Effect of Fallow Frequency, Fertilizer, and Available Water on Net N Mineralization under Wheat Grown in the Semiarid Brown Soil Zone

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INTRODUCTION

- Nitrogen (N) is the nutrient most limiting to cereal crops in the Canadian Prairies.
- The supply of N to crops typically comes from applied N fertilizer and N mineralized from soil organic matter.
- Numerous factors influence the process of N mineralization in soil, including available water, temperature, aeration, organic matter content, size of the active N pool, and tillage method.
- Producers need accurate methods of estimating net N mineralization in soil in order to determine optimum application rates of N fertilizer.
- Inaccurate estimates of N requirements can lead to over- or under-fertilization of crops, which is costly and may be damaging to the environment.

OBJECTIVES

(i) determine rates of N mineralization under well-fertilized continuous wheat [Cont W (N+P)], fallow-wheat [F-W (N+P)], and under F-W-W (+P) rotations, and (ii) determine the influence of fallow frequency, N fertilizer rate, and available water on apparent net N mineralization.

MATERIALS AND METHODS

Long-Term Crop Rotation Experiment

- The Swift Current crop rotation experiment was established in 1967 on a Swinton loam soil (Orthic Brown Chernozem).
- The 1976 average organic C concentration in the top 15 cm soil depth under F-W (N+P) and Cont W (N+P) were 1.67 and 1.98%, respectively; in 2003 the corresponding values were 1.92 and 2.14%.
- Fertilizer N was applied to designated treatments in accordance with soil NO_3-N (0-60 cm depth) levels in individual plots measured the previous fall, and the recommendation guidelines from the soil testing laboratory at the University of Saskatchewan.
- On average, wheat grown on fallow received about 8 kg N ha^{-1}, and wheat grown on stubble received about 30 kg N ha^{-1}. The N fertilizer, as ammonium

nitrate, was broadcast and soil incorporated with tillage used to prepare the seedbed.

- All treatments received about 10 kg P ha^{-1} yr^{-1} applied with the seed in accordance with the general recommendations for the area and crop.
- All phases of each rotation were present each year, and each rotation was replicated 3 times.
- During the 1967-1984 period, soil nitrate and moisture levels (0-15, 15-30, 30-60, 60-90, and 90-120 cm depths) and above-ground plant N were measured 8 times each year in early spring (prior to planting), at plant emergence, 3-leaf, 5-leaf, shot blade, soft dough, harvest, and again just prior to freeze-up in fall (Table 1).

Lysimeter Experiment

- Lysimeters (15 cm diam., 120 cm deep) were placed in Swinton loam soil that had been cropped to wheat the previous year and which contained 18 kg NO_3-N in the 0-60 cm depth at seeding. In 1975, wheat was planted into 140 lysimeters, representing two moisture regimes (rainfed and irrigated), seven N fertilizer rates (0, 20.5, 41, 62, 82, 123, and 164 kg N ha^{-1}), five times of sampling, and two replicates. All cropped plots received 50 kg P ha^{-1}. In addition, there were 20 summerfallowed lysimeters, representing two P fertilizer rates (0 and 50 kg P ha^{-1}), five sampling times, and two replicates.
- Soil N and moisture and plant N (roots and above-ground biomass, for cropped plots only) were determined (by destructive sampling) at planting, and then again at 3-leaf, tillering, shot blade, anthesis, and maturity of the wheat crop.
- The amounts of distilled water applied to the irrigated treatments were 25.4, 12.7, 38.1 and 101.6 mm during the period seeding to 3-leaf, 3-leaf to tillering, tillering to shot blade, and shot blade to anthesis, respectively.

Data Analysis

- Net N mineralized (Nmin) in the soil was calculated for two arbitrarily chosen intervals (harvest to freeze-up, and freeze-up to early spring prior to planting) and also for the spring to harvest period for cropped plots. We also calculated Nmin for four intervals of the 20-month summerfallow period (harvest to freeze-up, freeze-up to early spring, spring to freeze-up of the fallow year, and second freeze-up to just before planting).
- N mineralization for the selected periods was defined as:

$$\mathbf{Nmin = [Soil\ N_{(j+1)} + Plant\ N_{(j \blacktriangleright j+1)}] - [Soil\ N_{(j)} + Fert\ N_{(j \blacktriangleright j+1)}]} \quad \textbf{….(Eqn 1)}$$

  where, Soil N refers to NO_3-N in the 0-90 cm depth, Plant N is N uptake by the crop between two sampling dates J and J+1, and Fert N is the amount of fertilizer N applied between the two sampling dates. For fallow areas, Plant N and Fert N were set to zero.
- The calculations assume N lost by runoff and denitrification, and that gained by wet and dry depositions were negligible. The calculations also ignore N lost through leaf loss.

RESULTS AND DISCUSSION

Crop Rotation Study

- During the 20-month fallow period, net Nmin averaged about 118 kg N ha^{-1}. Of this about 15 kg ha^{-1} was mineralized between harvest and first spring, about 93 kg ha^{-1} between first spring and second fall (Table 2), and about 10 kg ha^{-1} between second fall and planting.
- Under cropped conditions, average net Nmin during the spring to fall period averaged 63, 56, and 53 kg ha^{-1} for F-(W) (N+P), F-W-(W) (+P), and Cont W (N+P), respectively (Table 2), with the values ranging from a low of 4 to 129 kg ha^{-1}. As found for plots that were fallowed, Nmin during the 8.5 month fall and winter periods averaged only 15 ± 28 kg ha^{-1}, with very little net Nmin occurring (about 4 kg ha^{-1}) during the 6-week period from harvest to freeze-up. These results were not unexpected because the previous crop dries out the surface soil where most of the N mineralization occurs, and the very cold conditions during winter would suppress microbial activity.
- We found reasonable relationships between net Nmin and total precipitation received between spring and fall for 3 of the 4 rotation phases (Fig. 1), with precipitation accounting for about 42% of the variation in net Nmin.
- All systems contained values that appear as outliers, likely reflecting NO_3-N losses related to leaching and denitrification during wet years (e.g., 1970, 1974, 1975, 1982) (Campbell et al. 1984), flushes in Nmin due to frequent wetting and drying events (1971, 1973) (Campbell 1978), changes in soil organic matter quantity and quality over time (Biederbeck et al. 1994), and/or unmeasured losses of leaf and root N.
- We found no relationship between net Nmin and mean daily temperatures between spring and fall (data not shown).
- Increases in soil NO_3-N, particularly during the summerfallow phase, were closely associated with tillage events in 63% of the occasions (Table 3). Tillage influences the soil environment and biological activity by disrupting aggregates and releasing entrapped organic substrates making them more accessible to microbial activity and decomposition (Doran and Smith 1987).

Lysimeter Study

- Under more controlled conditions, net Nmin between spring and harvest in cropped lysimeters averaged 40 kg ha^{-1} under dryland and 73 kg ha^{-1} under irrigated conditions (Table 4). The negative Nmin values between tillering and anthesis likely reflect the unmeasured loss of leaf and root N.
- The fallow systems mineralized 107 kg ha^{-1} over the spring to harvest period. Most of the Nmin in the fallow treatments occurred during the period prior to the tillering phase of wheat, when evaporation was not yet at a maximum, and after the anthesis phase of wheat when often there was significant precipitation falling on a dry soil surface.
- When expressed on a daily basis, the rate of Nmin was directly proportional to the amount of water received (0.56 kg ha^{-1} day^{-1} for dryland and 1.03 kg ha^{-1} day^{-1} for irrigated treatments).

- N fertilization at normal rates of application (<60 kg ha^{-1}) had little effect on net Nmin (Table 4).

CONCLUSIONS

- Our results show that it is possible to develop reasonable predictions of Nmin to improve N fertilizer recommendations; however, direct measurement is highly variable, reflecting the prevailing soil water conditions, amount and timing of rainfall events, soil temperature, soil organic matter content, and frequency of tillage. N losses associated with denitrification and leaching events, and that associated with leaf loss may also be significant and need to be quantified and included.
- Consequently, reliable estimates of Nmin will need to rely more on process-based models such as CERES, LEACHMN, DNDC, CENTURY, and EPIC to integrate these factors and their interactions.
- Data collected in these and other long-term studies will provide an invaluable resource to test and validate these process-level models for predicting net Nmin.

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Table 1. Eighteen-yr (1967-1984) mean plant N, soil NO_3-N in 0-90 cm depth, and total N^z at 8 sampling times between spring and fall, used to estimate net Nmin

Stage of growth^x	Average date of sampling	Days	(F)-W-W^y (+P)	F-W-(W)^y (+P)			F-(W)^y (N+P)			Cont W (N+P)		
			NO_3-N	Plant N	NO_3-N	Total N	Plant N	NO_3-N	Total N	Plant N	NO_3-N	Total N
			(kg ha^{-1})									
Spring	14 May	0	64	-	78	78.0	-	126	126.0	-	67	67.0
Emergence	17 may	3	78	-	53	53.0	-	126	126.0	-	108	108.0
3-Leaf	12 June	29	71	3.0	88	91.0	3.7	129	132.7	3.5	108	111.5
5-Leaf	18 June	35	76	11.0	79	90.0	17.5	106	123.5	14.2	112	126.2
Shot-blade	10 July	57	89	25.4	69	94.4	43.3	88	131.3	31.5	81	112.5
Dough	16 Aug	94	87	29.6	83	112.6	50.0	71	121.0	34.5	62	96.5
Harvest	19 Aug	97	89	36.3	43	79.3	54.1	59	113.1	39.8	56	95.8
Fall	16 Oct	155	104	-	58	58.0	-	72	72.0	-	55	55.0

[z] Average N applied = 7.7 kg ha^{-1} for F-W-(W) (+P), 6.4 kg ha^{-1} for F-(W), and 31.6 kg ha^{-1} for Cont W (N+P).

[y] Values pertain to the rotation phase in parentheses.

Table 2. Estimated annual net N_{min}[z] in four selected crop rotation phases during the 1967-1984 period, sampled for plant and soil NO_3-N 8 times between spring and fall

Year	(F)-W-W (+P)	F-W-(W) (+P)	F-(W) (N+P)	Cont W (N+P)	Precipitation[y]
	--(kg ha^{-1})			---	(mm)
1967	55	56	34	24	126
1968	66	72	39	43	183
1969	121	84	65	110	195
1970	55	35	27	19	287
1971	94	32	92	68	141
1972	83	48	19	34	166
1973	43	87	92	19	93
1974	69	4	48	90	275
1975	42	36	99	114	245
1976	88	83	58	75	234
1977	119	40	32	43	246
1978	166	40	73	27	194
1979	121	103	43	32	157
1980	114	58	52	-[x]	229
1981	188	80	111	51	250
1982	51	93	129	70	332
1983	116	42	-[x]	12	164
1984	90	21	76	62	186
Average	93	56	63	53	

[z] Based on soil NO_3-N measured in 0-90 cm depth.

[y] Precipitation received between spring and fall sampling.

[x] Missing data.

Table 3. Relationship between frequency of tillage and change in N_{min} in fallow phase of the (F)-W-(+P) rotation

Year	Tillage Date	Change[z] in NO_3	Proportion of tillage operations resulting in positive change (%)
1969	8/5, 4/7, 22/7, 5/9	(+) (+) (-ve) (+)	75
1970	15/5, 24/6, 24/7, 12/8	(+) (+) (+) (+)	100
1971	7/5, 9/6, 16/7, 5/8	(0) (+) (+) (+)	75
1972	4/5, 12/6, 7/7, 25/8	(+) (+) (0) (+)	75
1973	14/5, 11/7	(0) (+)	50
1974	16/5, 5/7, 2/8	(-ve) (+) (-ve)	33
1975	20/5, 10/7, 10/9	(+) (-ve) (-ve)	33
1976	5/5, 11/6, 6/7, 13/8	(-ve) (-ve) (+) (+)	50
1977	25/5, 4/7, 28/7, 29/8	(+) (+) (-ve) (-ve)	50
1978	22/5, 21/6, 11/7, 8/8	(+) (0) (-ve) (-ve)	25
1979	30/5, 10/7, 31/7, 31/8	(+) (-ve) (+) (+)	75
1980	5/5, 24/6, 22/7	(+) (+) (-ve)	66
1981	11/5, 2/7, 16/7, 4/8, 17/9	(0) (-ve) (+) (+) (+)	60
1982	26/5, 20/7, 10/8, 30/8	(-ve) (+) (+) (+)	75
1983	20/5, 23/6, 26/7, 29/8	(+) (+) (+) (+)	100
1984	9/5, 26/6, 25/7	(+) (-ve) (+)	66
Mean			63

[z] Change in soil NO_3-N associated with each tillage operation: (+) for increase, (-ve) for decrease, and (0) for no change during the associated period.

Table 4. Effect of soil water, N fertilizer and time sampled on apparent net Nmin between spring and harvest for dryland and irrigated treatments

			Fallow	Rate of N applied (kg ha^{-1})							Mean cropped
Period	Days	Precipitation	0	0	20.5	41	62	82	123	164	
Dryland		(mm)	Apparent Nmin (kg ha^{-1})								
3-Leaf to Tillering	11	41.6	26	7	10	10	3	-19	-16	14	5
Tillering to Shot blade	14	4.6	-4	18	5	14	-12	11	0	-39	7
Shot blade to Anthesis	12	5.0	6	-8	-3	-7	3	-16	2	12	2
Anthesis to Maturity	34	124.0	59	14	17	35	47	14	14	39	26
Total		175.2	107	39	32	49	53	25	16	65	40

			Rate of N applied (kg ha^{-1})							Mean cropped
Period	Days	Precipitation +Irrigation	0	20.5	41	62	82	123	164	
Irrigated		(mm)	Apparent Nmin (kg ha^{-1})							
3-Leaf to Tillering	11	54.3	3	5	15	26	-2	11	8	10
Tillering to Shot blade	14	42.7	10	3	-2	-18	12	-18	0	4
Shot blade to Anthesis	12	106.6	9	3	1	24	4	-4	-8	6
Anthesis to Maturity	34	124.0	37	63	76	39	40	35	29	46
Total		327.6	59	74	92	89	56	46	37	73

Fig. 1. Relationship between net N_{min} during the growing season and precipitation between spring and fall, for (a) (F)-W-W (+P), (b) F-(W) (N+P), (c) Cont W (N+P) and (d) F-W-(W) (+P) [possible outliers shown with a *]

Figure 1