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ACIDIFICATION FROM LONG-TERM USE OF UREA AND ITS EFFECT ON SELECTED SOIL PROPERTIES

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ABSTRACT

Soil acidity is one property associated with decline in soil fertility and low productivity. One important cause of soil acidity is the use of acid-forming inorganic fertilizers. A field study was conducted to examine the development of soil acidity from long-term use of urea and its effects on selected soil properties and whether burning of stover on land ameliorated soil acidity. Nitrogen was applied as urea (46%N) at 0, 60, 120 and 180 kg N ha^{-1} to maize grown on an Alfisol. Following 4 years of annual application of urea, the treated soil became more acid than the control plots with no added urea. The extent of soil acidification was significantly ($p<0.05$) greater with application of more than 120 kg N ha^{-1} than with no application, or 60kg N ha^{-1} as urea. Lower pH values were measured starting from the second cropping season, and at the end of the fourth season the pH had decreased 0.87 units on the plots that received 180 kg N ha^{-1}. From the third season a decrease of -0.04 pH every month (r^2=0.86, $p<0.01$) was measured at the highest rate of urea application. Burning of stover on land had a small and non-significant effect on the pH of the top soil (0-20cm). Application of urea also resulted in a significant ($p<0.05$) decrease in the exchangeable bases (Ca, Mg) in the soil. Compared to the control treatment, soil Ca and Mg decreased by 13 % and 28% respectively in urea treated plots. This study showed that long-term annual applications of urea resulted in soil acidification and decreased exchangeable bases (Ca and Mg) in soil. It also showed that annual burning of stover on the land is unlikely to mitigate the acidification associated with this urea application. These findings suggest that liming should become a necessary complementary programme with intensification of agriculture through increased use of inorganic N fertilizers such as urea.

Keywords: Acid-forming fertilizer, soil properties

INTRODUCTION

Many African soils which are predominantly Acrisols, Nitosols and Ferralsols, are acid due to old age (highly weathered), depletion of soil carbon and continuous cultivation [1, 2]. Inorganic fertilizers may aggravate the process, particularly with application of ammonium-based fertilizers such as ammonium sulphate, ammonium nitrate and urea. Previous studies on long term (5-10 years) soil fertility in Kenya and West African moist Savannah soils have shown an increase in soil acidity of between pH 1.0 to 5.0 [3, 4]. The problem of soil acidification is likely to increase with intensification of agriculture and increased fertilizer use.

Studies in Zambia have shown that crop yields on acid and unlimed soils have declined even with the application of adequate amounts of inorganic fertilizers [1, 5]. A review of data from the Zambia Agricultural Research Institute (ZARI) national soil advisory laboratories has revealed that the problem is widespread and increasing on intensively cultivated lands. Ammonium-based fertilizers such as ammonium sulphate, ammonium nitrate and urea cause soil acidity [6, 7]. In these studies, urea was reported to be of much less concern than the ammonium sulphate and ammonium nitrate sources of N, and therefore lime use is seldom recommended, at least in the short term.

The acidity from ammonium-based inorganic fertilizers arises from the nitrification reaction, or direct uptake of the ammonium ion (NH_4^+) [8]. If the NH_4^+ is taken up by the plant before nitrification takes place and in quantities greater than the accompanying anion, soil acidity will result from proton release from roots. However, nitrification takes place rapidly in most soils so that the window of opportunity for NH_4^+ uptake is usually limited [2]. Besides, maximum acidity does not occur partly because anion absorption such as of NO_3^- by plants releases equivalent amounts of alkaline HCO_3^- and OH^- . Therefore, only the excess NH_4^+ plays a role in soil acidification, and theoretically two moles of H^+ are released per mole of NH_4^+ converted to nitrate. However, urea produces one molecule of H^+ for every molecule of ammoniacal N because one OH^- is released upon urea hydrolysis to form NH_4^+. Thus, 3.57 kg of pure $CaCO_3$ is required to completely neutralize the acidity associated with the use of 1 kg of NH_4^+ -N (or 1.64 kg of pure $CaCO_3$ per kg of urea). However, the real situation regarding soil acidification from use of inorganic fertilizer N is better measured in the field than estimated in this way, and there is not much reported on these measurements in intensively cultivated tropical soils where high rates of fertilization are recommended.

The amount of N fertilizers applied to soils in Zambia varies depending on the cropping system [5]. In commercial intensive agricultural systems application rates range from 200-400 kg N ha^{-1} as top dressing at 6-8 weeks after crop emergence. Relatively cheap urea is applied at very high rates in localized situations, leading to low N recovery by crops and excess NH_4^+ in the soil. Because lime is seldom used with this application of urea soil acidity is often the resulting problem.

Retention of crop residues on land has potential to ameliorate soil acidity, especially if these are incorporated into the soil [9]. However, crop residues, which can interfere with seedbed preparation, are usually burned rather than ploughed-in. Burning is also used to control the carry-over of plant diseases and pests from one season to another. Residues contain considerable amounts of nutrients which are added to the soil through the resulting ash. The ash itself that is alkaline in reaction has a neutralizing effect on the soil [10].

The combined effects of application of urea and the practice of burning stover on soil acidification have not been evaluated on soils in Zambia, and yet this information could form the basis for guiding the N fertilizer practice and crop residue management. Therefore, the objectives of this study were to investigate soil acidification from long-term annual application of urea and its effects on selected soil properties and to evaluate the effect of burning stover on mitigating the soil acidity.

MATERIALS AND METHODS

The field experiment was conducted at the University of Zambia Farm (15^{o}21' – 15^{o}24'S and 20^{o}27' -20^{o}28'E). The site is situated at an altitude of 1140 m above sea level, and it has an average annual rainfall of 1028 mm, received almost entirely during November to April. Average minimum and maximum monthly temperatures at the site were 13^o C in July and 24^o C in October. The soil is classified as a mixed fine-loamy, isohyperthermic Oxic Paleustalf [11]. Selected initial chemical properties of the soil are given in Table 1.

One year prior to the experiment, the site had been under bush fallow. The urea treatments applied at the start of the experiment in December, 1985 were control (0 nitrogen), 60, 120 and 180 kg N ha^{-1} as urea (46 N %). Each treatment was replicated four times in a randomized complete block design. The treatment plots measured 8m x 4m.

Each season the N was applied in two equal split applications, once at planting and the other at the beginning of maize tasselling according to the recommended fertilizer practice for this crop. All treatments received a basal dressing of 45 kg P ha^{-1} as triple supper phosphate (43% available, P_2O_5), 50 kg K ha^{-1} as KCl and 20 kg S ha^{-1} as gypsum ($CaSO_4.2H_2O$). Maize (*Zea mays,* L.) was planted in rows 75 cm apart and 25 cm between plants within the rows. The variety used was a three-way cross long season hybrid, MM752 (165-170 days to maturity). The experiment was conducted over four cropping seasons (1984/85-1987/88), and the N treatments were applied annually on the same plots.

After harvest, the maize stover and other residues on the land were burned on the field in July when they were dry (i.e. single stover). Starting the second cropping season (1985/86), the treatment plot receiving 180 kg N ha^{-1} was split, and the stover were physically removed from one half of the main plot and added to the other one half where they were burned (double stover).

Five random soil samples were regularly taken with an auger from 0-20cm and 20-40cm depths of each treatment plot during and at the end of each season after harvest. A composite sample from each treatment plot was then used in the analysis of soil pH and exchangeable bases (Ca, Mg and K). Soil reaction (pH) was measured in 0.01 M $CaCl_2$ at a soil: solution ratio of 1:2.5. Exchangeable bases were extracted with a solution of neutral ammonium acetate and then measured in the filtrate by Atomic Absorption Spectroscopy. At the end of each season, maize cobs were harvested from 12 m^2 of each treatment net plot and dried. After shelling, grain weight was measured at 12.5% moisture content.

These data were statistically analyzed by analysis of variance (ANOVA) using the Hewlett-Packard Autostat Computer Programme for ANOVA, and the treatment means were separated using the Duncan's Multiple Range Test and the t-Test.

RESULTS

Soil Acidulation

The data relating to the long-term effect of urea application on soil acidity are presented in Fig. 1. Soil acidification increased significantly ($p<0.01$) by the application on urea to this soil. Application of urea at rates greater than 120 kg N ha^{-1} resulted in significantly ($p<0.05$) lower pH values than the control after four annual applications of urea. At the highest rate of urea application (180 kg N ha^{-1}) the topsoil pH decreased by 0.87 units from the value measured for the control. The linear regression of topsoil pH on time of continuous cropping with annual application of urea (Fig. 2) shows an increase in acidification at the rate of -0.04 pH per month, beginning from the third season.

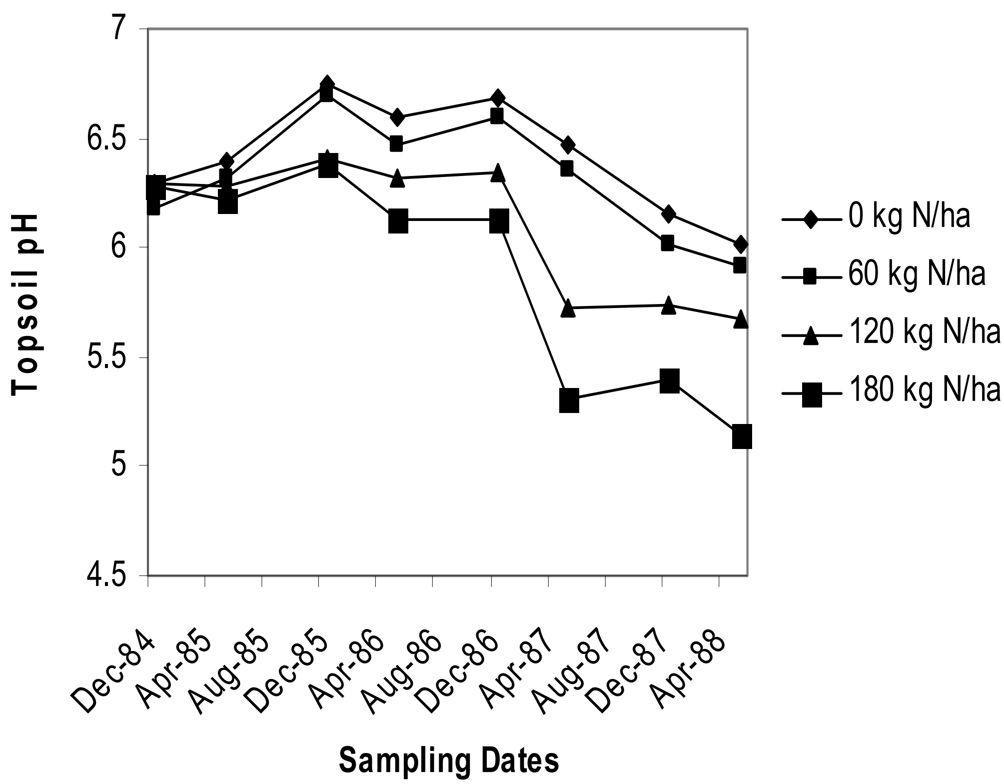

Fig.1: Changes in topsoil pH during continuous cropping with annual application of urea

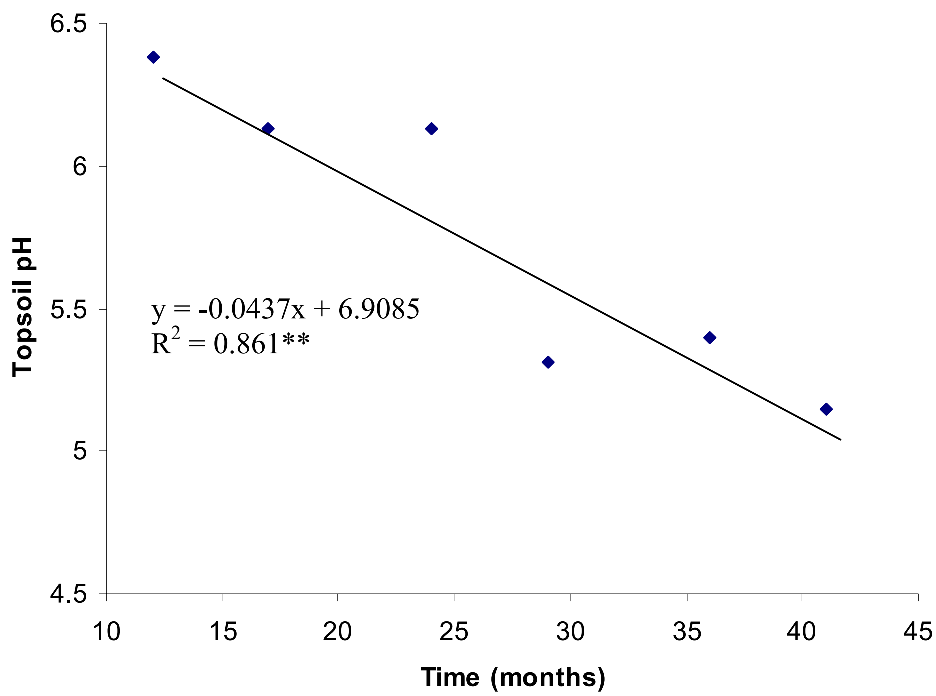

Fig. 2: Relationship between topsoil pH and time of continuous cropping with high annual application of urea (180 kg ha^{-1}) on an Alfisol from Zambia

Stover Management

The data in Table 2 show the effect of removing, or burning stover on the field. Burning of the stover had a small and non-significant effect on the pH of the topsoil (0-20cm). Only small temporal increases in pH of the topsoil were measured soon after the burn in the double -stover plots, but the effect disappeared after the start of the rains in November.

Exchangeable Bases

There were significant ($p<0.05$) effects of urea on the exchangeable bases in the soil (Table 3). Both exchangeable Ca and Mg were lower at higher rates of urea application (>120 kg N ha^{-1}) than at zero and 60 kg N ha^{-1}. Exchangeable K significantly differed ($p<0.05$) from the control only at 60 kg N ha^{-1} while the values at the other rates did not differ from the control. The decrease in exchangeable bases followed the trend in soil acidification from annual applications of urea.

Yield Trends

The mean grain yields were significantly influenced ($p<0.05$) by N application as expected (Table 4). During the four seasons, greater mean grain yields were obtained at higher rates of N application (>120 kg N ha^{-1}) than at lower rates (<60 kg N ha^{-1}). The seasonal variations in the yields did not follow the decreasing trend in soil pH from annual applications of urea to the crop. During the same period, annual rainfall varied and so the yield variations are also probably a result of the seasonal variations in rainfall. The contribution of this factor was not isolated in this study.

DISCUSSION

Urea is least suspected to cause soil acidity compared to the more familiar acid-forming ammonium fertilizers such as Ammonium Sulphate [6, 7]. As a result, lime is seldom recommended when urea is used, more especially among the small scale farmers. The results presented in Fig. 1 provide evidence that annual long-term applications of urea led to soil acidification. The linear regression presented in Fig. 2 showed that with continuous urea application soil acidification started in the third cropping season, and the rate increased with the level of urea application, being highest with 180 kg N ha^{-1} which was -0.04 pH units per month. In order to counteract this effect of soil acidification from urea and maintain soil productivity it is necessary to regularly apply lime.

Theoretically, 164.2 kg of pure $CaCO_3$ are required to completely offset the acidity caused by 100 kg of urea, or 46 kg N. In Zambia the recommended topdressing with urea is 200-400 kg N ha^{-1} under intensive agriculture on commercial farms and about half these rates on smallholder farms. Therefore, in order to maintain favourable soil pH in intensively cultivated lands, at least 330 kg $CaCO_3$ ha^{-1} should be applied with these rates of urea application. The recommended liming rate for the amelioration of soil acidity in Zambia is 500 kg ha^{-1} every three years [12], which is supported by data from this study.

Burning of stover on the field had only a small and non-significant effect on the pH of the topsoil (Table 2). Ash is alkaline (about pH 10.0), and if available in sufficient quantities can neutralize soil acidity. It has been reported that the pH of the topsoil (0-20cm) where a heap of Miombo wood was burnt increased 1.6 units compared to the unburned control site 39 hours after the burn [10]. However, this effect has been reported to be temporal, and the soil re-acidified to the original state as the control after 3-5 years of continuous cultivation [10]. These observations suggest that agricultural lime is the only efficient material for the control of soil acidity in arable lands. Agricultural lime is slow-acting in soil and therefore will have a longer lasting effect than easily soluble ash.

The amounts of exchangeable Ca and Mg in soil progressively deceased with annual applications of urea to this soil during the four seasons (Table 4). The data show that exchangeable Ca decreased by 13% and Mg by 28% compared to the control whilst the soil pH on the treatment plots simultaneously decreased from 6.0 to 5.0. Therefore, decreased exchangeable bases are associated with soil acidification. This observation is consistent with findings by several authors [e.g. 3, 7, 13]. Other studies have shown that decreased bases in an Alfisol were associated with soil acidification below pH 4.5 [13].

The initial exchangeable K in the soil used in this study was very high (>0.2 cmol kg^{-1}) which is recommended as the critical limit for adequate plant requirements in Zambia(Table 1), and the soil received 50 kg K ha^{-1} as basal dressing. This probably explains why soil acidification from urea application had only a small and non-significant effect on the measured exchangeable K at the last sampling. Both Ca and Mg were initially low in this soil (Table 1).

The decrease in exchangeable Ca and Mg can be explained by the surface charge characteristics of soils. In highly weathered tropical soils, a substantial amount of the charge is pH-dependent, and at low soil pH the Cation Exchange Capacity (CEC) decreases, reducing the soils capacity to retain cations such as Ca, Mg and K, which can even be leached. This observation has been confirmed in other studies that showed that Mg deficiency occurred more frequently and more severely on acid soils than on neutral ones[14].

There is indication that grain yields were progressively lower with continuous cropping during the four seasons. However, it is difficult to separate the contribution of soil acidity and annual applications of urea from that of rainfall (which varied seasonally) and other factors. For instance, burning of residues on land can reduce infiltration which can cause poor performance of a crop [15]. Besides, grain yield is probably not a sensitive and reliable indicator of soil degradation by soil acidification because by the time crop yields become depressed, it would probably be too late to prevent costly remedial measures to correct the problem.

CONCLUSION

This study showed that long-term annual application of urea resulted in soil acidification and decreases in exchangeable Ca and Mg, especially if these were already low in the soil. Burning of stover on the land, which is a common practice of seedbed preparation and control of carry-over pests and plant diseases, is unlikely to offset the acidity associated with the use of urea. Even with substantial amounts of crop residues burned on land, the small measurable effect is only temporal in its influence on soil reaction. Therefore, these findings suggest that it is advisable to recommend use of agricultural lime with the use of urea fertilizer in order to maintain favourable soil reaction (pH) and soil fertility.

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Table 1: Selected initial characteristics of soils used in the study

Soil depth (cm)	Clay content (%)	Organic C %	pH in $CaCl_2$	Exchangeable cations (cmol kg^{-1})			CEC (cmol (+) kg^{-1}
				Ca	Mg	K	
0-23	30.0	0.09	6.50	2.75	1.00	0.83	6.16
23-40	33.1	0.63	6.40	2.97	1.03	0.92	7.12
40-85	42.3	0.36	6.60	3.06	1.09	1.04	7.60
85-160	43.1	0.24	6.90	3.03	1.08	0.93	8.56

Table 2: Soil reaction (pH) in the top 20 cm of the soil in plots treated with 180 kg N ha^{-1} and on which stover was burned

Soil depth (cm)	Stover management	Date of sampling			
		Nov. 1986	May 1987	Nov. 1987	May 1988
		pH			
0-10	Burned	6.41	5.26	5.76	5.26
	Removed	6.18	5.25	5.20	5.11
	SE+_	0.27	-	0.40	-
10-20	Burned	6.29	5.31	5.23	5.21
	Removed	6.23	5.28	5.38	5.15
		NS*	NS	NS	NS

* NS = Statistically non significant

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Table 3: Exchangeable bases and the final pH in the topsoil (0-20 cm) following 4 years of annual urea application and burning of stover on the field

Treatment (kg N ha^{-1})	Exchangeable bases (cmol kg^{-1})			pH (in $CaCl_2$)
	Ca	Mg	K	
0 (Control)	3.63	1.36	0.61	6.02
60	3.37	1.24	0.70	5.91
120	3.19	1.04	0.57	5.68
180	3.15	0.98	0.57	5.15
SE +_	0.08	0.06	0.02	0.05
CV (%)	13.15	9.94	18.00	13.60

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Table 4: Mean grain yields* for four cropping seasons (t ha^{-1})

Treatment (kg N ha^{-1})	Cropping Season			
	1984/85	1985/86	1986/87	1987/88
0	5.05^{ab}	3.32^{a}	1.77^{a}	1.73^{a}
60	4.60^{a}	4.16^{b}	1.72^{a}	1.93^{a}
120	5.16^{ab}	6.86^{c}	2.62^{b}	4.05^{b}
180	5.64^{b}	9.50^{d}	2.90^{b}	6.11^{c}
Annual Rainfall (mm)	871	1187	698	783

*12.% moisture. Means followed by the same letter in a column are non significantly different ($p<0.05$).

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