm		7-15 cm		15-30 cm		30-60 cm		Total (0-60 cm)	
	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+
					kg/ha					
0	6.7	4.0	2.4	5.5	2.4	12.0	2.0	18.0	13.5	39.5
25 Urea	4.0	4.0	2.8	5.0	1.8	11.0	2.4	20.0	11.0	40.0
50 Urea	4.9	4.5	1.9	5.0	2.0	10.0	2.4	20.0	11.2	39.5
100 Urea	6.9	4.5	2.3	4.5	2.2	11.0	5.2	18.0	16.6	38.0
200 Urea	22.0	5.0	4.9	4.5	5.2	9.0	7.6	18.0	39.7	36.5
25 Urea + 0.3% ATC	5.9	5.0	4.3	4.5	3.2	10.0	6.0	20.0	19.4	39.5
50 Urea + 0.3% ATC	8.1	4.5	3.0	5.5	2.0	10.0	4.0	20.0	17.1	40.0
100 Urea + 0.3% ATC	11.5	5.0	3.8	5.0	4.8	9.0	4.8	14.0	24.9	33.0
200 Urea + 0.3% ATC	27.0	4.5	5.4	4.5	7.2	8.0	8.4	16.0	48.0	33.0
25 Urea + 1.0% ATC	3.8	4.0	2.1	5.0	1.4	8.0	2.4	16.0	9.7	33.0
50 Urea + 1.0% ATC	5.0	4.0	1.6	4.0	1.6	10.0	2.4	20.0	10.6	38.0
100 Urea + 1.0% ATC	6.7	4.0	1.5	5.0	1.8	10.0	2.8	16.0	12.8	35.0
200 Urea + 1.0% ATC	54.0	5.0	38.0	4.5	7.0	8.0	12.8	16.0	111.8	33.5

5. Selected Papers

5.1 ENERGY IMPLICATIONS IN SOIL MANAGEMENT *

E. de Jong

The primary energy source for agriculture is the sun. In practice less than 1% of the solar energy supply is captured by plants and an even smaller percentage is harvested as crops or forages. In the U.S. crops and grazing lands store annually 0.2% of the available solar energy, of this 0.2% only 1/16th is actually consumed as food (Stickler, Burrows and Nelson, 1975; Fig. 1). The difference between what is potentially available and what ends up on the table is mainly due to two factors: firstly, approximately 25% is left as residues in the field, and secondly a large portion (about 60%) goes to the dinner table via the relatively inefficient animal-conversion route. Of course, the bulk of the plant energy fed to animals is unsuited for human consumption and approximately one-half of this plant energy is excreted as manure and has potential value as fertilizer. In the process of conversion of plant energy to food energy about seven units of fuel energy (stored solar energy) are used for each unit of food energy consumed. This fuel energy includes the energy needed to manufacture machinery, fertilizers, fuel to operate equipment, energy used in transportation on and off the farm, and energy used in food processing. Only about 20% of this fuel energy is used on the farm; the remainder is added after the crops are harvested.

The situation in Canada is probably similar to that in the U.S., but in Saskatchewan there are some major differences. Extensive summerfallowing

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* Expanded version of a talk presented to meetings on "Energy Conservation in Agriculture", April 15 and 16, (1977), in Regina and Saskatoon.

will lead to an even lower capture of solar energy than reported for the U.S., and fossil fuel inputs will be relatively lower due to the low use of fertilizers. The product mix and its fate are also different, annual production is estimated at about 16.5×10^6 tons of grain, 24×10^6 tons of straw and 10.5×10^6 tons of useable forage (Laverty et. al. 1976). A large portion of the grain is exported.

In modern agriculture the trend is towards larger farm units worked by fewer persons with larger machinery, resulting in high inputs of fossil fuel energy and high food production per farmer. The fossil fuel is used to increase the efficiency of solar energy capture. With the present concern about the limited quantity of fossil fuel available, attempts have been made to analyze the energy efficiency of various agricultural systems (e.g. Pimental et. al., 1973; Lovering and McIsaac, 1976; Dekkers et. al., 1974; Heichel, 1976). In these analysis many potential problems arise, e.g. several measures of energy can be used (gross, digestable or food, and metabolizable energy), different forms of energy are added together (diesel fuel, electricity, muscle power, etc.), and the energy content of the inputs depends on manufacturing techniques used and will change as the supply of raw material changes. Thus, the usefulness of the calculated energy ratios (energy output/energy input) is sometimes questioned (Huettner, 1976; Gifford, 1976); nonetheless, these ratios indicate that most agricultural systems are net-energy producers (Fig. 2). Crops like alfalfa which combine a favorable energy ratio with high protein production per unit of input energy (Fig. 3) could play an important role in feeding humans if they could be processed in palatable form.

In this paper attention will be focussed on the implications of possible energy shortages for soil management practices in Saskatchewan. The emphasis will be on outlining possible methods for maximizing food output, minimizing energy inputs and maintaining or improving the quality of the soil and not on the actual amounts of energy involved. It should be realized that on-the-farm energy use is a small fraction of the total energy used in food production and processing. For example, 12 to 15% of Canada's energy consumption is used to put food on the table (Kettle, 1976) and slightly less than 1/5th of this energy is actually used on the farm, the remainder is used in processing, transportation and distribution, and preparation in the kitchen. The average on-the-farm distribution is direct fuel inputs, 57%, fertilizer 17%, machinery, trucks, etc., 7%, and miscellaneous 16% (Downing, 1975). In view of the small fraction of the total energy use that is consumed on the farm and the importance of food production, a high priority must be given to continued energy supplies to agriculture. This does not mean that savings need not be made or energy efficiency increased.

Historical Trends in Energy Inputs

Neumeyer (1973, 1977) has attempted an energy balance for wheat farming in Saskatchewan for selected years from 1945 to 1975 (Table 1). For comparison purpose data for corn production in the U.S. for some of the same years are included in Table 2. Although the Saskatchewan data involve many assumptions, two trends are noticeable: 1) a general substitution of machinery for human labor, and 2) a gradual increase in fertilizer and herbicide use. The data for corn show the same trends, but also show a considerable increase in yield (presumably due to the increased energy inputs and the introduction of hybrid corns) over the period studied and a decrease in output/input energy ratio. The diminishing energy return to increasing energy inputs is generally observed (Fig. 2), that this effect was not noticeable in the wheat data is probably due to the relatively low energy inputs. Wheat production in Saskatchewan showed great variations in energy efficiency between years, mainly due to the large variation in yields. The recent high energy ratios reflect improved management and favorable weather.

The energy ratio's for wheat production in Saskatchewan compare favorably with similar data from elsewhere (Table 3). This is probably largely due to the fact that Saskatchewan farmers have been able to draw on the supply of N stored in the soil at the time of breaking. In other areas N has to be supplied from fertilizers or from legumes included in the rotation as is the case for Australia. None of the energy ratio's is close to the theoretical limit for cereals shown in Fig. 2.

It has been estimated that approximately half of the organic nitrogen that was present in our soils at the time of breaking the soil has been lost (Rennie, 1976). About 1/3 of this nitrogen was utilized by the crops growing in the fields and mostly sold of the farm, the remaining 2/3 was lost by leaching, erosion of topsoil or conversion to gaseous N_2 (denitrification) that escaped to the atmosphere (Table 4). If the average loss of 42 lb N/acre is added to the energy inputs in Table 1, the "fertilizer" inputs would increase by 420 Mcal/acre and the energy ratios would be halved. Including the actual nitrogen removed in the crop in the "fertilizer" energy inputs would decrease the ratios by about 0.5.* In the past fertilizer-N has not significantly contributed to the N needs of the crop, the highest contribution was in 1967 when N fertilizer equivalent to 15% of the nitrogen removed by the crop was used (Beaton, 1974). This situation is likely to change dramatically, calculations show that nitrogen fertilizer will be needed soon on fallow as well as on stubble fields to maintain yields (Rennie, 1976). With time more and more N fertilizer will be needed until ultimately

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* An annual loss of 42 lb N represents an organic matter loss of about 800 lbs or a gross energy loss of 2000 Mcal (organic matter is about 2500 Kcal/lb, Martel, 1972) thus making the energy ratios very unfavorable.

all nitrogen needs of the crop will have to be supplied by fertilizers, unless alternative ways of supplying the nitrogen are found.

Extensive summerfallowing has contributed to the loss of organic soil nitrogen, soil erosion, and the spread of soil salinity. Clearly summerfallowing should be curtailed as much as possible. The period of rapid losses of nitrogen and organic matter from the soil is probably past for most soils, but its detrimental effect on soil quality continues. A decrease in soil quality will increase the need for fossil fuel inputs or take land out of production altogether.

Energy and Soil Management

The possibility of energy shortages in the near future warrants an assessment of soil management practices. One way of reducing agricultural inputs is by accepting a reduced yield, however, this is not an acceptable alternative in view of the increasing world population. Neither is it acceptable to increase or maintain present production if this leads to a decrease in soil quality. In the following two sections soil management practices are considered that could:

- lead to increased yields without greatly increasing inputs, or at least at favorable output/input energy ratios
- lead to a reduction in inputs without seriously reducing production.

Soil management techniques to increase output.

Last year Laverty et. al. (1976) estimated the average fertilizer nitrogen requirements on stubble and fallow in Saskatchewan as 96,000 tons/year; this amount would provide about 1/4 of the estimated 363,000 tons of N removed with the grain, the remaining 3/4 being supplied from the reserve of organic N in the soil. The yield increase from this N was estimated at 1,260,000 tons of grain, giving a gross energy efficiency ratio of 2.8 if the grain was wheat, or 2.7 if the grain was barley. Present fertilizer recommendations are based on a marginal return of $1.50 per $1.00 input, for wheat at $3.00/bu and nitrogen at $0.20/lb this would represent a marginal energy ratio of 1.3 (Fig. 4). Fertilizer use is part of a total management package including weed control. For example, wild oats reduced Saskatchewan's grain yields last year by 100 M bu, this is equivalent to twice the estimated yield increase from the 96,000 tons of N.

An obvious way to increase energy output of Saskatchewan soils is by decreasing summerfallowing. This change would increase the acreage on which solar energy is captured in a useful form, but would lead to an increased need for fertilizer inputs. On the other hand energy inputs for weed control during the summerfallow year, which vary between 150 and 300 Mcal/acre, (Jensen and Stephanson, 1975) equivalent to 15 to 30 lb N, would be eliminated. Extended crop rotations would also have incalculable benefits for soil quality.

Increased stubble cropping is possible only with more efficient use of precipitation. Under present conditions moisture storage during the summerfallow year and second winter is extremely inefficient, especially in the Black and Grey soil zones (Fig. 5). Overwinter storage can be increased up to 1½ inches by increasing the height of the stubble or using grass strips to trap snow, these gains are small but of the same magnitude as the soil moisture gained during the last 12 months of the summerfallow period. Longer rotations will undoubtedly cause problems with work scheduling both in spring and fall; for example, early seeding is more beneficial for stubble than for fallow crops (Ukrainetz, personal communication). Special machinery for stubble seeding may have to be developed.

Increased gross energy output per acre may be obtained by switching to forages. Alfalfa is especially attractive as it fixes its own nitrogen, Jensen and Stephanson (1975) calculated an output/input energy ratio of 17 for dryland alfalfa. At present the forage has to be cycled through animals before it is edible to humans and this drops the energy efficiency by an order of magnitude.

The possilbity of using crop residues to provide fuel is often discussed.* It has been calculated (Gifford, 1976) that residues of wheat production in Australia would be sufficient to provide all the fuel needed on the farm, the same is true for corn production in the U.S. This technique reduces the amount of organic material returned to the soil and may have adverse consequences for the soil structure. As well, energy would be needed to haul the residues, build the generators, etc., and the overall efficiency of burning residues to provide fuel will have to be assessed carefully.

Soil management techniques to decrease energy inputs.

The number of summerfallow tillage operations is often unnecessarily high, for example, Molberg et. al. (1967) showed that normal farm operations usually involved 1 to 2 more tillage operations than necessary for satisfactory weed control. Herbicides can reduce the number of tillage operations on fallow by about 50% (Bowren, 1977). Herbicide application takes less energy than tillage. Fuel energy requirements for a discer or cultivator are estimated at about 20,000 Kcal/acre, for a rod weeder at about 10,000 Kcal/acre and for a sprayer at about 5,000 Kcal/acre (W.B. Reed, personal communication). The energy content of the herbicide appears to be about 5,000 Kcal/acre (Jensen and Stephanson, 1975). The use of herbicides has additional advantages, it leaves the stubble standing, thus protecting the soil against erosion and improving the soil moisture status.

Complete zero tillage has not been tested in Saskatchewan. It would

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* The gross energy of straw is about 3150 Mcal/ton, by comparison cereal grains are about 3800 Mcal/ton (Downing, 1975).

involve a considerable change in machinery, possibly much lighter and smaller power units with consequent energy savings in manufacture and operation. Preliminary data for Manitoba (Townsend, 1977) estimate the drawbar energy requirements for zero-tillage as 1/5th of that for conventional tillage up to the end of the seedingoperation.

Of the three primary fertilizer elements, N is about 6 times more energy intensive than P and K. Large differences in energy content can occur between different forms of the same element. For example, the cheapest feedstock for N fertilizer is natural gas; naphta, oil or coal can also be used, but would increase the energy content by 7, 10 and 30% respectively (Beaton, et. al., 1976). Similarly the energy content of P can vary by a factor of nearly two depending on the amount of refining involved (White, 1977). The energy content of K depends to a large extent on methods used to mine and purify the ore (White, 1977; Dornom and Tribe, 1976). Transportation and application also add considerably to the energy costs of fertilizers and affect different forms of fertilizers differently (Table 5).

As fertilizers constitute a major energy input, research to increase efficiency of fertilizer uptake is essential. Uptake efficiencies of P fertilizer are in the order of 10%, fortunately the remainder of the P becomes gradually available to plants in future years. Uptake efficiency of N fertilizers is in the order of 50%; some of the remainder is temporarily tied up in plant residues and soil micro-organisms, but a large portion can be lost from the soil by leaching, denitrification, or volatilization. The losses depend on time and method of application, source of N and environmental conditions.

With Saskatchewan's unpredictable climate, fertilizer recommendations based on average precipitation are either too low or too high. In the future it may become economically and technically feasible to apply a minimum amount of N at seeding time and then add more as required, for this a reliable long-term (say 2 week) weather forecast would be of immense value. Adjusting fertilizer rates to different soil types that occur in a field could also pay substantial dividends. Techniques that presently are uneconomical may well become feasible with increasing energy prices.

Manure could be used to lessen the demand for chemical fertilizers; this would also reduce pollution problems. Animal manures in Saskatchewan contain about 37.5×10^3 tons N (Bole et. al., 1976), equivalent to 75% of all N sold as fertilizer in 1975. Only about one-half of this manure is concentrated in feedlots, the remainder is scattered over grazed forage land. Energy costs for handling and transporting manure are high and limit the distance over which manure can be hauled to less than 3 miles (Heichel, 1976). Manure does have unmeasurable side-benefits due to its effect on soil structure, the benefits increase with time (Fig. 6). The possibility of fuel production from animal wastes has not been proven for Saskatchewan; this technique supposedly does not affect the nutrient content of the residue.

Next to minimum tillage, the introduction of legumes in rotations is most often cited as a possible way of reducing energy inputs into agriculture. Legumes in the presence of effective strains of micro-organisms, can fix large quantities of N. Despite possible nitrogen fixation, crop rotations involving alfalfa have not always resulted in yield increases for following cereal crops. In the Brown soil zone, cereal yields following forages are often depressed for as many as two crops (Wiens and Kilcher, 1971). In the Dark Brown soil zone Austenson et. al. (1970) found a reduction in cereal yields following alfalfa, but no effect on cereal yields following an alfalfa-brome mixture. In the Black and Gray soil zones, rotations are generally beneficial (Bowren, 1974). The different effects of rotations in different soil zones are probably due to the soil moisture extracting ability of forages, especially alfalfa.

Other crops that fix nitrogen are faba beans and field peas. Biological fixation of nitrogen takes energy in the form of carbohydrates supplied by the plant to the nitrogen fixing organism. The major advantages of biological fixation are the relatively "free" nature of the energy involved, and the fact that there are no transportation and application costs involved.

Effect of soil types on energy efficiency ratios

The Canada Land Inventory grouped agriculture land into seven classes. Classes 1 to 3 have none to moderately severe limitations for annual crop production, class 4 soil are marginal for annual crop production, classes 5 and 6 are unsuitable for annual crops but are suitable for perennial forages, while class 7 is unsuitable for agriculture. The acreages in each class, and their long term average yields, are shown in Table 6 for each of the major soil zones of Saskatchewan.

In a recent study in Ontario, Patterson and MacIntosh (1976) found no large yield differences between class 1 and 2 soils, however production costs were generally higher for class 2 than for class 1 soils. In Saskatchewan few data are available on energy inputs on different soil types. A preliminary check on data collected on different farms from 1956 to 1958 shows large differences (Table 7). Differences in fuel costs for seeding and cultivators between the Asquith, Sceptre, Fox Valley and Elstow-Sutherland soils can to a certain extent be explained by differences in texture (Fig. 7), but it is surprising to see the same differences show up for the combining costs as yield differences between these sites were small. Fuel costs varied greatly between the sites in the Gray wooded soil zone, but were lowest on the site least plagued with excessive wetness. In a more recent study (Johnson, 1971) similar trends show with regards to costs for fuel and lubrication for combine harvesters (Table 8). One might speculate on the reason for these differences, but little would be gained as there are too many unknown variables. Clearly, energy inputs vary widely on different soil types and under different management; data on the effects of soil types and landscapes on operating costs should be gathered.

Data on potential production levels of various soil types are not readily available. Recently Rennie (1976) estimated potential wheat yields for class 1 to 4 land under different rotations and their fertilizer requirements (Table 9). Using Rennie's data and energy values for wheat and various inputs taken from Jensen and Stephanson (1975), energy ratio's can be calculated (Table 10). The calculated energy ratio's decrease as the length of the rotation increases, reflecting the increased dependance on fertilizer nitrogen rather than the soil N reserve. In none of the rotations shown is the dependance on the nitrogen reserve of the soil completely eliminated. If all nitrogen removed in the grain was to be replaced by fertilizer N, the fertilizer N requirements would be about 30% higher than those for 2nd stubble in Table 9 and this would drop the energy ratio's to 3.3, 3.2, 2.8, and 2.0 for class 1, 2, 3 and 4 soils respectively.

In view of the uncertainty in the calculation of energy values, and their large annual fluctuations (Table 1), it is doubtful if an average energy ratio of less than 2.5 presents an attractive proposition for energy use in Saskatchewan agriculture. This would suggest (Table 10) that class 4 soils should not be included in long term rotations, yet on these soils the detrimental effects of summerfallowing (erosion, salinity) would often be most pronounced. From Table 6 it would appear that only in the Brown and Dark Brown soil zones appreciable acreages of Class 4 soils are cultivated.

Perhaps these soils should be returned to improved pasture, in the other soil zones the energy ratio's of long term cereal rotations could be improved by including legumes.

Recent research at Swift Current (Kilcher, 1976) has shown that seeding alfalfa and grass in separate rows 2' apart can substantially increase yields on improved pasture (Table 11). Breaking native range and seeding it to a grass-legume mixture increases the carrying capacity 3 to 5 fold (Johnson and Smoliak, 1976). An alternative suggestion for management of native range involves stripseeding of crested wheatgrass (Olsen, 1977). As these strips are invaded by the native species, the nearby strips of native range would be torn out. This brush-grass program would utilize the nitrogen fixing capacities of some native range plants (sagebrush, rabbitbrush, cacti).

Substitution of labor and energy

In energy analysis, all forms of energy input are lumped together. The energy content of labor is usually based on the amount of energy consumed by a farm laborer (21.8 Mcal/week) and the number of hours he works, for a 40 hour week this represents an energy content of 5.4 Mcal/hour. The energy content of labor is very low compared to some of the other inputs (Leach, 1976) and in industrialized agriculture is negligeable compared to other energy inputs (see e.g. Tables 1 and 2). One could question the above approach as it does not include the food consumed before and after the useful working lifespan (say 18 to 65 years) and does not take into account that the laborer must also be fed during the winter. Thus energy calculations for machinery depreciate the energy used to produce the equipment over a period of years or over a number of acres. Substitution between energy inputs is to a certain extent possible and as fossil fuel energy increases in price it may be possible to replace it partly by labor.

In a recent publication de Wit (1975) has considered the possibility of substitution between energy and labor. In essence de Wit argues that, within reasonable limits, a particular yield may be obtained using different combinations of added energy and labor (Fig. 8). The actual values on the axes should not be taken very seriously, but the figure would intuitively appear to be conceptually correct. It may be impossible to determine the present position of Saskatchewan agriculture, but it is obviously of great importance with regard to the options open to achieve maximum (or potential) yields. If present agriculture is in the region to the left of 0.5 man/acre, significant further yield increases can be achieved at the cost of very large energy additions or at the cost of relative small amounts of labor. To the right of 0.5 man/acre the opposite would hold. With increasing scarcity of fossil fuels and rising unemployment, the most desirable growth path may well involve increasing the labor input per acre. This does not necessarily mean an increase in hard physical work, but rather more attention being paid to field variations, local spots of weeds and diseases by more men working with smaller equipment.

Future possibilities to improve energy ratios

Plant breeding offers many possibilities for increasing plant energy output per acre, for example, significant differences exist between varieties (Austenson, 1974). The development of suitable winter wheat varieties would increase yield and water use efficiency greatly compared to spring wheat. Nitrogen-fixing cereals are being studied at Lethbridge (Larson and Neal, 1976) and plant physiologists are investigating ways to improve the efficiency of the photosynthesis process by which plants transfer solar energy into plant energy. Fig. 9 (Johnston, 1973) shows broad areas of solar energy conversion efficiencies for different levels of agriculture and illustrates the need for the control of other inputs. As technology progresses man should be able to grow his food on less and less land and be able to take marginal lands out of cultivation.

As suggested in Fig. 9, management plays an important role in energy conversion efficiency. Real gains in management efficiency would be possible if reliable long-term weather forecasts were available to assist the farmer with scheduling his operations and matching his fertilizer inputs to the weather.

Summary

1. Agriculture generally is a net producer of energy and in the process transfers fossil fuel energy into digestible energy. In Canada the amount of fossil fuel used for agricultural production on the farms is less than 3% of total energy consumption.
2. The favourable energy balance of wheat production in the Prairies is made possible by exploitation of the nitrogen present in these soils at breaking. This nitrogen was accumulated over 10,000 years and does not represent "free" energy similar to solar energy. In the future nitrogen needs of the crops will have to be met largely by fertilizer-N and this will drop the energy ratio considerably.
3. Soil management systems must aim at maintaining soil quality while resulting in high production with as little energy input as possible.
4. Within the existing agricultural structure, output can be increased by more efficient use of water (e.g. more stubble cropping), however,

fertilizer inputs will have to increase to sustain these yields. Increased efficiency of water use will also have beneficial effects on land quality.

5. Continued research ensuring the most efficient use of fertilizers is needed. These studies should include consideration of the energy costs of the nutrient incurred during its production, transport to the farm, and application, as well as its uptake efficiency by plants.
6. Rotations including legumes can save on the high energy cost of N fertilizers and where possible their use should be encouraged. Energy savings by utilizing manure as fertilizer are probably small, however manure has long-term beneficial effects on the soil and if not used presents a pollution problem.
7. Minimum tillage has many advantages: improvement in water storage, less erosion losses, and lower energy requirements.
8. A study should be undertaken to measure potential yields on various soil types and the inputs needed to produce these potential yields. Until this data is available for various soil types, no recommendations can be made for land use leading to optimum energy efficiency.
9. Large and as yet unproven increases in energy efficiency could result from crop breeding, and long-range weather forecasting.

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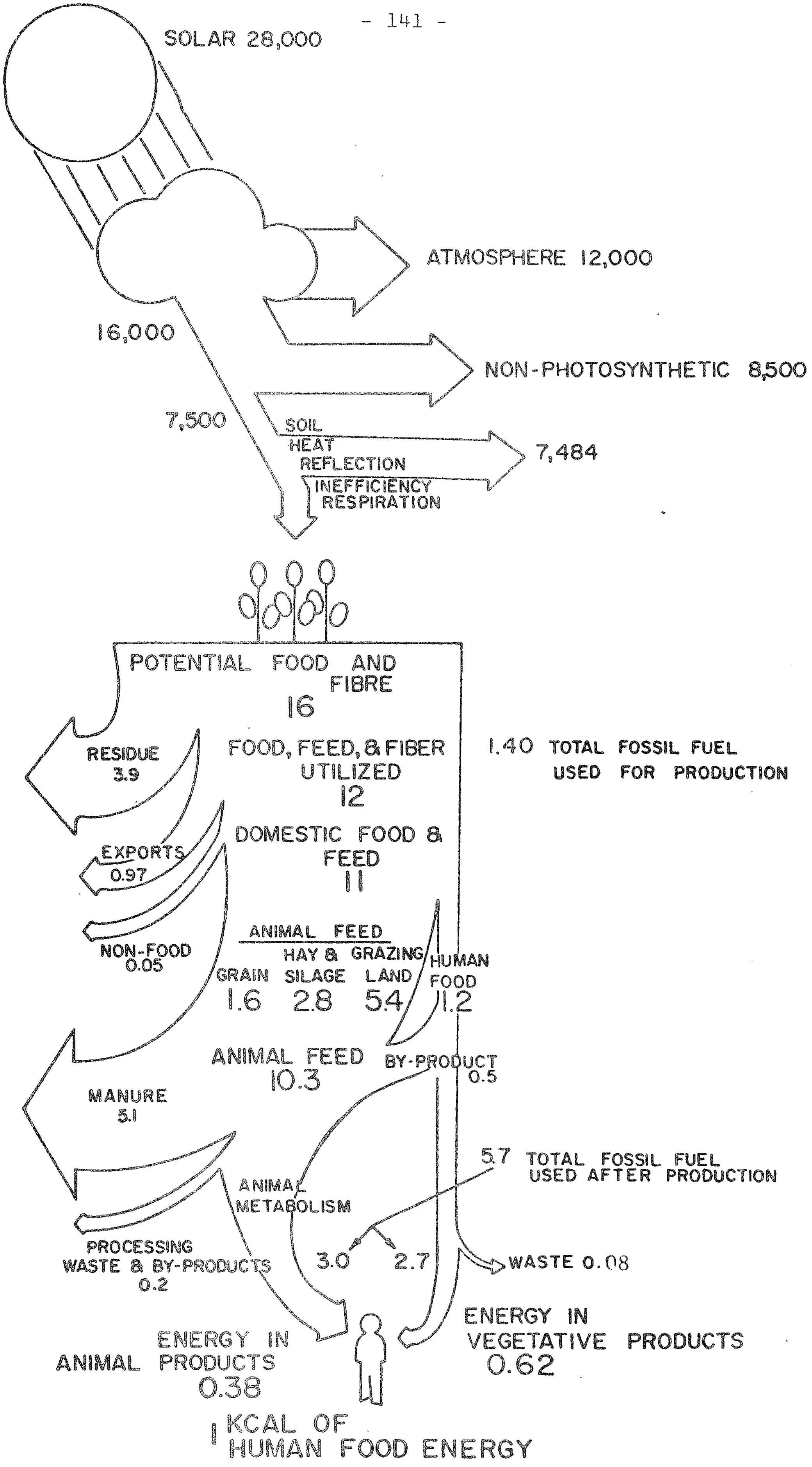

Fig. 1. Energy flow in U.S. agriculture (Stickler, Burrows and Nelson, 1975).

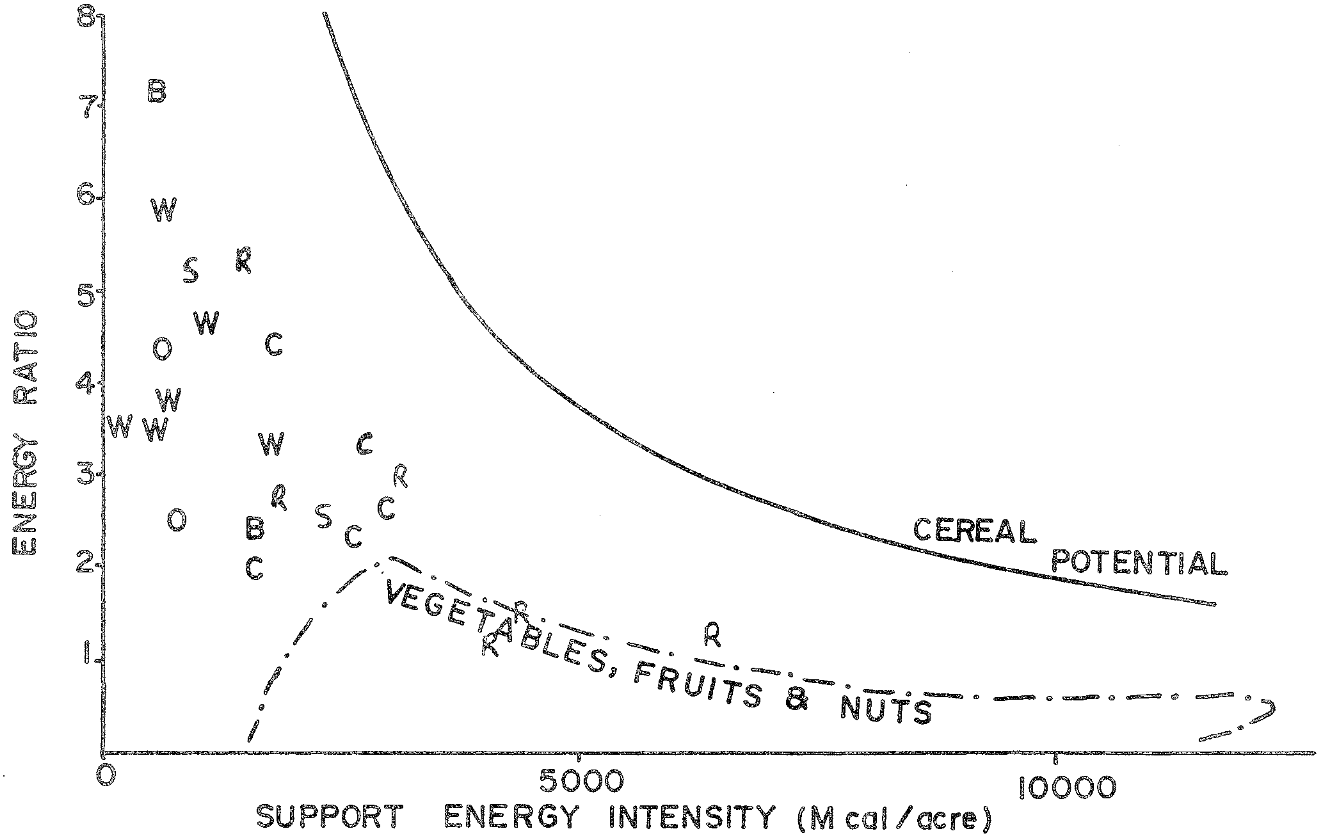

Fig. 2. Energy ratios for cereal crops (W = wheat, B = barley, O = oats, C = corn, R = rice, S = sorghum), for details on these and other crops see Gifford,(1976).

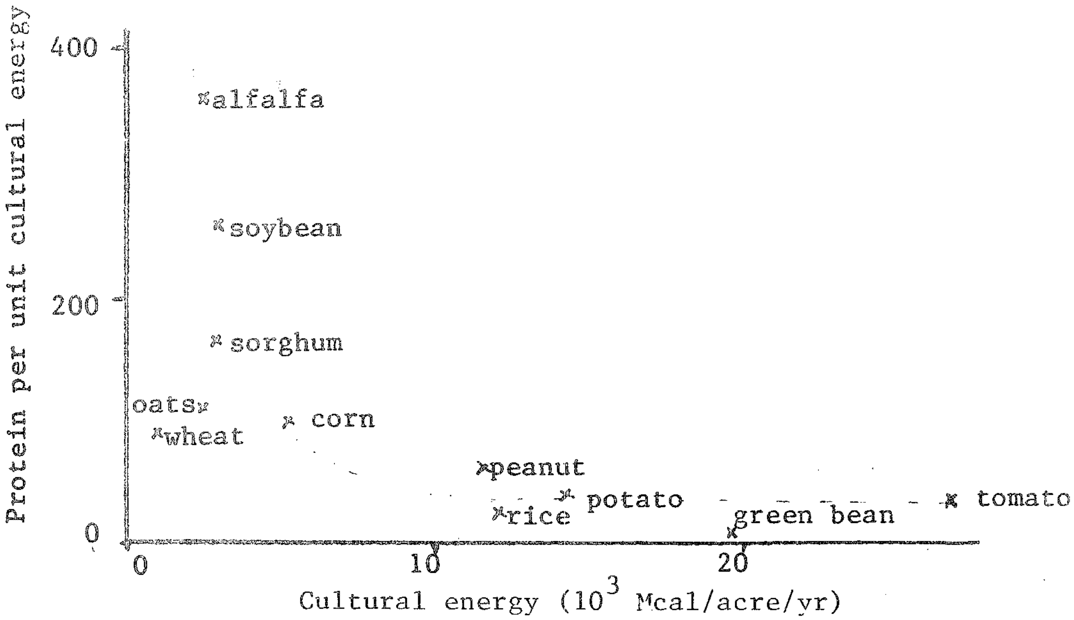

Fig. 3. The graph shows yield of protein per Mcal of cultural energy for forage, grain and vegetable crops (from Heichel, 1976).

Table 1. Energy inputs (in Mcal/acre)[1] for wheat production in Saskatchewan (Neumeyer, 1973, 1977).

	1945	1950	1954	1959	1964	1970	1971	1972	1973	1974	1975
Labor	3.0	2.7	2.5	2.2	1.9	1.6	1.5	1.5	1.5	1.4	1.4
Machinery and Transportation	25	30	47	36	34	103	46	43	48	47	62
Fuel	205	197	212	217	199	389	260	238	240	241	244
Fertilizers	1.4	4.6	3.7	4.2	19	18	20	26	41	60	68
Herbicides and Insecticides	0	2.0	1.7	1.5	2.6	2.2	1.5	1.9	2.7	3.6	2.5
Seed	154	154	154	154	154	154	154	154	154	154	154
Total input, Mcal	388	390	421	414	410	668	483	465	487	507	531
Yield, bu/ac	12.4	16.5	10.2	16.0	18.1	26.2	26.7	23.5	24.0	21.0	25.5
Mcal	1529	2034	1257	1972	2231	3230	3292	2835	2959	2589	3144
Mcal return/Mcal input	3.9	5.2	3.0	4.8	5.4	4.8	6.8	6.1	6.1	5.1	5.9

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[1] Mcal = 10^6 cal = 10^3 kcal = 1000 Calory (dietary) does not include energy inputs in the form of building materials.

Table 2. Energy inputs (in Mcal/acre)[1] for corn production in the U.S.A. (From Pimentel et al., 1973)

	1945	1950	1954	1959	1964	1970
Labor	12.5	9.8	9.3	7.6	6.0	4.9
Machinery and Transportation	200	280	345	410	490	490
Fuel	543	616	688	725	761	797
Fertilizers	75	152	295	429	583	1056
Herbicides and Insecticides	0	1.7	4.4	10.5	15.2	22.0
Seed	34	40	19	37	30	63
Others (drying, irrigation, etc.)	61	107	187	271	357	444
Total input, Mcal	926	1206	1548	1889	2242	2897
Yield, bu/ac	34	38	41	54	68	81
Mcal	3427	3830	4133	5443	6854	8165
Mcal return/Mcal input	3.7	3.2	2.7	2.9	3.1	2.8

[1] Mcal = 10^6 cal = 10^3 kcal = 1000 Calory (dietary)

Table 3. Ratio of digestible energy output to gross energy input for wheat farming systems.

	Inputs	Output	Efficiency Ratio
	Mcal/acre		
Wheat, U.K.	1723	5440 (3537 lb/ac)	3.2 Leach, 1975
Wheat, India	643	1084 (675 lb/ac)	1.7 Leach, 1975
Wheat, Australia	165	581 (415 lb/ac)	3.5 Handreck and Martin, 1976
Wheat, Alberta			
on summerfallow	939[1]	3550[2] (1920 lb/ac)	3.8 Jensen and
on summerfallow	631[1]	2215[2] (1200 lb/ac)	3.5 Stephanson, 1975
Wheat, Saskatchewan[3]			
1945-1965	405	1534[2] (878 lb/ac)	3.9 Neumeyer, 1973,
1970-1975	524	2557[2] (1426 lb/ac)	4.9 1977

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[1] Cost of summerfallowing included with following crop.

[2] Adjusted from gross energy to digestible food energy using a factor of 0.85 (Handreck and Martin, 1976).

[3] Dowing, 1975 reports an efficiency ratio of 8.7 for agriculture in Saskatchewan, however, it appears that his estimate of output is based on gross energy and includes some contribution from straw and manures.

Table 4. Nitrogen balance - SASK. (Rennie, 1976)

	lb/AC each year	lb/AC - 60 yrs	40 M AC cult. land (tons) x 10^6
Release from soil O.M.	42	2520	50.4
Sold off the farm	14	840	16.8[1]
Leached below rooting depth	11	660	13.2[1]
Denitrified	10	1020	20.4[1]
Erosion losses	7		

[1] These quantities of N are equivalent to 51, 40 and 62 x the N sold in the prairies in 1975 (.33 M T).

Table 5. Energy consumed in fertilizer production, transportation, and application (Hoeft and Seimens, 1975)

Fertilizer Material	Kcals/lb of N For production	 For transportation	Kcals/A for application
Anhydrous ammonia	6,250	277	25,386
Urea solution	7,845	758	6,955
Urea solid	8,120	505	10,433
Ammonium nitrate solution	7,245	1,083	6,955
Ammonium nitrate solid	8,435	669	10,433

Fig. 6. TOTAL INCREASE IN THE YIELD OF WHEAT ON FALLOW AND STUBBLE IN A 3 YEAR CROPPING SEQUENCE OF FALLOW, WHEAT, WHEAT WITH THE MANURE APPLIED EVERY THIRD YEAR (Indian Head Exp. station)

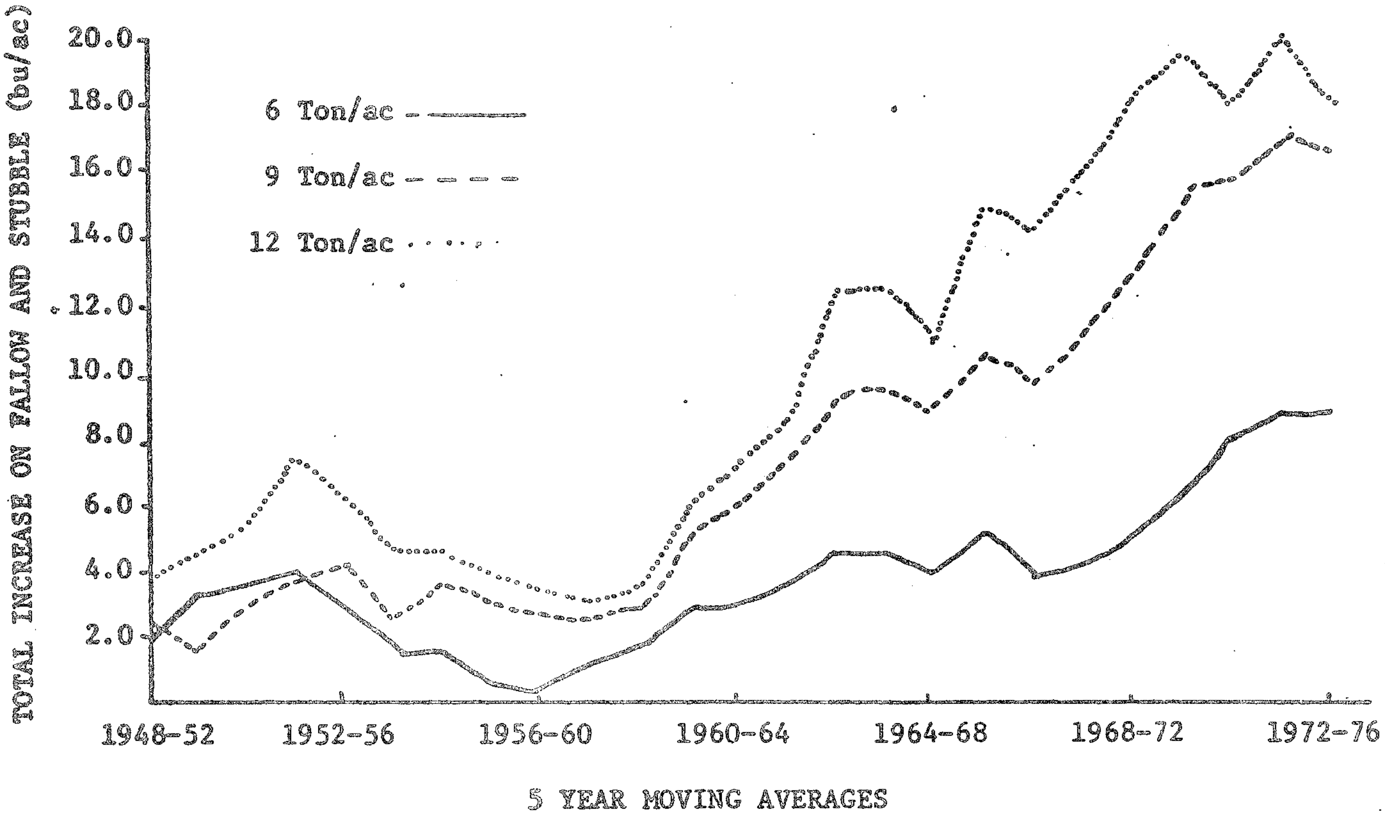

Table 6. Acreage summary (in 1,000 acres) of soil capability classes and their longterm productivity.1)

Capability Class and Land Use	Brown	Dark Brown	Thin Black	Thick Black and Dark Grey	Grey Wooded	Azonal
Class 1 Very good arable	0	0	546 (20.0-21.0)	1165 (21.0-24.4)	848	20
Class 2 Good arable	1188 (15.5-17.5)	2239 (16.9-19.1)	6070 (16.6-19.9)	1454 (17.8-19.7)	2044 (up to 19.0)	138
Class 3 Fair arable	5030 (11.2-14.1)	9591 (11.6-14.8)	2867 (13.1-15.5)	756 (14.8-15.6)	2672 (13.2-15.0)	568
Class 4 Poor arable	3777 (9.1-11.0)	2347 (10.8-11.0)	1043	154	441	370
Class 5 Suited for improved pasture	4543 (CP 1.0-1.5)	2949 (CP 1.0-1.1)	3594 (CP 0.4-1.8)	1046 (CP 0.5-1.8)	2462	2633
Class 6 Suited only for native pasture	909 (CP >4)	843 (CP >3)	757	198	411 (CP 5.2)	3081
Class 7 Unsuited for agriculture	59	61	80	30	70	191
Total cultivated acreage	9649	13372	9115	3090	4084	965

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1) Acreages: Shields, Rostad and Clayton, 1970.

Longterm productivity (in brackets underneath acreages): Hutcheon, Clayton and Rennie, 1964.
wheat in bu/acre
forage in acres/cow month

Table 7. Average costs for certain field operations in Canada Department of Agriculture Illustration stations (1956-1958).

		AVERAGE COST IN 0.01 $/ACRE/OPERATION FOR								
	CLI	SEEDING			CULTIVATOR			COMBINING		
Soil Type and Zone	Classification	M	F	L	M	F	L	M	F	L
Asquith f.s.l. Dark Brown	4^{10}_{m}	29	8	13	26	6	16	149	17	20
Sceptre c. Brown	2^{10}_{cm}	35	20	20	40	24	24	109	29	24
Fox Valley l. Brown	3^{10}_{m}	45	5	14	40	6	16	136	13	17
Elstow - Sutherland s.i.c.l. Dark Brown	3^{10}_{m}	20	16	16	21	15	15	174	31	23
Waitville l. Gray	$3^{6}_{x}2^{2}_{m}5^{2}_{w}$	54	19	33	40	20	33	146	29	50
Glenbush - Whitewood l. Dark grey	$2^{7}_{m}5^{3}_{w}$	30	14	28	31	17	35			
Dorintosh - Beaver l.-c.l. Grey-Dark Grey	$3^{8}_{d}5^{2}_{w}$	52	21	30	38	21	28			
Whitewood l. Dark Grey	$2^{9}_{d}5^{1}_{w}$	16	10	15	30	8	17	118	10	24
Loon River l. Grey	$3^{8}_{d}5^{2}_{w}$	36	12	25	51	18	39			

M: machinery, $0.01 is approximately equivalent to 0.1 x 10^6 cal (calculated from Neumeyer, 1973)
F: fuel, oil and gas, $0.01 is approximately equal to 1/20 gal or 2.2 x 10^6 cal
L: labor, $0.01 is approximately equal to 1/100th of an hour or 0.054 x 10^6 cal

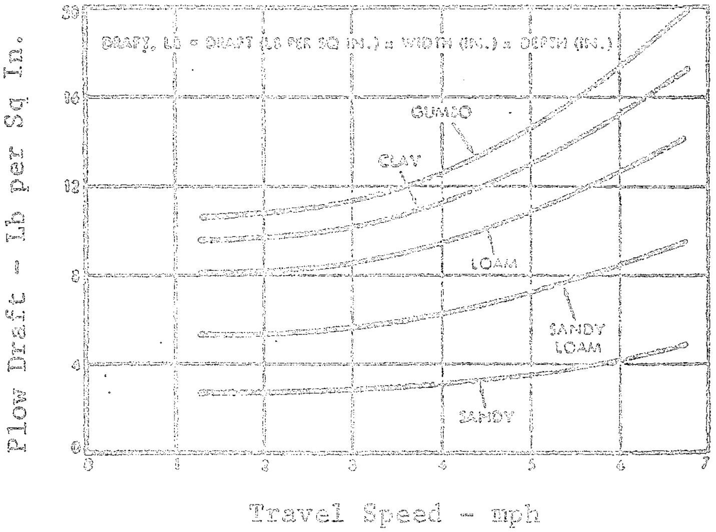

Fig. 7. Moldboard Plow Draft showing the effects of texture and speed (1975 Agricultural Engineers Yearbook).

Table 8. Fuel and lubrication costs of combines in three areas in Saskatchewan. (Johnson, 1971)

Area	Dominant Soil Type and class	Fuel and Lubrication Costs $/harvest acre
Rosetown	Regina, Sceptre, Sutherland 60% class 2, 15% class 3	0.12
Elbow	Weyburn, 83% class 3	0.15
Wishardt	Oxbow, 18% class 1, 50% class 2	0.24

Table 9. Yield of wheat (bu/acre) on fallow and stubble seeded land and nitrogen and phosphorus (lb/acre) required to reach potential yields (Rennie, 1976).

YIELDS

Soil Capability Class	1966-1975		Potential	
	Fallow	Stubble	Fallow	Stubble
1	35.1	24.6	43.1	34.5
2	29.8	20.9	36.6	29.3
3	24.6	17.2	30.2	22.7
4	17.5	12.3	21.6	15.1

FERTILIZER NEEDS

Soil Class	Fallow		Stubble		
	P_2O_5	N	P_2O_5	Nitrogen	
				1st stubble	2nd stubble
1	30	6	30	40	55
2	25	6	25	32	45
3	20	10	20	28	35
4	20	10	20	25	30

Table 10. Energy efficiency ratios for wheat as affected by length of rotation[1].

Soil Capability Class	Fallow	1st Stubble	2nd Stubble
1	5.9	4.4	3.8
2	5.0	4.1	3.6
3	4.0	3.4	3.1
4	2.9	2.3	2.2

[1] Gross energy ratios based on data in Table 9 and other energy inputs for a model farm in the Three Hills district, Alberta (Jensen and Stephanson, 1975) with summerfallowing inputs included with energy inputs for the next crop.

Table 11. Average hay yields reported for the Brown soil zone. (Wiens and Kilcher, 1971).

Oat hay	1.6 (0.75 - 2.25)*
Grass-legume mixed	0.75 (0.13 - 0.9)*
Grass-legume in separate rows	1.25

*range in 70% of the years

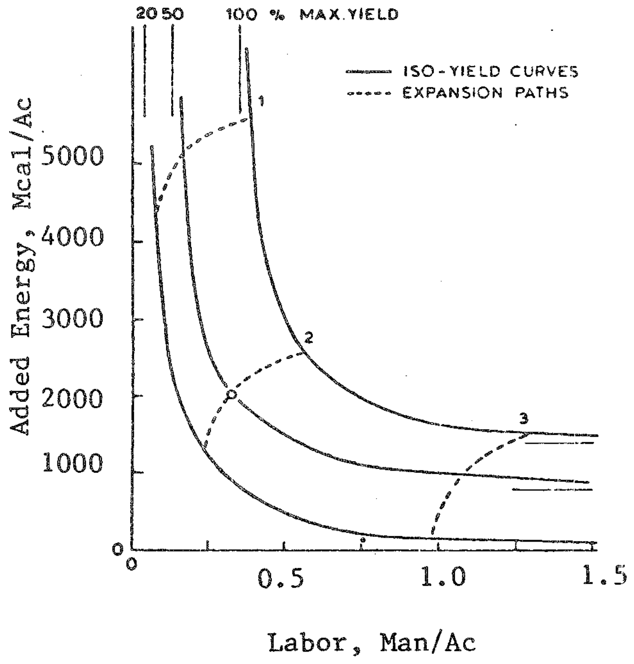

Fig. 8. Iso-yield functions of added energy versus added labor for the 20, 50 and 100% yield level. The curves are assumed to hold for farms in the south-western clay district in the Netherlands around 1965 (de Wit, 1975).

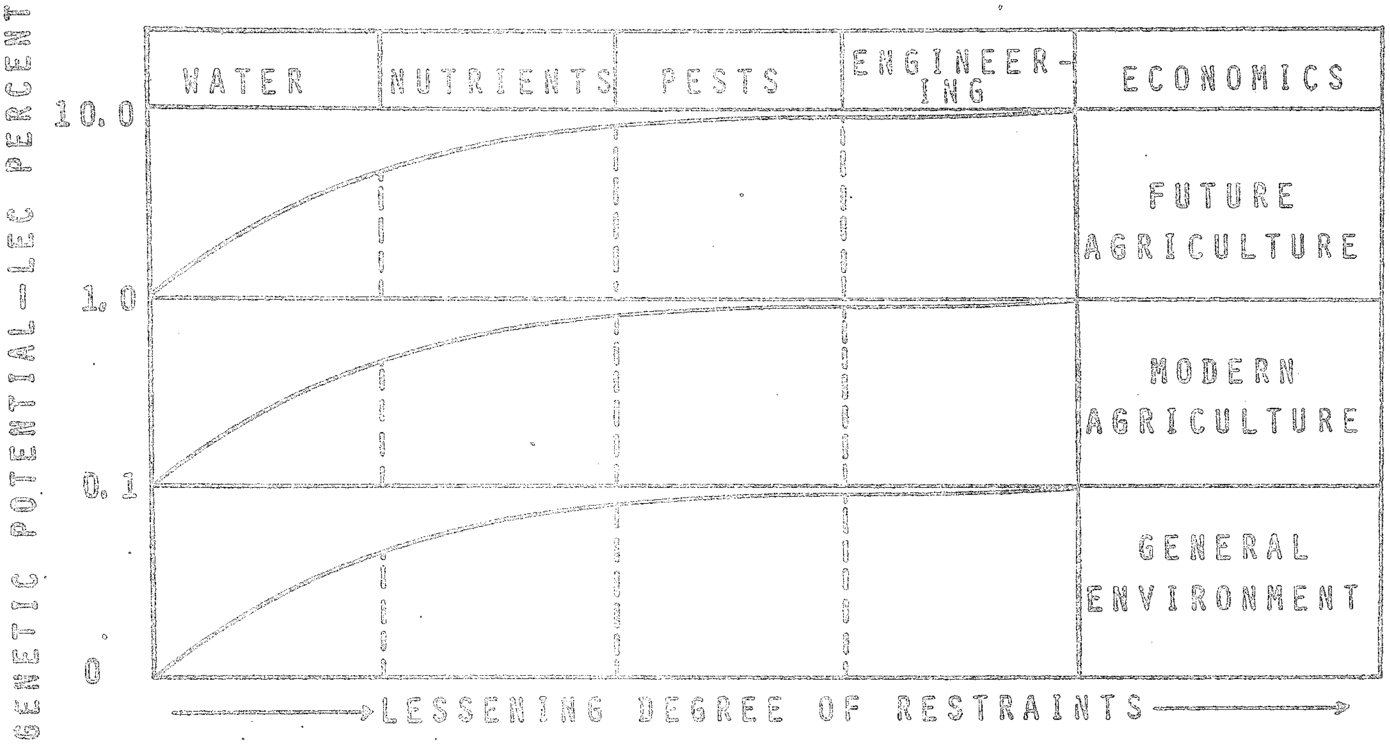

Fig. 9. CONCEPTUAL RELATIONSHIP BETWEEN RESTRAINTS AND LIGHT ENERGY CONVERSION (LEC) BY GREEN PLANTS FOR A GIVEN ENVIRONMENT.