THE EFFECT OF CROP ROTATION HISTORY ON NITROGEN AND SULPHUR MINERALIZATION IN LUVISOLIC SOILS

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Over 90% of nitrogen (N) and sulphur (S) compounds in soil are organic and are released as available nutrients by mineralization. Mineralization is a microbial process and is, therefore, affected by everything that modifies the soil environment.

Cultivation of virgin land will alter the biological and physico-chemical environment of the soil. Luvisolic soils change markedly when converted from native conditions to cultivation in that surface leafy litter is mixed into the soil. Many projects have studied the effect of cultivation on the total carbon, nitrogen and sulphur levels in the soil. Less is known of the effect of cultivation on mineralizable N and S. The objectives of this research were:

i) To study the effect of a wide variety of crop rotations, including virgin forest, on the mineralization of N and S in Luvisolic soils, and

ii) To study the relationships among mineralizable N and S, and total organic C, N, S and HI-reducible sulphur (HI-S). HI-S refers to ester-bonded sulphur (C-O-S) as opposed to carbon-bonded sulphur (C-S). HI-S is considered more labile.

Two locations were selected in the Luvisolic (Grey) soil zone of Saskatchewan. Both locations were mapped as Waitville loam. The first location was south of Star City (Township 44, Range 17, W2) and the second

location was north of Hafford (Oscar Lake - Township 46, Range 10, W3). These locations will be referred to as SC and OL, respectively. Both locations are in well-established farming districts. Reasonably accurate histories were obtained for each site, in an effort to produce results which would reflect the farming practices used on the land (Table 1). Each location included a comparable virgin site with native aspen vegetation. Table 1 provides descriptive histories of each site.

Samples were taken in the summer of 1984. A volumetric probe (15 cm deep) removed the Ap horizon of the cultivated sites, and the approximate depth to which cultivation would mix the soil at virgin sites. Small roots were included but top growth was removed. Three cores were obtained, dried and weighed for bulk density calculation, then mixed and subsampled for analysis of organic C, and total N, S and HI-S (Table 2).

Three replicates of each site were placed in incubation units at 28°C for the mineralization experiment. Each soil was leached with 0.001 M $CaCl_2$ and a nutrient solution lacking either N or S. The leachates were analyzed for mineralized N and S with a Dionex exchange column. This procedure was repeated on days 7, 21, 35, 54, 70 and 84; a total of 12 weeks were therefore involved.

The data were expressed as kg/ha, with a hectare volume being one hectare in area and 15 cm deep.

RESULTS

Initial C, N and S Interrelationships

There was as much organic C and slightly more N and S in the long-term cultivated soils as compared to virgin and short-term cultivated soils. This is in contrast to grassland soils, which generally have less organic matter

Table 1. Descriptive histories of sites.

Site	Cropping (vegetative) history	Designation
SC01	Virgin aspen forest.	V
SC02	Pasture; cleared of forest about 1900	P
SC03	Cultivated in wheat-fallow rotation with occasional clover since 1900; presently in fallow.	LT
SC04	Originally sampled as a 30-year continuous fallow; however, sample apparently was contaminated by discarded grain and retained only for experimental comparison.	?
SC05	Recently cleared by chain-saw; most surface litter incorporated into soil.	ST
SC06	Cleared of bush between 1900 and 1910, with alfalfa from 1973 to 1983. Flax was present (1984) crop. Comparable to SC07 and SC08.	LT
SC07	Virgin aspen forest.	V
SC08	Similar to SC06, but without alfalfa crop. Sampled after a wheat crop.	LT
OL01	Cleared of bush about 1925, farmed in crop-fallow rotation with a sweet clover forage crop every 5 years. Presently in fallow.	LT
OL02	As OL01, about 10 meters away.	LT
OL03	Virgin aspen forest.	V
OL04	Similar to OL01, but with a alfalfa-grass forage mix for the past 4 years.	LT
OL05	Cultivated since 1964 as OL01.	MT
OL06	Virgin aspen forest.	V
OL07	Recently cleared with a blade, with most surface litter removed.	ST

Key: Virgin (V); Pasture (P); Long-term cultivation (LT); Short-term cultivation (ST); Medium-term cultivation (MT); History unknown (?)

Table 2. Average amount of organic nitrogen, sulphur and carbon in the upper 15 cm of soil water various rotations

Crop rotation	Bulk density (g/cm^3)	Organic C (kg/ha)	Organic N (kg/ha)	Organic S (kg/ha)	Organic HI-S (kg/ha)	C/N/S ratio
Virgin†	0.91	4.88×10^4	3220	277	78	186/11.7/1
Long-term cultivationΨ	1.31	4.60×10^4	4033	380	133.7	121/9.32/1
Short-term cultivation∝	1.11	4.56×10^4	3163	302	91	166/10.5/1
Pasture∈	1.09	5.35×10^4	3368	322	93	166/10.5/1

†Average of SC01, SC07, OL03, and OL06

ΨAverage of SC03, SC06, SC08, OL01, OL02, OL04 and OL05

∝Average of SC05 and OL07

∈SC02 only

when cultivated. Higher total and HI-S in long-term cultivated sites, despite crop removal, may be due to additions of S fertilizer, but probably results from a more efficient storage of S in soil organo-mineral complexes. In addition, there was a significant increase in the percentage of S as HI-S, from 27.6 ± 5.2 in the virgin sites to 35.4 ± 3.3 in the long-term cultivated sites.

Crop rotation was a significant factor affecting organic C, N and S (Table 2). Organic C was more strongly correlated with organic N than organic S, since one-third of the organic S was as HI-S, and not directly bonded to C.

Organic N and S were strongly correlated in the total soil (Table 3). This indicates a constant form and amount of N and S in Luvisolic soils which cultivation did not affect.

Table 3. Comparison of r values of selected relationships on total organic matter of all sites, and of virgin and long-term cultivation sites.

Relationship	All sites	Virgin (4 sites)	Long-term cultivation (7 sites)†
Organic C vs. Organic N	0.716**	0.957**	0.934***
Organic C vs. Organic S	0.620**	0.464	0.936***
Organic N vs. Organic S	0.965***	0.858*	0.961***
Organic S vs. Organic HI-S	0.960***	0.994***	0.982***

†Long-term sites include SC03, SC06, SC08, OL01, OL02, OL05 and OL06

*Significant at P = .05

**Significant at P = .01

***Significant at P = .001

Mineralization Characteristics

Over the 84 days, N and S mineralization was highly correlated with time (Table 4; Figure 1). Site SC07 was representative of native sites that showed marked initial depressions in N mineralization. No discernible depressions were seen in S mineralization.

Significance of past rotation practices was established with t-tests (Tables 5 and 6). A comparison of t-tests shows significant differences in N mineralization among soils from long-term cultivated sites, probably related to recent cropping. Largest differences were between short-term cultivated and long-term cultivated sites. The long-term pasture site (SC02) was significant from all others, being closest to SC06, the soil broken from alfalfa. With S mineralization, the greatest differences were between long-term cultivated soils and virgin or short-term cultivates sites, indicating a change in organic S with cultivation. Differences among cultivation treat-

Table 4. Analyses of cumulative nitrogen and sulphur released with time.

Site	Cumulative N mineralized ± σn-1 (kg/ha)	r^2 of N mineralized vs. time	Cumulative S mineralized ± σn-1 (kg/ha)	r^2 of S mineralized vs. time
SC01 (V)	184.3 ± 15.6	0.988	13.5 ± 1.3	0.998
SC02 (P)	221.5 ± 13.1	0.998	15.5 ± 1.7	0.990
SC03 (LT)	197.8 ± 9.7	0.982	22.6 ± 0.96	0.964
SC04 (?)	179.8 ± 6.0	0.996	13.6 ± 1.1	0.998
SC05 (ST)	98.3 ± 42.9	0.996	9.04 ± 2.9	0.998
SC06 (LT-A)	263.8 ± 17.4	0.994	16.7 ± 0.15	0.998
SC07 (V)	144.4 ± 8.6	0.922	11.7 ± 0.45	0.998
SC08 (LT)	175.8 ± 16.7	0.998	14.1 ± 1.4	0.998
OL01 (LT)	285.4 ± 8.9	0.995	17.9 ± 0.98	1.000
OL02 (LT)	277.4 ± 21.5	0.998	20.5 ± 1.0	0.998
OL03 (V)	242.5 ± 18.4	0.994	14.5 ± 0.99	0.996
OL04 (LT-F)	263.8 ± 14.1	0.998	18.3 ± 0.99	0.994
OL05 (MT)	306.0 ± 38.9	0.994	35.4 ± 0.27	0.998
OL06 (V)	178.3 ± 48.9	0.992	12.9 ± 1.3	0.988
OL07 (ST)	234.2 ± 5.8	0.996	15.8 ± 0.53	0.998

Key: Virgin (V); Pasture (P); Long-term cultivation (LT); Short-term cultivation (ST); Medium-term cultivation (MT); Long-term cultivation with recent alfalfa (LT-A); Long-term culitivation now under forage (LT-F); History unknown (?)

Figure 1. Mineralization curves for nitrogen and sulphur.

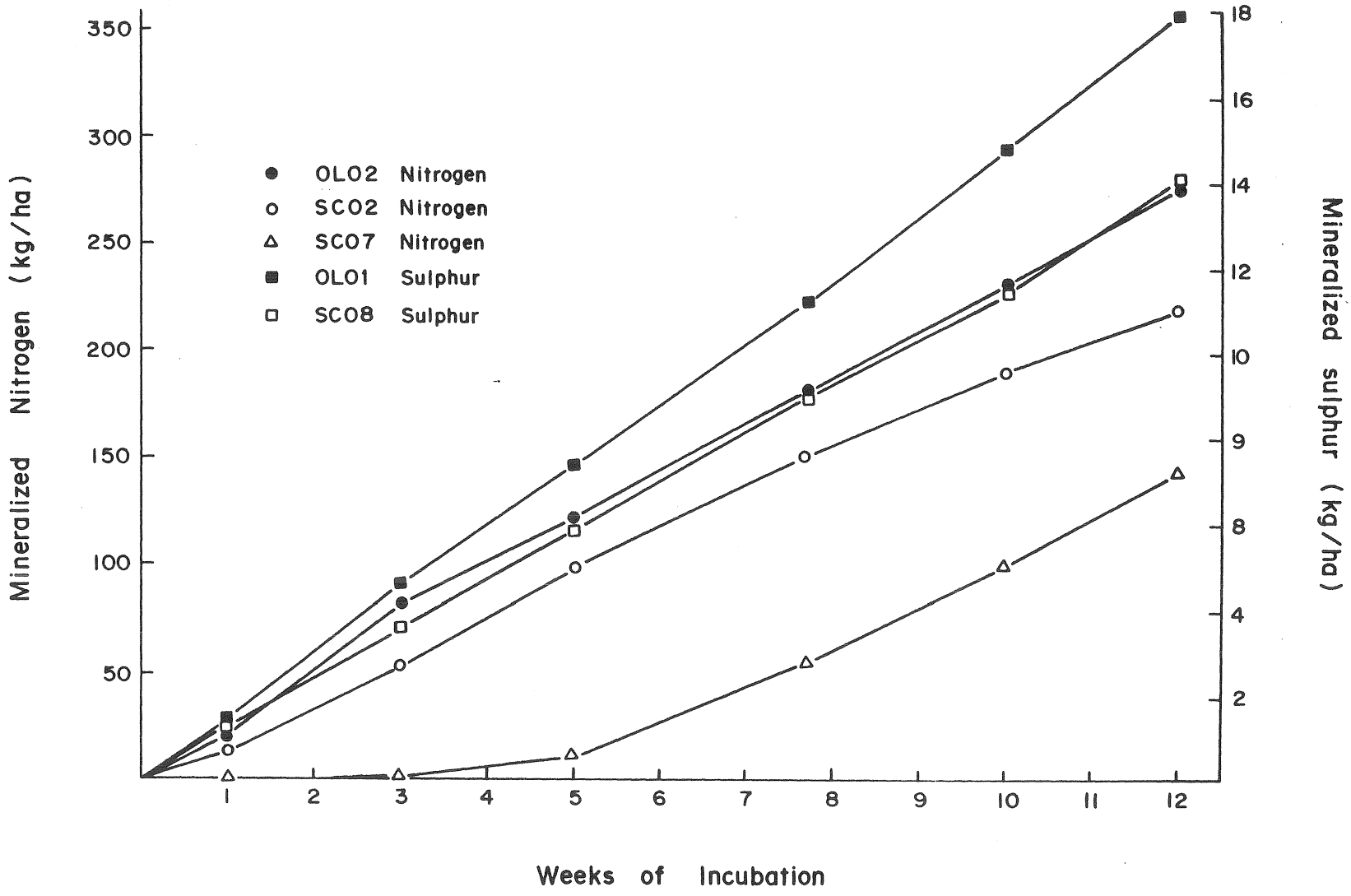

Table 5. t-tests for nitrogen mineralization.

Star City Nitrogen

	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08
SC01		6.83	2.75	1.01	18.06	6.52	6.39	1.39
SC02			5.44	10.83	29.42	3.53	13.24	8.06
SC03				5.90	28.72	5.61	10.03	4.26
SC04					29.08	7.26	7.20	0.84
SC05						14.15	8.89	15.44
SC06							9.65	7.15
SC07								4.87

Oscar Lake Nitrogen

	OL01	OL02	OL03	OL04	OL05	OL06	OL07
OL01		1.29	7.85	4.85	1.93	8.06	18.03
OL02			4.61	1.98	2.41	6.94	7.26
OL03				3.44	5.52	4.60	1.61
OL04					3.82	6.29	7.26
OL05						7.65	6.83
OL06							4.26
OL07							

$$t = \frac{\bar{d}}{S_{\bar{d}}}$$

$n = 28$

$P = 0.001$; $t = 3.674$
$P = 0.01$; $t = 2.763$
$P = 0.05$; $t = 2.048$

Table 6. t-tests for sulphur mineralization.

Star City Sulphur

	SC01	SC02	SC03	SC04	SC05	SC06	SC07	SC08
SC01		3.51	18.82	0.22	12.05	3.84	5.06	1.20
SC02			11.80	3.52	13.76	1.38	13.76	8.31
SC03				20.58	44.32	6.06	38.12	16.24
SC04					14.26	3.81	6.30	1.07
SC05						9.87	20.98	12.52
SC06							6.51	3.04
SC07								6.18

Oscar Lake Sulphur

	OL01	OL02	OL03	OL04	OL05	OL06	OL07
OL01		6.81	9.08	0.617	64.34	11.29	6.88
OL02			15.58	3.17	51.82	16.81	14.91
OL03				5.58	76.06	3.68	4.43
OL04					26.98	7.52	3.84
OL05						61.59	122.85
OL06							7.71
OL07							

$t = \frac{\bar{d}}{S_{\bar{d}}}$ $\quad n = 28$

P = 0.001; t = 3.674
P = 0.01; t = 2.763
P = 0.05; t = 2.048

ments were significant as well. The pasture (SC02) differed from all sites except the alfalfa breaking, consistent with observations for N mineralization.

At Oscar Lake, the OL05 site differed markedly from all others in S mineralization. This site had the greatest amount of HI-S, but otherwise was not different from the other sites.

Factors Influencing Mineralizable N and S

Total mineralizable N and S were strongly correlated. If sites SC03 and SC05 are not included, an r value of 0.941 results. The N/S ratios of the total soil ($\bar{x}$ = 10.7) were lower than the mineralized ratios ($\bar{x}$ = 13.5) in all but two sites. There appears to be a small pool of organic compounds which is most important to mineralization, and this pool had a wider N/S ratio than the total organic matter.

Correlation coefficients of several relationships of mineralized N and S were calculated (Table 7). Crop rotation had a definite effect on several relationships. The relationship between HI-S and mineralized S remained significant, indicating the importance of this fraction in supplying plant available S.

Effect of Specific Crop Rotations on Mineralization

Virgin sites. Virgin sites showed initial lags in N mineralization. This may reflect the high C/N ratios of virgin sites, an initial lag in microbial activity, or a possible enzymatic inhibition by tannins and related compounds from the leaf litter.

No lag was shown in S mineralization, though the virgin sites did have lower S mineralization rates. It must be remembered that the virgin soil was not in a natural state, as it was mixed before incubation. Thus, the mineralization rates cannot be transposed to the native environment.

Table 7. Comparison of r values of selected relationships of mineralized nitrogen and sulphur in all sites, and virgin and long-term cultivation sites.

Relationship	All sites	Virgin (4 sites)	Long-term cultivation (7 sites)†
Mineralized N vs. Total C	0.251	0.632	0.554
Mineralized S vs. Total C	0.078	-0.642	-0.246
Mineralized N vs. Total N	0.642**	0.738	0.606
Mineralized S vs. Total S	0.559*	0.785	0.512
Mineralized N vs. C/N	-0.713**	-0.736	0.122
Mineralized S vs. C/S	-0.571*	-0.796	-0.146
Mineralized S vs. Total HI-S	0.663**	0.816*	0.788*

†Long-term sites include SC03, SC06, SC08, OL01, OL02, OL05 and OL06

*r value significant at P = 0.05

**r value significant at P = 0.01

Short-term cultivation sites. Both SC05 and OL07 showed low N and S mineralization rates. SC05, in particular, released little inorganic N or S. The incorporation of relatively more leaf litter into SC05, cleared with a chain-saw, than OL07 (cleared with a bull-dozer) may explain the lowre net mineralization of S at SC05.

Long-term pasture site. SC02 showed increased total C, N and S. In addition, bulk density was not significantly increased from the virgin SC01 site. N and S mineralization was also relatively high. Permanent pasture definitely improved the quality of the soil.

Long-term cultivation sites. Long-term cultivation generally increased bulk density, reduced organic C levels, but increased organic N, S and HI-S levels (Table 2). The highest mineralization rates were observed in

long-term cultivation sites.

Site SC06 showed the effect of a long-term alfalfa crop. Though total N and S were not increased, more N and S were mineralized. Alfalfa built up the pool of mineralizable organic compounds, though organic matter levels were not increased.

SC08, adjacent to SC06, did not have the recent alfalfa crop and had lower mineralization rates. SC08 also had low S mineralization, despite a large HI-S pool. This suggests there is a subfraction of HI-S most responsible for mineralization and that this fraction was depleted by crop growth.

OL sites showed similar results. Cultivation increased N and S mineralization in all sites.

Physical Properties of the Soil

Cultivation also affects physical properties of the soil. This is reflected by the increased bulk density in cultivated sites (Table 1). Adverse soil structure was evident when the soils were leached during the incubation procedure. Cultivated soils became more difficult to leach with time. Structural problems are likely a greater limitation in Luvisolic soils than fertility problems. It is interesting to note that many of the Luvisolic soils with an apparent soil structure problem have as much as 2.5% organic carbon (4% organic matter), an amount adequate for good structure in Chernozemic areas. In this respect, forage rotations and limited fallow would improve the soil.

CONCLUSIONS

Crop rotation proved to be a significant factor in determining total organic C, N, S and HI-S. N/S ratios of both the soil and the mineralized fraction was not affected by cultivation. There was a significantly higher

proportion of HI-S in cultivated soils than in forest or short-term cultivated soils. HI-S and mineralized S were strongly correlated.

A long-term pasture site maintained total organic matter and increased mineralization rates.

Long-term cultivation sites showed gains in total N and S despite slight losses of organic C. This resulted in increased mineralization rates in long-term cultivation sites. Thus, quality of organic matter increased despite a slight decrease in quantity. Soil bulk density was higher in the long-term cultivated sites, a consequence of lower organic matter (carbon) concentrations.

Legumes increased mineralization rates, apparently by increasing the mineralizable pool of organic matter. Legumes should be considered in field management by the farmer.

Crop rotation history is definitely a significant factor which must be accounted for in studying the mineralization of N or S, and in assessing the long-term effects of different management practices.