NITRATE LOST FROM VARIOUS LONG-TERM FALLOW AND CONTINUOUS CROPPING ROTATIONS AT SWIFT CURRENT

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INTRODUCTION

In analyzing the mineral N data collected for the first 12 years (1967-78) of the Swift Current Research Station's long-term rotation study, it was observed that in years with above-normal growing season rainfall, NO_3-N appeared to be leached beyond the rooting zone (data not shown).

Since the experimental site is known to have a deep water table (>10 m), it was decided to determine if the leached NO_3-N was accumulating in the subsoil below the 120-cm depth. Fortunately, we picked a year (1982) of well above-normal growing season rainfall to carry out this assessment. Our objective was to compare the influence of fallowing, continuous cropping, a fall-seeded crop, and N fertilizer application on the amount and distribution of NO_3-N that might be leached beyond the root zone of a cereal crop in a year of above-normal precipitation.

MATERIALS AND METHODS

The Swift Current long-term rotation plots that were initiated in 1966 (Campbell et al. 1983) formed the basis of this study. Six rotations (Table 1), four that included a fallow year and two continuous wheat rotations, were sampled three times during the 1982 spring to fall period. The four fallow rotations were Rot. 1, 2, 4,and 11 with only the rotation-year that was fallow in 1982 (Rot. 1-1, 2-1, 4-1 and 11-1) being sampled. Rot 11 was a fallow-wheat rotation with essentially no N fertilizer applied during the study period. Rot. 1 and 2 were fallow-wheat-wheat rotations with P fertilizer applied at rates as indicated according to soil tests, but with N fertilizer applied only to Rot. 2. Rotation 4 was a fallow-fall rye-wheat rotation that received both N and P fertilizers according to soil tests. The two continuous spring wheat rotations were Rot. 8 (N and P fertilizer applied) and Rot. 12 receiving only P fertilizer. Each rotation treatment was replicated three times.

Table 1. Crop Rotations and Treatments Analysed in 1982

Rot. No.	Rotations+	Comments
1	Fallow-wheat-wheat	P applied as required but no N applied.
2	Fallow-wheat-wheat	N & P applied as required.
4	Fallow-fall rye-wheat	N & P applied as required.
8	Continuous wheat	N & P applied as required.
11	Fallow-wheat	N & P applied as required.
12	Continuous wheat	P applied as required but no N applied.

+ In the 2-yr and 3-yr rotations only the rotation-yr that was fallowed in 1982 was sampled (i.e., rotations 1-1, 2-1, 4-1 & 11-1).

Soil samples were taken on all plots on May 18 and June 10, and again on September 2 for fallow plots and October 14 for cropped plots. Samples were taken with a Giddings soil coring truck at depth of 0- to 15-, 15- to 30-cm, and at 30-cm intervals thereafter to depth of 240 cm. Soil moisture (gravimetrically) and NO_3-N (Hamm et al. 1970) were determined. Bulk density by coring, mechanical analysis by the Bouyoncous method and the moisture held at -0.03 and -1.5 MPa were determined on a separate set of samples collected for this purpose.

The NO_3-N concentration (ppm) was converted to $kg.ha^{-1}$ by multiplying by the appropriate bulk density (Table 2) and the volume for that depth of soil. The water (% by wt) was converted to cm by using the equation: cm water = % water by wt x bulk density x depth of segment 100. The particle size distribution (Table 2) showed that there was a sandy region located between 60 and 150 cm, although the texture of this region was classified as clay loam.

Precipitation was assumed to be similar to that recorded at the meteorological site located 1 km away from the plots (Table 3). During the period May to the end of September, precipitation was 20% greater than the long-term averages for this region.

Rotation 8-1 was fertilized with 34-0-0 broadcast at a rate of 23 kg $N.ha^{-1}$ on May 11, but the plots were not seeded until June 5 because of a heavy snowstorm received during the last week of May.

The moisture and NO_3-N data were analyzed statistically as a split plot in time and space.

Table 2. Physical Characteristics of Test Plot Soil

Soil Depth (cm)	Bulk+ Density ($g.cc^{-1}$)	Water held at -0.03 MPa % by wt	cm‡	-1.5 MPa % by wt	cm‡	Particle size dist. Sand	Silt (%)	Clay	Text.
0-15	1.22	22.00	4.03	9.60	1.76	30.0	50.0	20.0	L-Sil
15-30	1.28	24.35	4.68	11.21	2.15	27.0	50.0	23.0	L-Sil
30-60	1.36	20.70	8.45	9.81	4.00	32.0	41.0	27.0	SiL-CL
60-90	1.39	20.51	8.55	10.14	4.23	40.0	28.0	32.0	CL
90-120	1.55	20.61	9.58	10.02	4.66	40.0	28.0	32.0	CL
120-150	1.76	15.02	7.93	8.20	4.23	39.0	26.0	35.0	CL
150-180	1.65	17.95	8.89	9.67	4.79	27.0	31.3	41.7	C
180-210	1.78	18.64	9.95	9.54	5.09	18.0	40.0	42.0	C
210-240	1.72	19.93	10.28	11.25	5.80	16.3	40.0	43.7	SiC

+ Each value is the mean of determinations on 39 plots.

‡ Centimeters water per depth = % water (by wt) x bulk density x depth

Table 3. Growing Season Precipitation During 1982

	Precipitation+ Actual	L.T. Av.
	---- mm ----	
‡May	40.6	24.0
June	42.7	72.8
July	119.2	51.2
August	40.8	42.6
September	30.4	30.5
Total	273.7	221.1

+ Precipitation between Oct. 1 and Oct. 14 was 6.8 mm

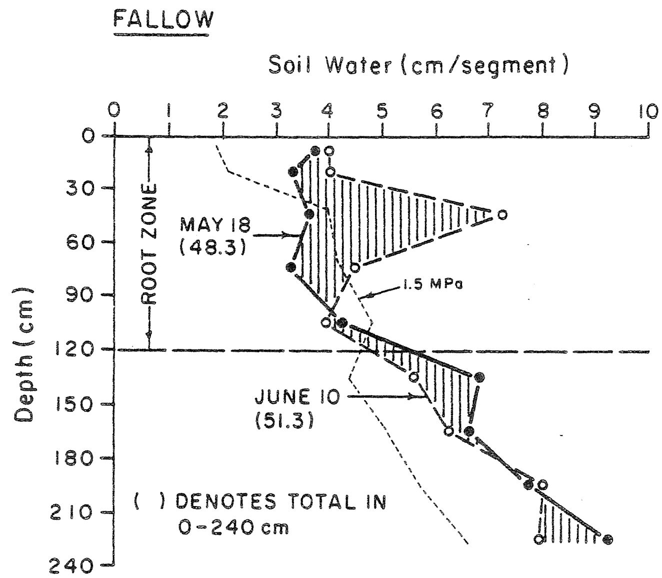
‡ May 18-31

RESULTS AND DISCUSSION

The analysis of variance of the soil water results showed that depth, time, and the interaction of depth and time were the only significant factors P (< 0.01) (data not shown). The analysis for NO_3-N data showed that the factors affecting water, as well as the interaction of sequences (rotation) and time, and sequence and depth were also significant P (< 0.01) (data not shown). Consequently, the data were summarized to demonstrate the various two-way interactions (Fig. 1, 2, and 3).

Changes in Soil Moisture and NO_3-N During Growing Season

Fallow: There was no significant difference in soil moisture between



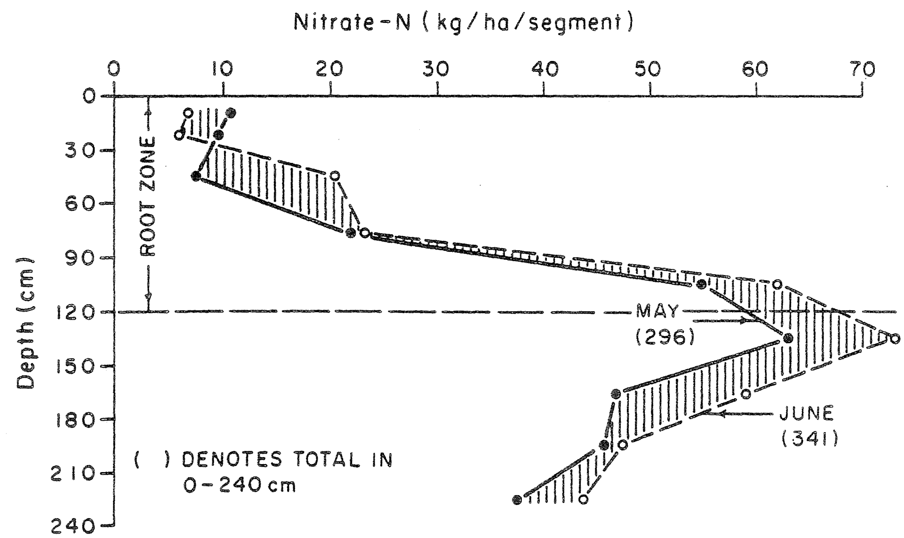
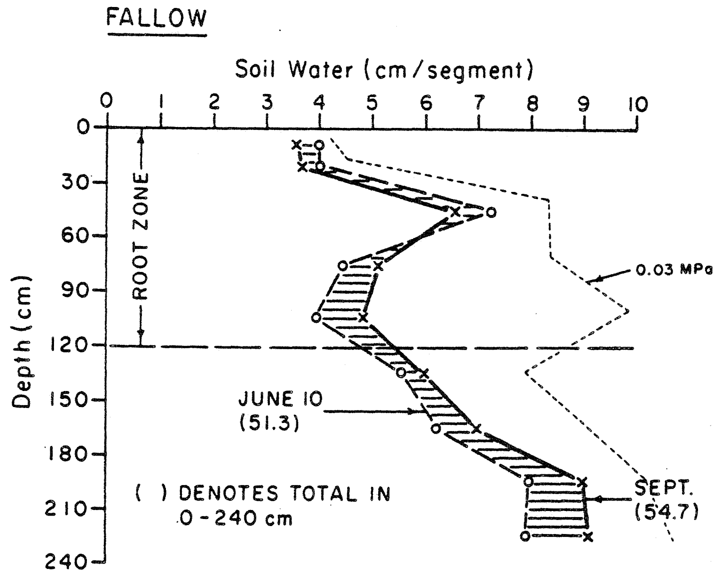


Fig. 1a. Changes in soil moisture and NO_3-N distribution in fallow during the early period of growing season.



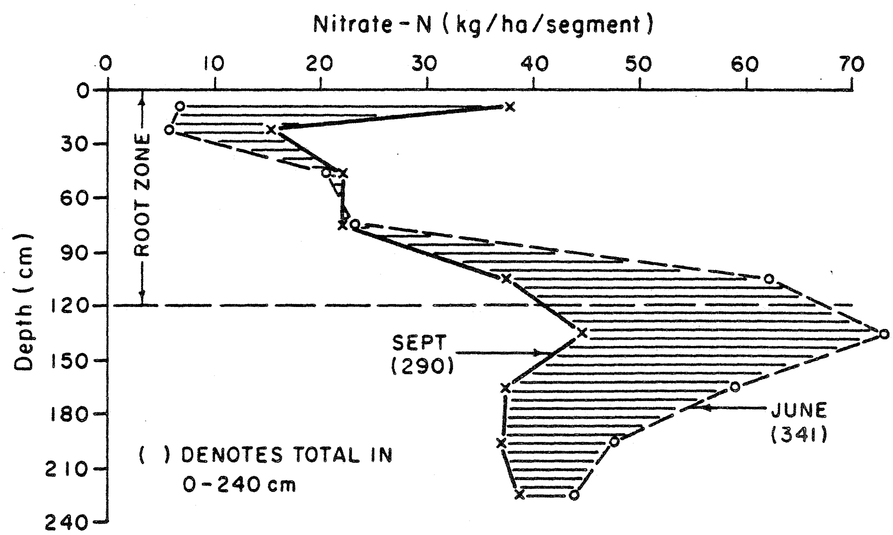


Fig. 1b. Changes in soil moisture and NO_3-N distribution in fallow during the later part of the growing season.

fallow treatments, thus Fig. 1a and 1b represent the mean of the four fallow treatments. In mid-May, soil water in the top 30 cm was well above the -1.5 MPa potential (Fig. 1a) reflecting entry of the winter snow melt water into the soil. Between the 30 and 120 cm depth, the soil was drier than wilting point, reflecting water use by the previous year's crop. Below the root zone, the soil moisture was about midway between the -1.5 and -0.03 MPa potentials.

Between May 18 and June 10, 70 mm of precipitation was received (a large part as snow) and this was readily apparent in the soil moisture increase in the top 90 cm of the profile (Fig. 1a). The surprising observation, however, was the decrease in water that occurred in the soil zone between 120 and 150 cm during this same period. As seen later, this trend was also apparent in the continuous cropping rotations (Fig. 2a). We were unable to explain how this water was "lost".

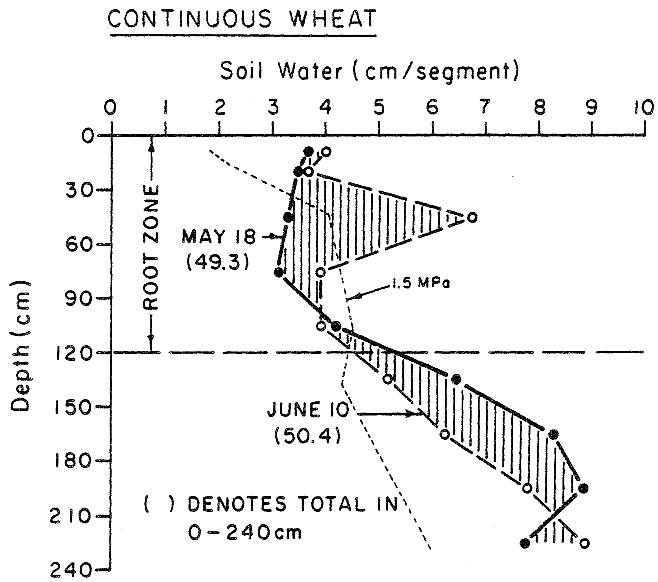
The NO_3-N levels in the top 90 cm of the treatments that were being fallowed in 1982 were generally low in May (Fig. 1a). This was due to N uptake by the previous year's crop. But, there were still large quantities of NO_3-N located between 90 and 240 cm, confirming our hypothesis that in wet years, (or even when heavy rains are received in early June of some drier years), considerable NO_3-N is being leached out of the root zone of some of these rotations and deposited in the subsoil.

The 70 mm of precipitation that was received between May 18 and June 10 moved some NO_3-N from the top 30 cm into lower segments as deep as the 240 cm, and perhaps deeper (Fig. 1a). Although there was considerably more NO_3-N gained below than lost from above, it must be remembered that the wet-dry spells associated with the copious precipitation would have resulted in considerable net N production.

During the period from June 10 to September 2, 199 mm of precipitation was received. This caused an increase in soil water content down to at least the 240 cm depth (Fig. 1b) (although the surface 60 cm shows a deficit this deficit was due to evaporative losses).

The NO_3-N changes occurring between June and September (Fig. 1b) reflect the two major processes that were in action. In the top 30 cm there was a pronounced increase in NO_3-N due to recent N mineralization, while in the subsoil there was a marked depletion of the NO_3-N that had been moved into this segment in June. This was attributed to the leaching of the NO_3-N out of the top 240 cm, although there could have been some denitrification losses as well.

Continuous wheat: The soil water distribution in the continuous wheat profiles on May 18 and June 10 were very similar to those of the fallow plots on comparable dates (compare Fig. 1a and 2a). This was not surprising since the treatments had been similar in 1981 and the



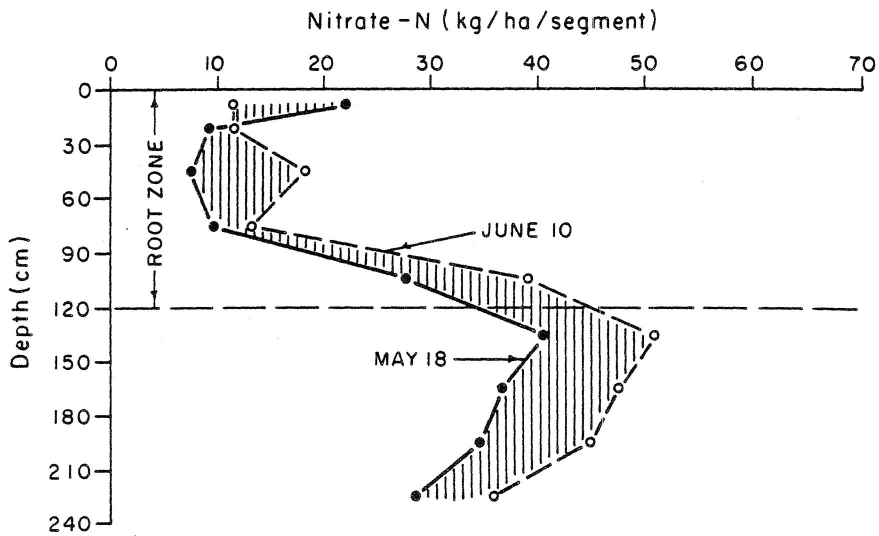
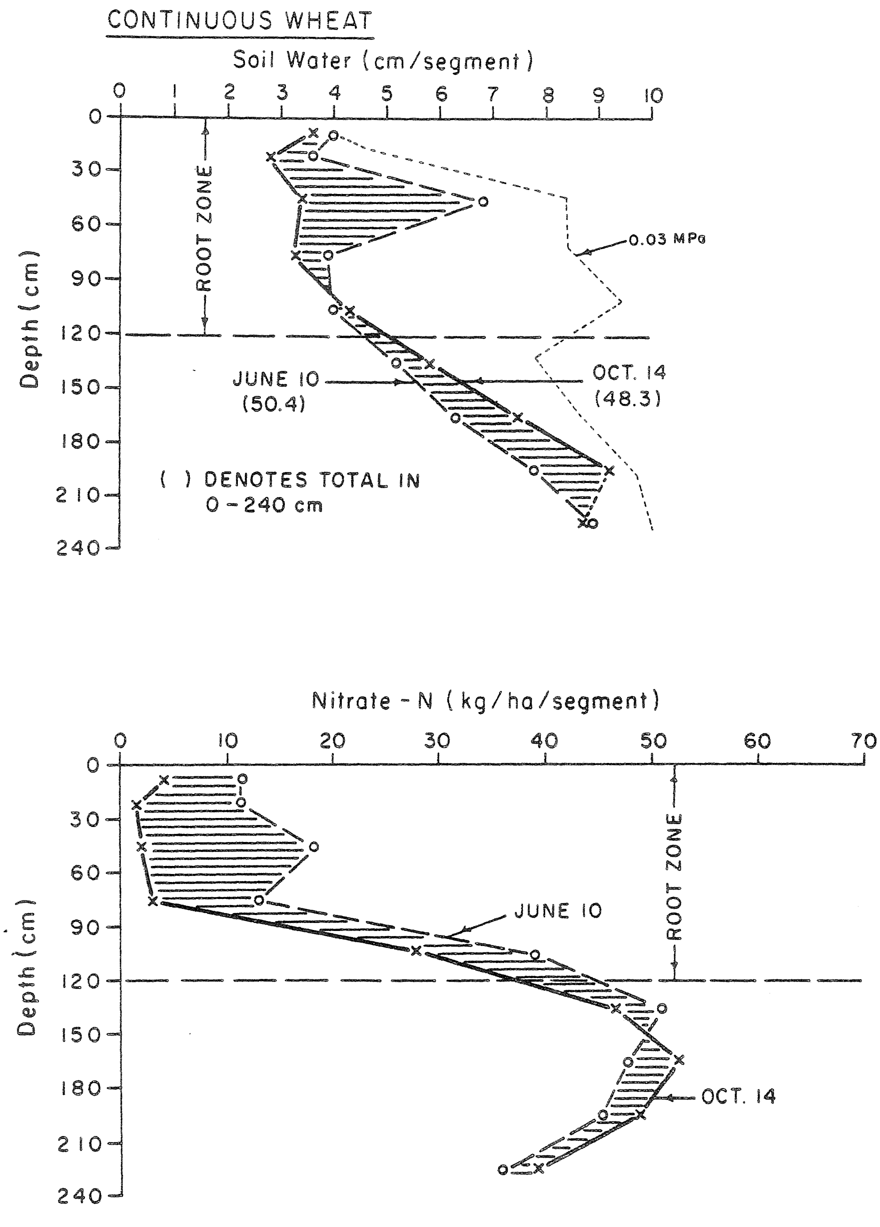


Fig. 2a. Changes in soil moisture and NO_3-N distribution in continuous cropping rotations during early period of the growing season.



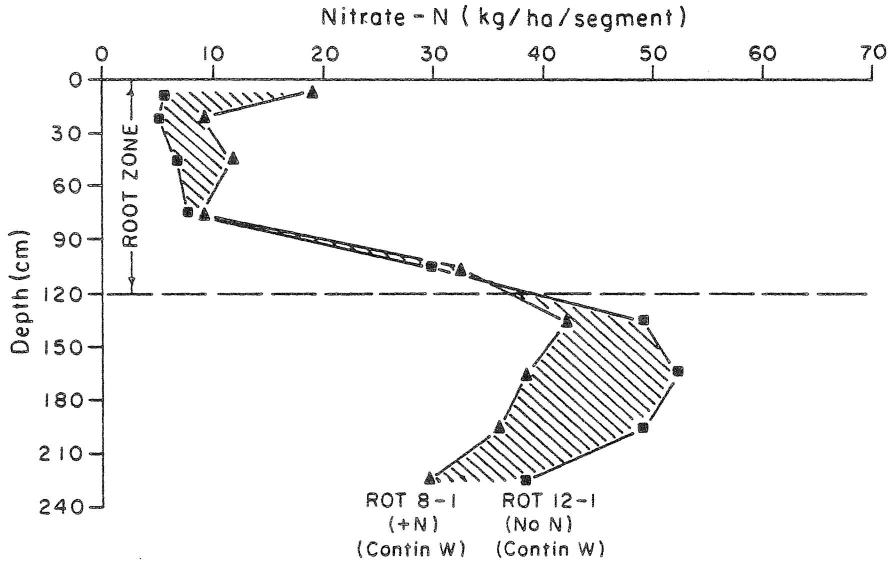
Fib. 2b. Changes in soil moisture and NO_3-N distribution in continuous cropping rotations during the later part of growing season.

crop was only seeded in the continuous wheat plots on June 5. Furthermore the soil NO_3-N distribution in both continuous wheat and fallow plots was similar in pattern and changed in a similar manner between May and June in response to the 70 mm of precipitation received (Fig. 1a and 2a). The difference between the continuous and the fallow systems to that stage was in the absolute amounts of NO_3-N. The continuous wheat system had slightly more NO_3-N in the top 15 cm, but much less NO_3-N in the subsoil compared to the fallow systems (compare Fig. 1a and 2a). The difference in subsoil NO_3-N will be discussed later; the difference in NO_3-N in the top 15 cm was due to the fertilizer N that was applied in May to continuous wheat plots.

Between June 10 and October 14, the soil water decreased in the root zone under continuous wheat due to crop use, but apparently extra water still escaped into the subsoil (below the root zone) even though the land was being cropped (Fig. 2b). This movement probably occurred in late June and perhaps early July before the crop was well established.

The NO_3-N distribution confirms the movement of water into the subsoil since extra NO_3-N was pushed into the 180 to 240 cm depth (Fig. 2b). In contrast to the fallow situation, the extra water leaching into the subsoil was not enough to leach out the NO_3-N from the top 240 cm since an accumulation (note tailing off of the curve) occurred. Much of the decrease in NO_3-N that occurred in the root zone between June 10 and October 14 was likely due to crop uptake.

Effect of Cropping, N fertilizer and Fall Rye: The various cropping sequences had marked effects on the distribution of NO_3-N in the soil (Fig. 3a & b). As expected, the fallow systems, except for the one including fall rye, had considerably more NO_3-N both within and below the root zone than did continuous wheat (Fig. 3 and Table 4). A summary of the NO_3-N located between 120 and 240 cm (Table 5) showed: (i) N fertilizer applied at recommended rates does not lead to ground water pollution, instead it increases plant production, and thereby, soil N uptake, thus reducing NO_3-N leaching compared to unfertilized crops; (ii) some NO_3-N may be leached into the subsoil even under continuous cropping rotations, but it is only about one-half as much as is leached in a 2- or 3-yr fallow-wheat system without N fertilizer; (iii) although there was less NO_3-N found in the subsoil (to 240 cm) under the 2-yr than under the 3-yr fallow-wheat (no N applied) system, we believe that if sampling had been done to a deeper depth this result would have been reversed. The latter conclusion was based on the observation that the NO_3-N distribution profile for the 2-yr rotation (Rot. 11) was just peaking at 240 cm depth while all other NO_3-N profiles had peaked and were decreasing rapidly in NO_3-N at 240 cm (Fig. 3). Although fall rye had only a slightly lower amount of subsoil NO_3-N in the 120 to 240 cm depth than the fallow-wheat-wheat rotation (with N applied) (Table 5), the difference



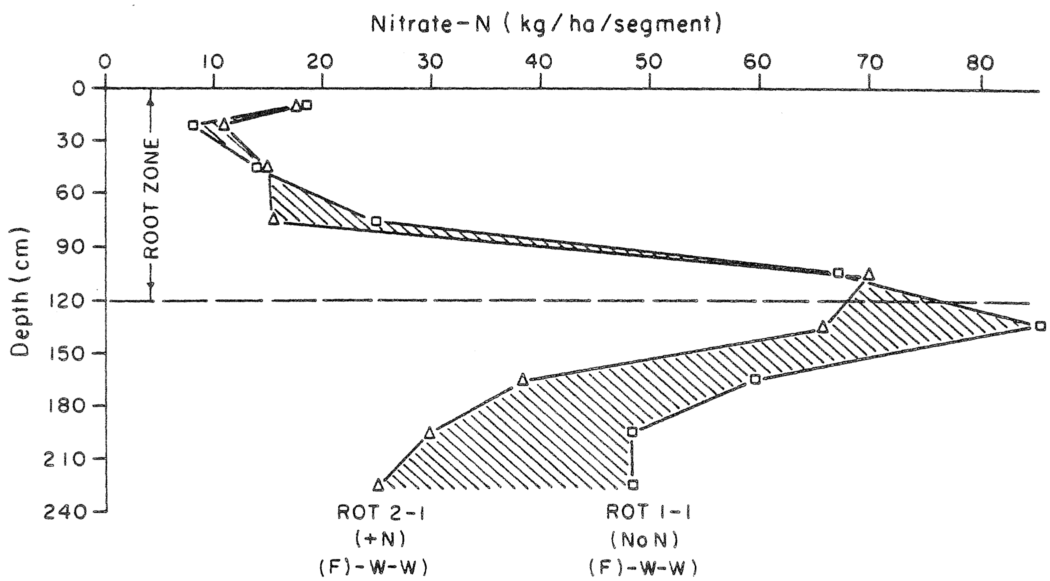


Fig. 3a. Effect of cropping and N fertilizer on soil NO_3-N distribution in a wet year

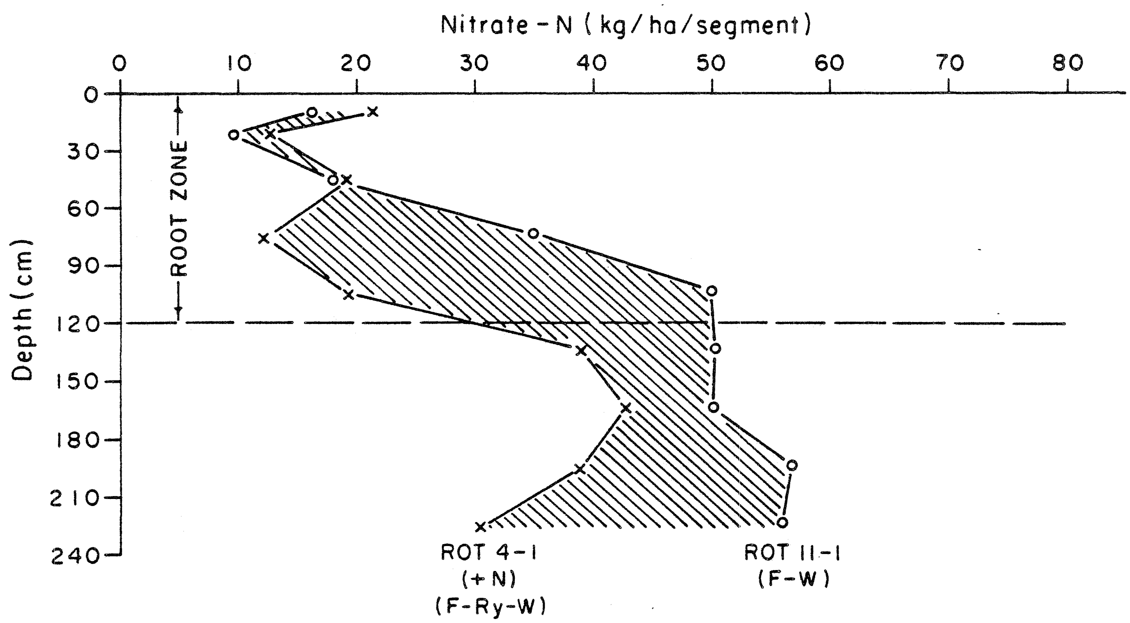


Fig. 3b. Effect of cropping and fall rye on soil NO_3-N distribution in a wet year

was about 60 kg $N.ha^{-1}$ in favour of fall rye (averaged over the three sample times) if the 90 to 120 cm depth was included in the analysis (Fig. 3). This then shows the value of fall rye in reducing the amount of soil NO_3-N available for leaching because of its early growth and N uptake in the spring.

It is difficult to measure accurately the amount of N that might have been lost from the soil based on three time samples because mineral N is continually being formed near the soil surface and transported to lower depth when it rains. Nonetheless, we attempted to make an estimate of this loss.

Table 4. Average NO_3-N in fallow and cropped soil profiles in 1982

Depth (cm)	Fallow (av. 4 treatments) Date soil sampled May 18	June 10	Sept. 2	Cropped (av. 2 treatments) May 18	June 10	Oct. 14
	kg NO_3-N.ha^{-1}.segment^{-1}					
0-15	10.5	6.6	38.0	22.1	11.3	3.8
15-30	9.5	5.9	15.1	9.0	11.1	1.4
30-60	7.5	20.3	22.0	7.4	18.2	2.0
60-90	20.9	23.1	21.4	9.6	13.0	2.9
90-120	54.8	62.0	37.4	27.8	39.1	27.2
Root zone	103.2	117.9	133.9	75.9	92.7	37.3
120-150	62.8	72.9	44.4	40.5	50.9	46.3
150-180	46.8	58.9	37.2	36.5	47.6	52.6
180-210	45.6	47.5	36.6	34.7	45.0	48.8
210-240	37.6	44.0	38.3	28.3	35.8	38.7
Sub soil	192.8	223.3	156.5	140.0	179.3	186.4
Total	296.0	341.2	290.4	215.9	272.0	223.7

It appeared that at least 46 kg N.ha^{-1} was produced during the 23 days between May 18 and June 10 (Table 4). Since it was just as rainy in the ensuing 83 days, between June 10 and September 2 as between May 18 and June 10, we assumed that 3.5 times as much NO_3-N was produced in the June to September period as in the May to June period, (i.e., 161 kg N.ha^{-1}) for a total of 207 kg N.ha^{-1} for the growing season. The 12-yr average NO_3-N production in these fallow soils was 106 kg.ha^{-1} between May and October, and values as high as 176 kg.ha^{-1} were estimated based only on analysis of the top 90 cm of the profile (data not shown). With the considerable wetting and drying that accompanied the frequent rainfalls in 1982 it is conceivable that 200 kg N.ha^{-1} could have been mineralized in the fallow treatments. In the fallow plots, the NO_3-N in the top 240 cm was the same in September as in May (Table 4). Thus, a loss of about 200 kg N.ha^{-1} (i.e., the amount generated by mineralization) occurred due to leaching. At a value of 75 cents per kg of urea-N, this is a loss of 150 \$.ha^{-1}. Even if the N mineralized during the growing season was only half that estimated, the loss in N by leaching in 1982 would be about 75 \$.ha^{-1}. The amount of N lost in selling the grain from an average crop of wheat in the Brown soil zone is about 40 kg N.ha^{-1}. Thus, in a wet year we are losing twice as much N to leaching as we lose through marketing the grain. This is a serious problem because the loss is not as readily apparent as the sale of wheat.

Table 5. Nitrate-Nitrogen found in 120 to 240 cm depth ($kg.ha^{-1}$) in 1982

		Date sampled+		
		May 18	June 10	Sept.-Oct.
Contin. wht.	(No N)	149	198	224
Contin. wht.	(+N)	131	160	149
Fal.-wht.-wht.	(No N)	269	286	169
Fal.-wht.-wht.	(+N)	141	176	159
Fal.-rye-wht.	(+N)	130	170	151
Fal.-wht.	(No N)	231	262	147

+ Precipitation: May 18 to June 10 = 70 mm; June 10 to Sept. 2 = 199 mm.

The treatment-year underlined refers to the one sampled.

Our precipitation records show that in the past 96 years, 30 years have had as much or more rainfall than was received in the fallow period of 1982. Most of these wet years occurred between 1886-1935, i.e., during the period when much of the land was just being broken and when rates of N mineralization would have been greatest. If we extrapolate the 1982 N loss to these wet years, then a rough estimate of the N lost from the Wood Mountain loam due to leaching during these 30 years is 30 x (150-200) = 4500 - 6000 kg $N.ha^{-1}$. If we assume that the virgin sod had about 6000 kg $N.ha^{-1}$ in its A horizon and 8000 kg $N.ha^{-1}$ in its B horizon (a fair estimate we believe), then about 37.5% of the soil's N has been leached out over the past 100 years. This would be a maximum estimate since it assumes that the land was fallow during every wet year. If we assume that a 2-yr rotation was followed then the land would be fallow for at least half the number of wet years and the loss would be between 2250 and 3000 kg N/ha, or 19% of the soils initial N content.

CONCLUSIONS

This study has shown that:

(1) In wet years considerable NO_3-N is being leached out of the top 2.4 m of the soil profile under rotations that include fallow.

(2) In 1982, rainfall was 20% above average and it was estimated that fallow soils lost 150-200 kg $N.ha^{-1}$ due to leaching.

(3) Even continuous wheat rotations and rotations that included fall-seeded cereals lost some NO_3-N from the root zone.

(4) The application of N fertilizer, according to soil tests, significantly reduced NO_3-N lost to leaching (presumably due to the positive effect of fertilizer N on plant N uptake).

(5) The lowest amount of leaching loss occurred under the fallow-fall rye-wheat rotation.

(6) The greatest amount of leaching loss occurred under the fallow-wheat-wheat rotation receiving no N; however, circumstantial evidence suggests that losses from the 2-yr fallow-wheat rotation, though only second worse in this study, was actually the worst of all.

(7) Extrapolation of the data using long-term precipitation records suggest that as much as 4500-6000 kg $N.ha^{-1}$ might have been leached from the Wood Mountain loam in the past 100 years; this is equivalent to a loss of about 37.5% of the original soil N that was present at breaking. A minimum estimate would be about 19% of the original soil N.

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