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SOIL DEGRADATION UNDER THE INFLUENCE OF LONG-TERM NITROGEN FERTILIZATION AND POSSIBILITY OF COUNTERACTING BY LIMING

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Introduction

The use of ammoniacal fertilizers in crop production has been shown to acidify soils [PIERRE et al. 1971; HOYT, HENNIG 1982]. The acidification of soil by N fertilizer is caused by nitrification of ammonium. The uptake of N as ammonium in the crop also contributes to soil acidification. In the Prairie Provinces of Canada, forage grasses account for a significant proportion of the total feed supply to beef cattle. Most soils in these regions are usually deficient in plant-available N, and forage grasses respond strongly to fertilizer N [MALHI et al. 1986; HARAPIAK et al. 1992]. The long-term application of ammoniacal fertilizer to grass results in marked acidification of soils and changes in soil chemical properties [ABRUNA et al. 1958; OWENSBY et al. 1969; SCHWAB et al. 1990; MALHI et al. 1991].

The objective of this study was to determine the effects of 27 years of fertilization with ammonium nitrate on soil acidification, and on Al, Mn and Fe content in soil.

Materials and methods

A field experiment was conducted on a permanent smooth bromegrass (*Bromus inermis* Leyss.) stand at Crossfield, Alberta, Canada. The soil was a thin Black Chernozem (Typic Boroll) with 9.5% organic matter and a loam texture. The mean annual precipitation of the area is about 450 mm. The growing season extends from May to September. The experiment was initiated in 1968. There were six rates of N applied: 0, 56, 112, 168, 224, and 336 kg N·ha^{-1}. The N fertilizer was ammonium nitrate surface broadcast annually in early spring (mid to late April) of each year including 1994. The treatments were arranged on 3.0 m x 3.0 m plots in a randomized complete block design in six replications. A portion of each N plot was treated with surface-applied finely ground lime in calcium carbonate form in 1991. Bromegrass was harvested for hay every year at summer/fall, once in some years and twice in others, depending on amount and timeliness of precipitation. Both the limed and non-limed portions of each plot were sampled for soil in 1994.

The soil samples were taken with a coring tube (1.9 or 2.4 cm diam) in the autumn of 1994 from the 0–5, 5–10, 10–15, and 15–30 cm depths. The samples were dried at room temperature and finely ground. Soil pH was measured in a 1:2.5 soil : water mixture. Aluminum in soil was extracted with 0.02 mol $CaCl_2$ solution in a 1:2 ratio by the method of Hoyt and Nyborg [1971]. The DTPA-extractable Fe and Mn in soil were measured using the method of Lindsay and Norvell [1978].

The data were subjected to analysis of variance (ANOVA) and least significant difference (LSD at $p=0.05$) was used to determine the statistical significance among treatments.

Results and discussion

The soil pH in the 0–5 cm layer decreased markedly with the increasing N rate: from pH 6.85 in the zero-N treatment, to 3.82 with the 336 kg $N{\cdot}ha^{-1}$ rate (Table 1). The pH in the 5–10 cm soil layer was also depressed with N application but only at rates of 168 kg $N{\cdot}ha^{-1}$ or higher. In the next two layers, the pH decreased only at the highest N rate. Liming in 1991 (four growing seasons prior to soil sampling) increased soil pH markedly in the 0–5 cm layer but only slightly in the next layer.

The amount of $CaCl_2$-extractable Al in the 0–5 cm soil layer increased considerably along with the N rate, but in the next two layers Al content increased only at high N rates. In the 15–30 cm layer, there was no effect of fertilizer N on Al in soil. Addition of lime to the surface decreased the concentration of Al in soil considerably in the 0–5 cm layer and moderately in the 5–10 layer.

The content of DTPA-extractable Fe in soil regularly increased with N rate in the upper two layers. In the 10–15 cm layer, the concentration of Fe in soil visibly increased only at the 336 kg $N{\cdot}ha^{-1}$ rate. Liming caused increase of Fe concentration in the 0–5 cm soil layer but decreased its content in the next two layers.

The concentration of DTPA-extractable Mn first increased up to 112 kg $N{\cdot}ha^{-1}$ in the 0–5 cm layer and up to the 224 kg $N{\cdot}ha^{-1}$ rate in the next layer, and then sharply decreased. However, in the 10–15 cm layer, Mn increased only at the highest N rate. Liming caused decrease of Mn content in the 0–5 cm layer at the lower doses of N-fertilizer but increased its level at the doses beyond 112 kg $N{\cdot}ha^{-1}$. It also decreased Mn content in the next two layers.

As statistically estimated the dose of N fertilizer had a significant effect on concentration of Al, Fe and Mn in all soil layers, except in the 15–30 cm depth (Table 1). The effect of liming to increase soil pH was significant in the upper two soil layers. Liming also had significant effect on extractable Al content in these layers, amount of Fe up to 15 cm depth, and extractable Mn in the 5–30 cm depth. The lime x N fertilizer interaction effects were significant for all parameters in the 0–5 cm layer, for soil pH, extractable Al and Fe in the 5–10 cm, and for only soil pH in the 15–30 cm layer.

The annual application of AN to bromegrass for 27 successive years caused a marked acidification of the surface soil layer and resulted in changes of elements concentration in soil. However, these changes varied with elements and were associated with magnitude of soil acidification under the influence of N application.

Other researchers have also reported acidification of soils from long-term annual applications of ammoniacal fertilizers to grass forages; the depression in pH was increased with increasing the amount of applied N [PERL et al. 1982] and depended on a form of N fertilizer [HARAPIAK et al. 1999]. In the present study, the majority of the soil acidification occurred in the 0–5 cm layer because the N fertilizer was broadcast on the surface, coming in contact with the uppermost portion of the soil. Consequently the 0–5 cm layer became more acid. Similarly, in other research, where N fertilizer was also surface-broadcast on no-tilled soils, the upper 4 cm soil became acidified much faster than tilled soils [MAHLER, HARDER 1984].

In previous investigation at the same site where soil samples were taken after 16 years of ammonium nitrate application [MALHI et al. 1995], there was no acidification of soil below the 10 cm depth. However, in the present study, there was a depression in soil pH in the 10–15 cm layer at the 336 kg $N \cdot ha^{-1}$ rate after 27 years. In addition, in this study, there was greater reduction of pH in the top 10 cm soil than in the previously reported results after 16 years. This indicates that soil is becoming more acid with time and also acidification is extending to deeper soil layers.

The concentrations of $CaCl_2$-extractable Al in soil indicated that there was no accumulation of Al in soil when pH was close to 6.0 or greater. In the upper three layers, the increase in Al concentration in soil from N fertilization corresponded with the depression in soil pH. There was a close relationship of Al content in the 0–5 cm soil depth and rate of N ($r=0.92$) or soil pH ($r=-0.88$). In the same order, the r-values for the 5–10 cm soil layers were 0.78 and –0.80.

The increase in concentration of extractable Fe in the upper two soil layers was closely associated with increasing N rate or decreasing pH, and there was a strong correlation between Fe content in soil and N rate (r-values of 0.97 and 0.95, respectively, for 0–5 and 5–10 cm layers). In the 10–15 cm layer, the correlation was not so strong ($r=0.68$) because extractable Fe in soil increased only at the 336 kg $N \cdot ha^{-1}$ rate. There were large accumulations of extractable Mn in soil in the first layer at the lower N rates, in the 5–10 cm layer at the medium N rates and in the 10–15 cm layer at the highest N dose. However, the Mn content in soil decreased considerably, despite a substantial depression in soil pH in the 0–5 cm layer at the 224 and 336 kg $N \cdot ha^{-1}$ rates and in the next layer at the highest N dose (when pH was ≤ 4.10). This large decrease of Mn amount at the high N rates in the top 10 cm soil was most likely caused by leaching of Mn from the surface to the subsurface layers during the development of acidity, and followed by a subsequent decrease in the amount of Mn in readily available form at strong acidity [TRUOG 1946].

Table 1; Tabela 1

Influence of 27 years of ammonium nitrate application to bromegrass and liming on soil pH and content of extractable Al, Fe and Mn ($mg \cdot kg^{-1}$) in different soil horizons

Wpływ 27-letniego stosowania saletry amonowej pod stokłosę bezostną i wapnowania na pH gleby oraz zawartość rozpuszczalnego Al, Fe i Mn ($mg \cdot kg^{-1}$) w różnych warstwach gleby

N dose Dawka ($kg \cdot ha^{-1}$)	Lime treatment Stosowanie wapnia	Soil pH pH gleby	Content in soil Zawartość w glebie			Soil pH pH gleby	Content in soil Zawartość w glebie			Soil pH pH gleby	Content in soil Zawartość w glebie			Soil pH pH gleby	Content in soil Zawartość w glebie		
			Al	Fe	Mn		Al	Fe	Mn		Al	Fe	Mn		Al	Fe	Mn
Depth; Głębokość		0–5 cm				5–10 cm				10–15 cm				15–30 cm			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	No lime Bez wapna	6.85	0.26	42.8	27.5	6.80	0.10	52.3	30.2	6.95	0.09	58.3	24.8	7.10	0.01	50.7	18.8
56		6.00	0.32	94.4	48.6	6.70	0.10	61.2	32.9	7.08	0.22	51.0	24.3	7.42	0.00	42.2	16.7
112		4.92	1.85	184.3	77.9	6.80	0.10	58.2	24.9	7.32	0.08	41.7	17.4	7.62	0.03	56.2	12.1
168		4.10	24.15	265.5	14.1	5.90	0.18	112.9	71.6	7.27	0.07	45.5	22.0	7.60	0.03	47.6	13.9
224		4.05	29.18	296.8	5.1	4.82	3.37	188.8	89.7	7.13	0.27	50.3	20.2	7.52	0.03	75.9	14.3
336		3.82	33.92	349.2	2.8	3.90	67.51	287.0	19.5	5.37	1.62	120.6	133.1	7.04	0.04	66.4	17.0
0	Lime Wapnowane	7.13	0.18	47.0	29.7	7.00	0.07	53.0	29.2	6.75	0.01	44.8	22.9	6.90	0.04	40.3	14.5
56		6.55	0.27	93.7	39.5	7.00	0.53	57.5	28.0	7.02	0.01	37.9	18.7	7.10	0.04	37.1	13.3
112		5.90	0.54	240.5	49.5	7.00	0.10	60.2	25.9	7.20	0.01	34.7	14.6	7.27	0.06	53.1	10.6
168		5.78	0.37	319.2	28.5	6.35	0.14	87.8	48.1	7.07	0.01	37.2	16.9	7.33	0.01	42.1	11.1
224		6.07	0.22	391.2	10.4	4.82	2.82	159.2	75.2	6.92	0.06	41.9	18.5	7.30	0.01	59.8	13.4
336		6.17	0.19	412.1	8.0	3.98	27.07	239.6	13.4	5.52	0.58	99.9	101.8	6.98	0.05	56.6	16.8
$LSD_{0.05}$; $NIR_{0,05}$ (Nf x L)		–	6.54 ***	22.6 ***	12.3 ***	–	2.81 ***	18.2 **	n.s.	–	n.s.	n.s.	n.s.	–	n.s.	n.s.	n.s.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
0	Mean for N dose Średnia dla dawki N	6.99	0.22	44.9	28.6	6.90	0.09	52.7	29.7	6.85	0.05	51.6	23.9	7.00	0.02	45.5	16.7
56		6.28	0.29	94.0	44.0	6.85	0.31	59.3	30.4	7.05	0.12	44.4	21.5	7.26	0.02	39.7	15.0
112		5.41	1.19	212.4	63.7	6.90	0.10	59.2	25.4	7.15	0.06	41.1	22.1	7.44	0.05	54.6	11.3
168		4.94	12.26	292.4	21.3	6.13	0.16	100.4	59.9	7.17	0.04	41.3	19.5	7.47	0.02	44.9	12.5
224		5.06	14.70	344.0	7.7	4.82	3.09	174.0	82.4	7.03	0.16	46.1	19.4	7.41	0.02	67.9	13.9
336		4.99	17.06	380.6	5.4	3.94	47.29	263.3	16.5	5.55	1.08	107.4	111.4	7.01	0.04	61.5	16.9
$LSD_{0.05}$; $NIR_{0,05}$ (Nf)		–	4.40 ***	27.4 ***	10.2 ***	–	5.32 ***	20.6 ***	11.3 ***	–	0.65 *	18.2 ***	12.6 ***	–	n.s.	n.s.	n.s.
No lime Bez wapna	Mean for liming Średnia dla wapnowania	4.96	14.95	205.5	29.3	5.82	11.89	128.4	44.8	6.85	0.39	61.2	40.3	7.38	0.02	56.5	15.5
Lime Wapnowane		6.27	0.29	250.6	27.6	6.03	5.12	109.5	36.6	6.74	0.11	49.4	32.2	7.15	0.03	48.2	13.3
$LSD_{0.05}$; $NIR_{0,05}$ (L)		–	2.67 ***	9.2 ***	n.s.	–	1.15 ***	7.4 ***	5.9 **	–	n.s.	6.5 ***	6.9 *	–	n.s.	n.s.	1.3 **

Explanation; Objaśnienia: Nf – N fertilization; nawożenie N
L – liming; wapnowanie
*, **, ***, – significant at p=0.05, p=0.01, and p=0.001; różnice istotne odpowiednio dla p=0,05, p=0,01 i p=0,001
n.s. – differences not significant; różnice nieistotne

Acid soils are known to contain high concentrations of Al, Fe and Mn in soil solution along with a reduction in pH [TRUOG 1946; HOYT, NYBORG 1987]. The accumulations of Al, Fe and Mn in soil with increasing N rates in the present experiment was most likely due to a marked increase in soil acidity as a result of N application. Acidification possibly creates an environment that favours more rapid weathering of minerals, which may have contributed to the release of elements in soil. This is also mainly the result of the solubility product related to the pH. At the same site after 16 years of experiment [MALHI et al. 1995], there was little or no accumulation of Al and decrease in pH in the deeper layers at high N rates. However, after 27 years the effect of N fertilization on pH and Al appears to be greater and extend deeper into the soil profile as compared to results previously reported.

In the present study, when the soil pH was raised to 6.0 or higher with liming, the Al content in soil decreased nearer to the zero-N treatment. The amount of Fe and Mn in the 5–10 and 10–15 cm soil layers also decreased with liming but to a lesser extent than Al. This suggested that the release of these elements in soil was pH dependent.

The results of this study indicate that long-term of N fertilizer application to forage grasses may cause of soil degradation by increase of soil surface acidity (mean annual rate of soil pH depression in the 0–5 cm layer was 0.07 units at 112 kg $N \cdot ha^{-1}$ rate). Consequently lime application would be needed to overcome soil acidification from N fertilizer and counteract unfavourable changes of soil properties.

Conclusions

1. There was a significant depression in soil pH in the top 10 cm soil with long-term ammonium nitrate fertilization to bromegrass. Lowering of soil pH was related to the rate of N applied. The magnitude and the depth of soil acidification increased with time.
2. Addition of lime to the soil surface visibly raised the pH in the 0–5 cm soil layer.
3. The concentration of Al, Fe and Mn in the top 10 cm soil increased with N rate. The Mn content also raised in the next layers under the influence of the highest doses of N fertilizer.
4. Liming counteracted unfavourable changes of soil properties by decline the content of extractable Al nearer to the zero-N treatment when the soil pH was $\geq$6.0. Fe and Mn contents in the upper two soil layers also decreased but to a lesser extent than Al.

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Key words: long-term N fertilization, soil acidification, Al, Fe and Mn content, soil degradation, liming

Summary

Effects of 27 years of fertilization with ammonium nitrate (in rates: 0, 56, 112, 168, 224 and 336 kg N·ha^{-1}·yr^{-1}) to bromegrass (*Bromus inermis* Leyss.) on the soil acidification, and on Al, Fe and Mn content in the soil studied in field experiment set up in 1968 on a Thin Black Chernozem soil in Alberta. A part of

each N plot was treated with surface-applied lime in calcium carbonate form in 1991 at rates to bring soil pH (in H_2O) to near 7.0. Both the limed and non-limed portions were sampled for soil in the autumn 1994.

Under the influence of N fertilizer the soil was acidified. In the 0–5 cm layer soil pH was 6.85 when no N was applied, and drastically decreased along with N dose (pH≤4.10) when the N rate was ≥168 kg $N \cdot ha^{-1}$. There was also distinct depression in soil pH from the three higher N doses in the 5–10 cm layer, and in the next layer only at the highest N rate (336 kg $N \cdot ha^{-1}$). Liming increased markedly soil pH only in the 0–5 cm layer, particularly at higher N doses.

The content of extractable Al and Fe visibly increased along with the N dose in the upper two layers and was closely correlated with the decrease in soil pH from N fertilization. The Mn content also raised in the upper three layers but the scheme of changes was different. In the 0–5 cm soil layer the lower three N doses caused regular increase of DTPA-extractable Mn, and beyond 112 kg $N \cdot ha^{-1}$ dose decreased the Mn content. In the next layer increase of extractable Mn was induced by 168 and 224 kg $N \cdot ha^{-1}$ rates, while in the 10–15 cm layer the same effect appeared only at the highest N dose. Liming drastically decreased extractable Al in soil in the two upper layers, while increasing extractable Fe in the 0–5 cm and decreasing it in the lower layers. Visible changes caused by liming in extractable Mn in the 0–5 cm soil layer after statistical estimation appeared no significant, but lime decreased Mn content in the next two layers.

DEGRADACJA GLEBY POD WPŁYWEM DŁUGOTRWAŁEGO NAWOŻENIA AZOTEM I MOŻLIWOŚĆ PRZECIWDZIAŁANIA PRZEZ WAPNOWANIE

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Słowa kluczowe: długotrwałe nawożenie N, zakwaszenie gleby, zawartość Al, Fe i Mn, degradacja gleby, wapnowanie

Streszczenie

Skutki 27-letniego nawożenia stokłosy bezostnej (*Bromus inermis* Leyss.) saletrą amonową (w dawkach: 0, 56, 112, 168, 224 i 336 kg $N \cdot ha^{-1} \cdot rok^{-1}$) na zakwaszenie gleby oraz zawartość Al, Fe i Mn w glebie badano w doświadczeniu polowym założonym w 1968 r. na czarnoziemie w stanie Alberta. Część każdego poletka zwapnowano w 1991 r., stosując na powierzchnię gleby wapno w formie węglanowej w dawkach podnoszących pH w H_2O do około 7,0. Z obu części wapnowanej i niewapnowanej pobrano próbki gleby jesienią 1994 r.

Pod wpływem nawożenia N gleba zakwaszała się. W warstwie 0–5 cm pH wynosiło 6,85 jeżeli nie stosowano N i drastycznie obniżało się ($pH \leq 4,10$) ze wzrostem dawki $N \geq 168$ kg $N \cdot ha^{-1}$. Wyraźna obniżka pH gleby nastąpiła także pod wpływem wyższych dawek N w warstwie 5–10 cm, a w następnej warstwie po zastosowaniu najwyższej dawki N. Wapnowanie znacząco podniosło pH gleby tylko w warstwie 0–5 cm, zwłaszcza w kombinacjach z wyższymi dawkami N.

Zawartość Al i Fe ekstrahowanego DTPA wyraźnie wzrastała ze wzrostem dawki N w dwóch wierzchnich warstwach gleby i była ściśle skorelowana z obniżeniem jej pH pod wpływem nawożenia N. Zawartość Mn też wzrastała w trzech pierwszych warstwach gleby, ale kierunek zmian był inny. W warstwie 0–5 cm trzy niższe dawki N powodowały regularny wzrost, a dawki ponad 112 kg $N \cdot ha^{-1}$ spadek zawartości Mn. W następnej warstwie wzrost zawartości Mn wywołały dawki 168 i 224 kg $N \cdot ha^{-1}$, a w warstwie 10–15 cm – najwyższa dawka N. Wapnowanie drastycznie obniżało zawartość ekstrahowanego Al w dwóch wierzchnich warstwach gleby. Jednocześnie podwyższało zawartość ekstrahowanego Fe w warstwie 0–5 cm, a obniżało jego poziom w głębszych warstwach. Zmiany zawartości Mn pod wpływem wapnowania w warstwie 0–5 cm po oszacowaniu statystycznym okazały się nieistotne, ale następowało znaczące obniżenie jego poziom w kolejnych dwóch warstwach gleby.

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