

Crop tolerance of soil acidity resulting from long-term continuous application of Nitrogen fertilizers

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Abstract:

The effects of long-term (12 years) continuous cultivation and application of different N-sources (ammonium sulphate, urea and calcium ammonium nitrate) on soil acidity and the growth of three crops were determined.

Continuous cultivation, with and without nitrogen fertilizer addition, for twelve years led to a marked reduction in soil pH and an increase in the soil exchange acidity. The exchange acidity in $(\text{NH}_4)_2\text{SO}_4$ treated plots were significantly higher than all other treatments. Of the three N-sources used, ammonium sulphate gave the worst effect on the growth of the crops studied. The acid tolerance of the test crops as reflected in the growth parameters measured was in the order: maize > cowpea > tomato. The production of tomato appeared absolutely impossible under an acid soil condition.

Introduction:

Continuous cropping with addition of nitrogen fertilizers over a long period of time has been known to aggravate the soil conditions required for optimal crops growth. Various workers (Abruna *et al.*, 1958; Obi, 1976; Mahler and Harder, 1984) have reported the acidifying conditions emanating from continuous use of N-fertilizers. The magnitude of the acidity thus developed is a function of both the type of N-fertilizers (Fox and Hoffman, 1981) and the rate and method of application (Mahler and Harder, 1984). Rao *et al.*, (1971); Sarigumba and Pritchett (1974) observed that ammonium sulphate is more prone to leaching and causes more soil acidity than urea. In areas of intensive rainfall, leaching of anions will hasten the development of soil acidity (Jackson *et al.*, 1967). This explains the widespread occurrence of acid soils in the humid tropics.

The subsequent effect of acid soil conditions on plant growth may be indirectly exhibited by the presence of toxic substances, and the absence of essential elements in soil solution. The pH of the rhizosphere exerts a stronger influence than the bulk soil pH on the availability of nutrients to

plants and on biological interaction around the roots. An impairment of root development due to acid soil condition has earlier been reported (Shoji *et al.*, 1980; Wallace and Anderson, 1984). A high degree of acid condition in the rhizosphere may prevent the uptake of phosphate by the root. Also toxic substance in the living cell of plant may interfere with sugar phosphorylation (Clarkson, 1966).

Crop sensitivity to the toxic substances emanating from acid soil conditions varies between species (Lance and Pearson, 1969) and also within species (Long and Foy, 1970). Wheat and soybean have been reported to be more tolerant of acid soil conditions than cotton and millet (Foy and Brown, 1964). The present study was aimed at investigating the effect of acid soil conditions, developed from long-term continuous application of nitrogen fertilizers, on the growth of three important crops of Nigeria.

Materials and Method

This investigation was conducted on a site which had been continuously cultivated and treated with different nitrogen fertilizers for twelve years. The site is situated on an Iwo soil series (*Typic Paleustult*) which is sandy loam in texture with a field moisture capacity of 12.6 percent. At the time of the present study, the soil pH ranged from 3.44 to 4.14 with an average value of 3.83 pH units. The mean soil content of the organic matter (chromic acid digestion method (Allison, 1955) was 0.801%. The cation exchange capacity by sodium bicarbonate extracting procedure varied from 0.50 to 6.25 meq/100g soil. The available P by Bray No. 1 Method averaged 3.58 ppm; exchangeable K averaged 51.6 ppm and the nitrate nitrogen ($\text{NO}_3^- \rightarrow \text{N}$) determined colorimetrically was 9.2 ppm. Application of nitrogen fertilizers was by banding. Basal dressing of phosphorus (P) and potassium (K), based on the initial levels of these elements was made by applying 40 kg P/ha as ordinary superphosphate and 60 kg K/ha as potassium chloride. The three test crops grown for this investigation were: maize (*zea mays* L. Var. TZSR), Tomato (*Lycopersicon esculentum* L. Walp.) and cowpea (*Vigna unguiculata*).

The crops were planted in the late season and constant wetting was carried out when the need arose. The experimental design was a 3 x 4 x 3 factorial design as follows: Three sources of N—fertilizers, 4 levels of nitrogen application and three crop types. The treatments were in 5 replicated blocks. Detail of the different N—fertilizer treatments are shown in table 1. Growth parameters measured were dry matter yield, and root length of plants at 2 weeks. Heights of crops at 2, 4, 6, 8 and 10 weeks after planting were also determined. Height measurement was accomplished with the aid of a metre rule and this was taken from the ground surface. Recorded plant heights are means of five measurements.

Table 1: SOURCES AND RATES OF NITROGEN FERTILIZERS APPLIED

Treatment	Source of N-Fertilizer	Rates of Application kgN/ha	
		Early	Late
1.	No fertilizer (control)	0	0
2.	$(\text{NH}_4)_2\text{SO}_4$	23	46
3.	„ „ „	46	92
4.	„ „ „	92	184
5.	„ „ „	138	0
6.	$(\text{NH}_2)_2\text{CO}$	23	46
7.	„ „ „	46	92
8.	„ „ „	92	184
9.	„ „ „	138	0
10.	$\text{CaNH}_4(\text{NO}_3)_3$	23	46
11.	„ „ „	46	92
12.	„ „ „	92	184
13.	„ „ „	138	0

Root sampling and measurement:

After 2 weeks of growth in the field, plant samples were taken from each plot by excavating the soil within 8cm radius of the plant base to a depth of 20cm. Sufficient care was taken to avoid root damage. The shoot was severed, weighed fresh and dried in the oven at 75C. Both the soil and root samples were placed in 1mm sieve partially immersed in water. The soil was washed off and the roots were rinsed with distilled water. The roots were preserved in toluene treated distilled water and stored in the refrigerator at 5C pending root length determination. Root length was determined by the 'Line Intercept Method' (Newman 1966). The roots were thereafter spread between two filter papers to remove the surface moisture. The fresh weight was taken before the roots were dried in the oven at 70C for 48 hours and the dry weight was determined.

Results and Discussion

After the experimental site had been continuously cultivated and different nitrogen carriers applied for twelve years, the crop in soil pH ranged from a low of 2.58 in calcium ammonium nitrate (CAN) treated plot to a high of 3.54 in plots that received ammonium sulphate treatments (Table 2)

Table 2: EFFECT OF LONG TERM CROPPING AND APPLICATION OF DIFFERENT N-FERTILIZERS ON SOIL PH and EXCHANGE ACIDITY

*Treatment Number	Treatments (N-Source)	Soil pH		Δ pH	Mean Δ / N-Source		Exchange-able Acidity (meq/100g)
		pH _i	pH _c		Δ pH	%	
1.	Control	6.76	4.14	2.62	2.62	38.7	1.15 a
2.	(NH ₄) ₂ SO ₄	6.38	3.78	2.60	3.01	45.5	2.25 b
3.	" "	6.48	3.56	2.92			2.43 b
4.	" "	6.98	3.44	3.54			2.65 b
5.	" "	6.58	3.62	2.96	2.84	42.4	2.40 b
6.	(NH ₂) ₂ CO	6.66	3.86	2.80			1.75 ab
7.	" "	6.70	3.88	2.82			1.52 a
8.	" "	6.86	3.90	2.96	2.79	41.4	1.70 a
9.	CaNH ₄ (NO ₃) ₃	6.78	4.06	2.72			1.15 a
9.	" "	6.60	3.82	2.78			1.10 a
10.	CaNH ₄ (NO ₃) ₃	6.78	4.06	2.72	3.00		1.15 a
11.	" "	6.58	4.00	2.58			1.23 a
12.	" "	6.80	3.80	3.00			1.14 a
13.	" "	6.80	3.94	2.86	2.79	41.4	1.40 a

pH_i = Initial soil pH

pH_c = Current soil pH

Δ pH = Change in pH (pH_i - pH_c)

Means not followed by the same letter differ at a 0.05 probability level according to Duncan's multiple range test.

* = Explained in Table 1.

The drop in soil pH in control plots averaged 2.62. Since the experimental site was in the rainforest zone of southern Nigeria, leaching loss of cation might have contributed to the drop in soil pH. Of the three nitrogen sources used in this study, the mean percent drop in soil pH per nitrogen source was highest with ammonium sulphate and least with calcium ammonium nitrate treated plots. The mean drop in soil pH in the control plot was about 3% less than the least pH drop of the nitrogen fertilizer treatments.

The exchange acidity of the control and that of both urea and calcium ammonium nitrate treated plots were not significantly different ($P > 0.05$) from one another. Thus, the continuous application of these N-sources did not result in a significant contribution to the soil exchange acidity. Conversely, continuous addition of ammonium sulphate significantly contributed to soil exchange acidity. The exchange acidity from ammonium sulphate treated plots were significantly greater ($P < 0.05$) than both the control and all the other N-treatments. Exchange acidity of a soil is constituted mainly by both the hydrogen and aluminium ion content of such soil. Since there was no significant difference ($P > 0.05$) among the treatments in the pH drop of the soil, it can be concluded that the significant difference in the exchange acidity, obtained in the ammonium sulphate treated plots, was contributed solely by the aluminium ions.

The long-term continuous application of N-fertilizers and the consequent soil reaction considerably affect the dry matter yield of crops after two weeks of growth (Table 3). The mean dry matter yield of crops per N-source, expressed as a percentage of the control was least with ammonium sulphate treated plots. At this stage of growth (2 weeks) there was no definite trend in the dry matter yield of crops in response to the long-term application of $(\text{NH}_2)_2\text{CO}$ and $\text{CaNH}_4(\text{NO}_3)_3$. The least mean dry matter yield of 39% of the control was obtained with tomato grown in the $(\text{NH}_4)_2\text{SO}_4$ treated plots. This suggests that tomato was the most sensitive to soil acidity among the three test crops planted.

After two weeks of growth, the roots of the crops seem not to be significantly affected by the long term application of different N-carriers (Table 4). The highest mean increase in root length per N-source of 15% above the control was obtained with $\text{CaNH}_4(\text{NO}_3)_3$ treatment when cowpea was the test-crop. The least increase in root length was obtained on $(\text{NH}_4)_4\text{SO}_4$ treated plots. A similar trend was obtained for tomato. Long-term application of $(\text{NH}_4)_2\text{SO}_4$ as a source of N to tomato depressed the mean root length by 9% after two weeks of growth. With the three N-carriers, the mean root length obtained with $(\text{NH}_4)_2\text{SO}_4$ treatment was the least for the three test crops. This is most pronounced with tomato crop and it further indicates the sensitivity of this crop to the acidifying effect of $(\text{NH}_4)_2\text{SO}_4$.

Table 3: EFFECT OF LONG TERM APPLICATION OF DIFFERENT N-SOURCES ON DRY MATTER YIELD (g) OF CROPS AFTER 2 WEEKS OF GROWTH

Treatments	Cowpea	Maize		Tomato		
	Mean/ N-Source %	Mean/ N-Source %	Mean/ N-Source %	Mean/ N-Source %		
1. Control	0.33 a	100	0.32 a	100	1.62 ab	100
2. (NH ₄) ₂ SO ₄	0.21 a	61	0.36 a	93	0.61 b	39
3. " " "	0.19 a		0.26 a		0.69 ab	
4. " " "	0.19 a		0.30 a		0.68 ab	
5. " " "	0.22 a		0.27 a		0.53 b	
6. (NH ₂) ₂ CO	0.26 a	75	0.36 a	115	2.24 a	109
7. " " "	0.29 a		0.34 a		1.56 ab	
8. " " "	0.24 a		0.40 a		1.78 ab	
9. " " "	0.20 a		0.37 a		1.50 ab	
10. CaNH ₄ (NO ₃) ₃	0.26 a	80	0.33 a	105	1.43 ab	83
11. " " "	0.36 a		0.35 a		1.39 ab	
12. " " "	0.22 a		0.38 a		1.61 ab	
13. " " "	0.22 a		0.28 a		0.98 ab	

*Means not followed by the same letter differ at a 0.05 probability level according to Duncan's multiple range test.

After twelve years of continuous cultivation of the experimental site with or without application of N-fertilizers, the growth of the three test crops were substantially depressed. Ammonium sulphate was the worst N-source for maize when growth is measured in terms of crop height. The greatest crop height depression occurred in plots that received $(\text{NH}_4)_2\text{SO}_4$ as the source of N. (Fig. 1). This was about 57% of the control while maize plots treated with $\text{CaNH}_4(\text{NO}_3)_3$ had an average height of about 71% of the control.

A similar trend was obtained for cowpea (Fig. 2). Cowpea height in the $(\text{NH}_4)_2\text{SO}_4$ treated plots was 44% of the control by the tenth week of growth. There was no substantial difference in crop heights between plots that received other N-sources and the control.

Table 4: EFFECT OF LONG TERM APPLICATION OF DIFFERENT N-SOURCE ON ROOT LENGTH OF CROPS AT 2 WEEKS

Treatments	C r O p s					
	C o w p e a		M a i z e		T o m a t o	
	Mean/ N-Source		Mean/ N-Source		Mean/ N-Source	
	cm	N-Source (%)	cm	%	cm	%
1. Control	633 a	100	926 a	100	454 a	100
2. $(\text{NH}_4)_2\text{SO}_4$	570 a		971 a		410 a	
3. „ „ „	748 a		971 a		303 a	
4. „ „ „	606 a	101	944 a	103	454 a	91
5. „ „ „	624 a		944 a		490 a	
6. $(\text{NH}_2)_2\text{CO}$	633 a		864 a		535 a	
7. „ „ „	659 a		1140 a		481 a	
8. „ „ „	686 a	103	1247 a	119	615 a	113
9. „ „ „	633 a		1149 a		419 a	
10. $\text{CaNH}_4(\text{NO}_3)_3$	713 a		1069 a		517 a	
11. „ „ „	668 a	115	1052 a	115	704 a	118
12. „ „ „	748 a		1024 a		445 a	
13. „ „ „	775 a		1122 a		481 a	

*Mean not followed by the same letter differ at a 0.5 probability level according to Duncan's Multiple Range test.

With tomato, crop height did not exceed 40cm in any of the treatments throughout the ten weeks of growth (Fig. 3). There was no difference between the $(\text{NH}_2)_2\text{CO}$ and $\text{CaNH}_4(\text{NO}_3)_3$ treated plots, and the control. With $(\text{NH}_4)_2\text{SO}_4$ treated plots, tomato attained a height of 20cm by the second week of growth. There was no further increase in height throughout the ten weeks of growth. Field observation during the cropping period indicated that the tomato plant in the $(\text{NH}_4)_2\text{SO}_4$ treated plots were thin-stemmed and stunted.

The growth response by the three test crops was in consonance with the drop in soil pH after twelve years of continuous cultivation. The worst

MAIZE

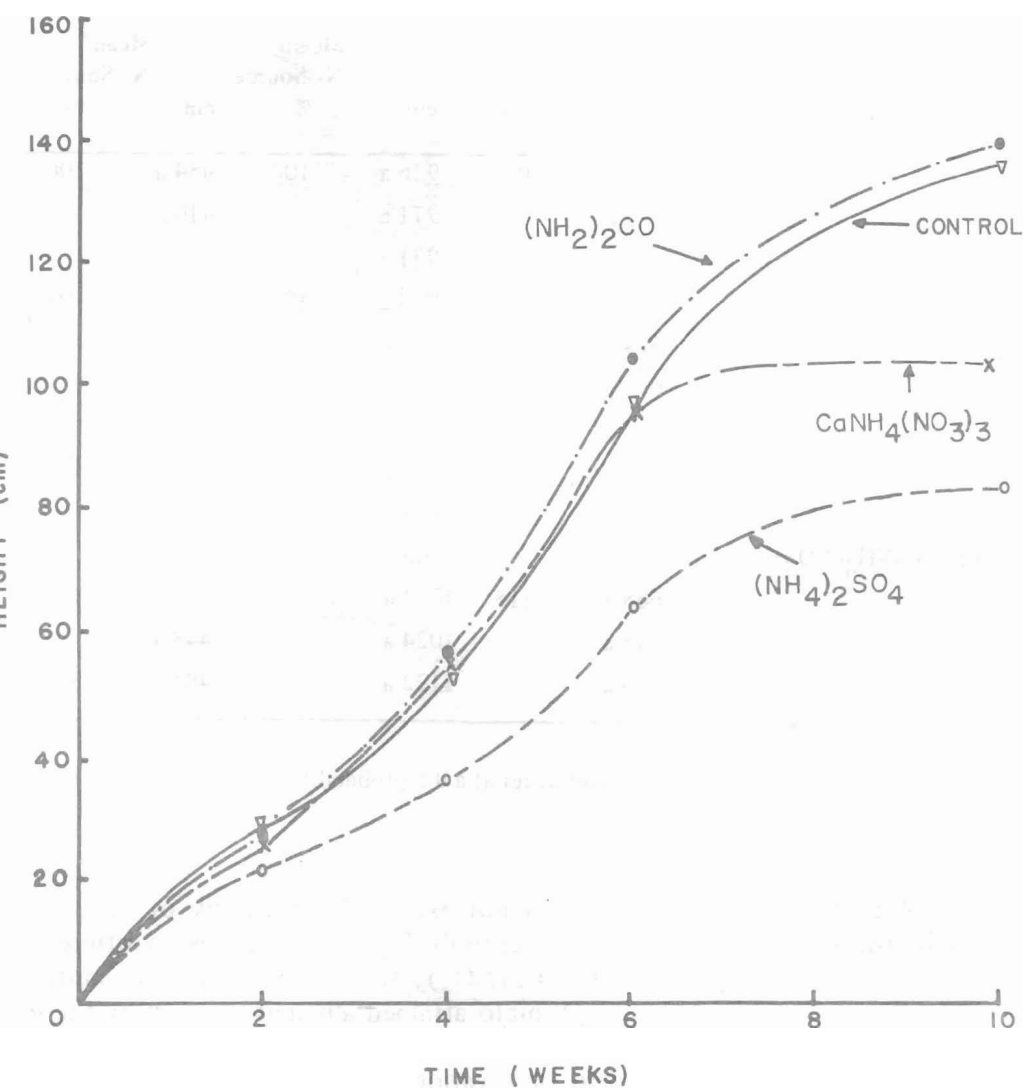


Fig. 1: EFFECT OF LONG TERM APPLICATION OF N-FERTILIZERS ON HEIGHT OF MAIZE

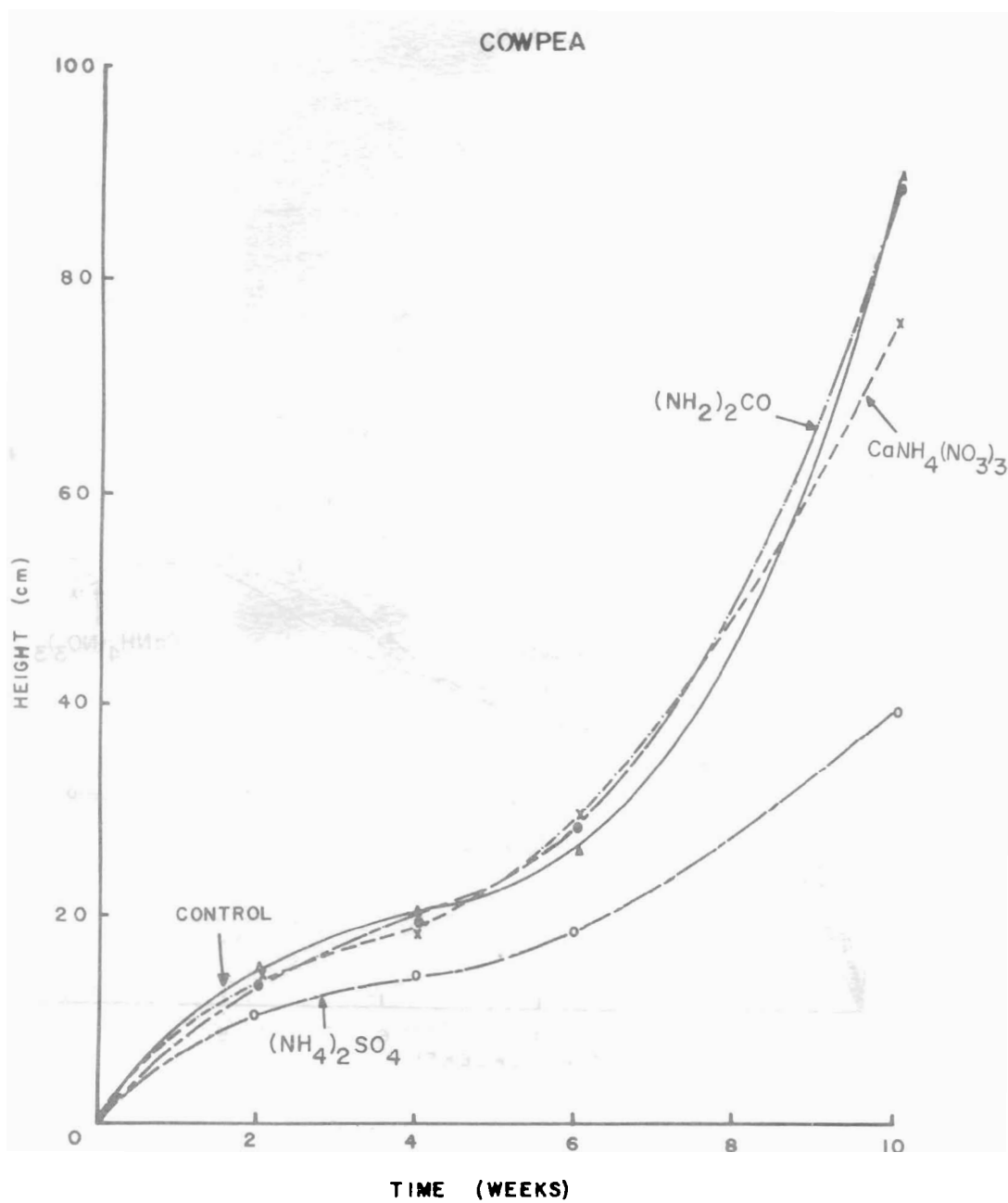


Fig. 2: EFFECT OF LONG TERM APPLICATION OF N-FERTILIZERS ON HEIGHT OF COWPEA

TOMATO

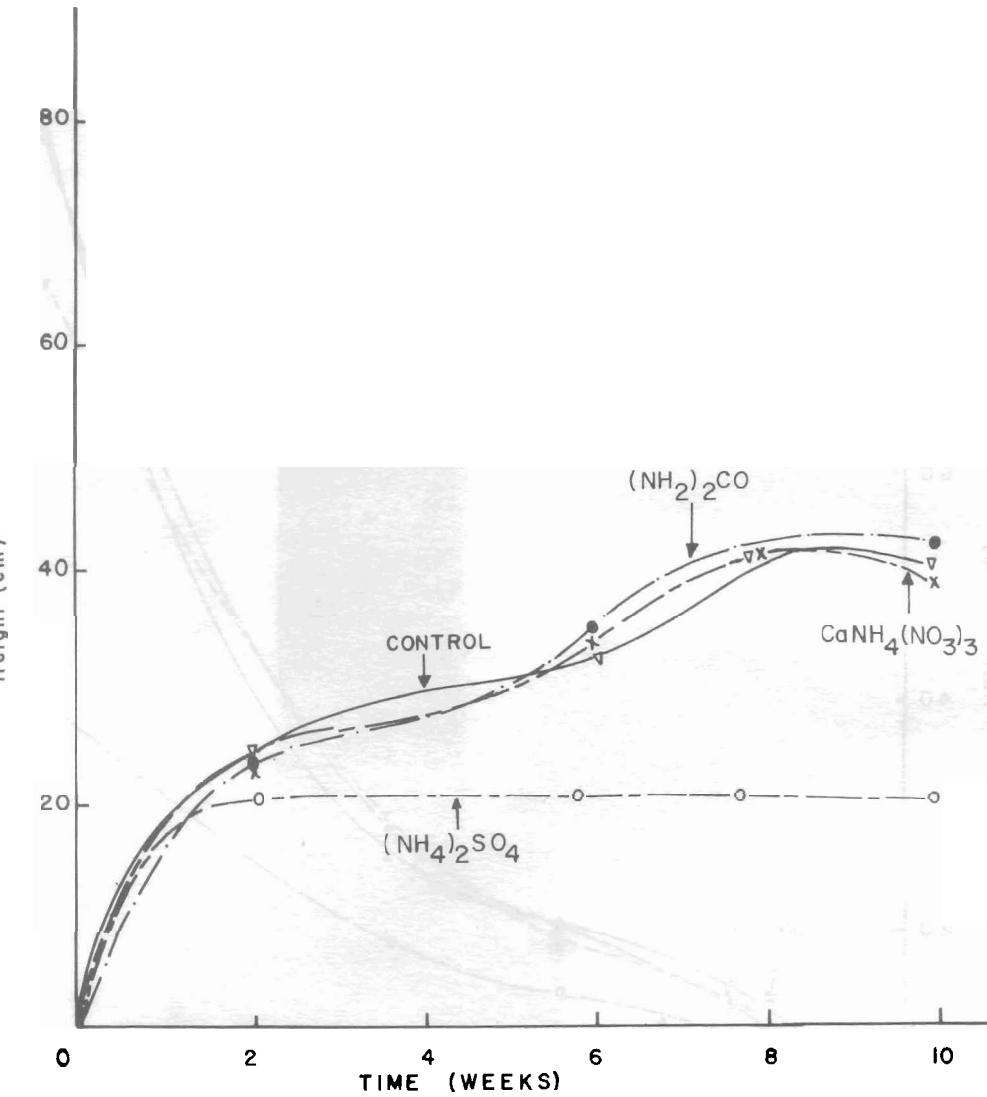


Fig. 3: EFFECT OF LONG TERM APPLICATION OF N-FERTILIZERS ON HEIGHT OF TOMATO

growth for all crops obtained from plots treated with $(\text{NH}_4)_2\text{SO}_4$ was attributable to the significant exchange acidity obtained on such plots. Since the current soil pH is less than 4.00, the exchange acidity is mainly dominated by exchangeable aluminium (Saigusa *et al.*, 1980). The exchange acidity of the $(\text{NH}_4)_2\text{SO}_4$ treated plots were significantly higher than that of all other treatments. Continuous application of $(\text{NH}_4)_2\text{SO}_4$ as a source of N most probably led to an increase in the soil content of the exchangeable aluminium. The extensive growth depression suffered by the three test crops in the $(\text{NH}_4)_2\text{SO}_4$ treated plots could be due to aluminium toxicity; and out of the three crops, tomato plants was the most sensitive to this condition.

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