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EFFECTS OF ZINC AND BORON FERTILIZATION ON THE ALLEVIATION OF POOR CROP GROWTH IN HEAVILY LIMED TWO ACIDIC SOILS

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ABSTRACT

Screenhouse experiments were conducted to determine the effect of Zn and B fertilization on the alleviation of poor crop growth of corn in heavily limed Antipolo sandy clay and Luisiana sandy clay soils.

The Antipolo and Luisiana sandy clay soils are highly weathered aluminous ultisols. They are highly acidic (pH 4.6 and 4.9 respectively) with high exchangeable Al and very low available P.

Gradual increments of lime rate up to 5.0 tons/ha for Antipolo and 3.0 tons/ha for Luisiana soils significantly increased the growth of corn. Beyond these rates, growth gradually declined. However, with the addition of Zn at the rate of 8 kg/ha to the 7 and 9 tons lime rates in Antipolo sandy clay and to the 4 and 5 tons lime rate in Luisiana sandy clay, the growth reduction problem disappeared. In contrast, boron fertilization had little or no effect on the growth of corn at high lime rates in both soils.

With increasing lime rates, exchangeable Zn and soluble B decreased. The same trends were observed on the concentration of Zn and B in corn tissues.

The optimum levels for 94% relative dry matter yield of corn on the Antipolo sandy clay were pH 5.35, 4.0 ppm exchangeable Zn and a tissue concentration of 18.5 ppm Zn. On a Luisiana sandy clay, 94% relative dry matter yield of corn was produced at pH 5.32, 3.0 ppm exchangeable Zn and a tissue concentration of 17.5 ppm Zn.

It can be concluded that growth depressions at high lime rates on Luisiana and Antipolo sandy clay soils were due to Zn deficiency and it can be corrected by applying approximately 7 to 9 kg Zn/ha.

INTRODUCTION

Extensive areas of the Philippines are covered by ultisols. These soils are acidic in reaction, generally contain toxic levels of Al and Mn, low levels of P, Mo, Mg and Ca. Liming is the usual method for improving growth performance on these soils. It is an established fact that liming acid soils improve the conditions for plant growth by increasing soil pH (Bhaumik and Asthana, 1969), decreasing the concentration of exchangeable Al ions (Evans and Kamprath, 1970) and increasing the supply of Ca (Del Valle, *et al.,* 1977). However, it has been observed recently that liming may also cause negative effects on soil properties and plant growth. Phosphorous and manganese deficiencies can be induced by lime applications (Kamprath, 1970). Samonte (1985) also reported that liming increased the native molybdenum while decreasing the native Zn and B in few acidic soils. A reduction in the uptake of P, Zn, B and Mn by corn (Farina, *et al.,* 1980) and Mg content of plants (Pavan, *et al.,* 1984) were observed as liming raised soil pH to neutral value.

It has also been reported that the availability of almost all plant nutrients in soils are affected by pH and no two elements are alike in rate and extent of increase or decrease in availability with change in pH (Lucas and David, 1961). It is reasonable to expect that the availabilities of Fe, Mn, B, Cu and Zn which begin to decrease at moderate to slightly acidic values could become too low to meet a crop's needs if too much lime is added to an acidic soil. Therefore, this study was conducted with the following objectives:

1. To determine the effect of lime and corresponding pH levels on the availability of native zinc and boron in Antipolo sandy clay and Luisiana sandy clay.

2. To determine any antagonistic effect of Ca on the uptake of boron and zinc on corn.

3. To evaluate the effect of boron and zinc on the growth of sweet corn grown on the two heavily limed red-yellow soils.

MATERIALS AND METHODS

The Antipolo sandy clay and Luisiana sandy clay soils were used in this investigation. These soils are classified as typic Tropudult, clayey, kaolinitic isohyperthermic and Orthoxic Tropudult, clayey, kaolinitic, isohyperthermic, respectively. Bulk samples from the 0-15 cm surface layer were collected from Siniloan and Cavinti in the province of Laguna. The soil samples were air dried, pulverized and sieved through 1 x 1 cm mesh screen.

Three kilograms of Antipolo sandy clay and 5.0 kg of Luisiana sandy clay soils were placed in each of size 8 and size 10 pots that have been previously cleaned and the inner surface painted will coal tar.

This investigation involving two acid soils (Antipolo sandy clay and Luisiana sandy clay) and corn as the indicator crop was conducted in the screenhouse of the Soil Science Department, UPLB.

An additive type experiment was conducted for each soil type. The treatments consisted of 6 to 7 lime rates alone and the additive combinations of Zn and B to the three highest lime rates. The treatments were arranged in a completely randomized design.

The following treatments were used to evaluate the effect of lime, zinc, and boron on corn growth on Antipolo sandy clay:

Treatment No.	Lime Rate (Ton/ha)
1	0.0
2	1.0
3	2.0
4	3.0
5	5.0
6	7.0
7	9.0
8	5.0 T lime + Zinc
9	7.0 T lime + Zinc
10	9.0 T lime + Zinc
11	5.0 T lime + Boron + Zinc
12	7.0 T lime + Boron + Zinc
13	9.0 T lime + Boron + Zinc

To evaluate the effects of lime, zinc and boron on corn on a Luisiana sandy clay, the following treatments were used:

Treatment No.	Lime Rate (Ton/ha)
1	0.0
2	0.75
3	1.50
4	3.0
5	4.0
6	5.0
7	3.0 T lime + Zinc
8	4.0 T lime + Zinc
9	5.0 T lime + Zinc
10	3.0 T lime + Boron + Zinc
11	4.0 T lime + Boron + Zinc
12	5.0 T lime + Boron + Zinc

Agricultural lime which was 90% pure was mixed with the soil one month before planting and the moisture content was maintained close to field capacity. Five seeds of sweet corn were planted to each pot and later thinned to two plants one week after planting.

The plants were allowed to grow for 6 week after which they were harvested for dry matter yield.

Nitrogen, P_2O_5 and K_2O were applied at the rate of 240-480-320 kg per 2×10^6 kg soil, respectively. Nitrogen was supplied as $(NH_4)_2SO_4$ (21% N), while P_2O_5 and K_2O were supplied as superphosphate (18% P_2O_5) and muriate of potash (60% K_2O), respectively.

The total amounts of P and K fertilizers were applied as basal. One half of the N-fertilizer was applied as basal and the other half four weeks after planting. Zinc and boron were applied at 8.0 and 3.75 kilograms per 2 x 10^6 kg, respectively, one week after seedling emergence. These micronutrients were supplied as zinc sulfate ($ZnSO_4.7H_2O$) and boric acid (H_3BO_3). Tap water in equal amounts was applied to all pots to maintain a moist condition.

Data Gathered

Plant height was recorded every week from germination until harvest. The two corn plants in each pot were harvested six weeks after planting. Oven dry weights of shoots and roots were recorded and subsequently ground in Wiley mill in preparation for plant analysis.

Soil samples were collected after 6 weeks and soil pH, exchangeable Ca, 0.05N HCl extractable boron and 0.1N HCl extractable zinc were determined. The methods of analysis outlined in Tables 1 and 2 were used. Available zinc was extracted with 0.1N HCl and Zn in solution was determined with atomic absorption spectrophotometer at a wavelength of 214 nm. Soluble boron was extracted with 0.05N HCl and boron in solution was determined using simplified curcumin procedure (Dible, *et al.,* 1954).

The Ca and zinc in the plant tissue were determined after dry ashing at 550°C in a muffle furnace. The Zn in solution was measured using atomic absorption spectrophotometer, while calcium was determined using EDTA titration. Boron in the tissue was extracted using 0.05N HCl solution after which it was determined colorimetrically using simplified curcumin method as mentioned above.

Statistical Analysis of Data

The various data gathered were subjected to analysis of variance. Duncan's Multiple Range Test (DMRT) was employed to stratify the treatment means. Regression analysis was done to establish the relationship between selected soil and plant parameters and dry matter yield.

RESULTS AND DISCUSSION

Plant Growth on Antipolo and Luisiana Sandy Clay Soils

The growth of corn was significantly improved up to a certain lime rate. To specifically delineate the critical rate, smaller increments of lime were used and Zn and/or boron were added to the rates where the growth was expected to dimish. On Antipolo sandy clay, the tallest plant as well as the highest shoot and root dry weights were observed at 5 tons $CaCO_3$/ha (Table 3). The increments over the control were 43%, 90% and 152%, respectively for the height, shoot and root dry weights. Lime rate higher than five tons per hectare definitely resulted in reduced growth indicating a new nutritional problem.

The addition of Zn to lime rates that cause yield reductions resulted in improved plant growth. For example, at 7 tons lime, the complementary addition of zinc significantly improved the height and shoot growth over the five tons lime alone. However, at the same amount of zinc and the lime was increased to 9 tons, height, shoot and root growth decreased slightly as a result of lowering the availability of zinc. Addition of boron of lime-Zn treatments had no significant effects on corn growth.

The relationship between lime rate and the relative shoot dry weights on Antipolo sandy clay indicated that maximum yields were obtainable at 5.3 tons $CaCO_3$/ha (Fig. 1). The favorable effects of added Zn where lime are excessive are also shown in Figure 1.

On a Luisiana sandy clay the height, shoot and root growth were continuously increased up to 3 tons per hectare. Above this rate the plant growth diminished (Table 4). The optimum lime rate as indicated by maximum yield was 3.1 tons/ha (Fig. 2).

The addition of Zn to lime rates where yield diminished improved yields over the high lime rates alone. For example, the increase in height and yield with the addition of zinc to 5 tons lime were 24% and 38%, respectively. The favorable effects of zinc at high lime treatments are shown also in Figure 2. The addition of boron to the lime-zinc treatment had no further significant effect on the growth of the plants.

Deficiency Symptoms of Plants

Deficiency symptoms occurring on the corn grown at the highest lime rate were characterized by yellowing from the tips and edges of the lower leaves. Plants were stunted and had short nodes compared to the healthy plants. Krantz and Brown (1961) reported that this kind of symptoms in corn was due to the deficiency of zinc in plants. Typical deficiency symptoms of boron in plants were not shown and plant growth was only responsive to zinc application. Therefore, the deficiency symptoms and growth depression were due to the low zinc in the plant. Tissue analysis further showed that zinc concentration in plants grown at high lime rate was within the deficiency range which was less than 15 ppm.

Changes in Some Soil Chemical Properties and Nutrient Concentration with the Application of Lime, Zinc and Boron on Antipolo Sandy Clay

There was a gradual increase in pH up to 6.45 as lime rate was increased to 9 tons/ha (Table 5). The relationship is described by the equation $y = 4.68 + 0.25x$; $r = 0.96^{**}$. The increase in pH even on soil receiving complementary zinc and boron applications was primarily controlled by the lime rates. The relationship between pH and relative dry matter rates would indicate an optimum pH of 5.35 (Fig. 3).

Exchangeable Ca was increased to 7.73 meq/100 g with 9.0 tons lime but the lime treatment producing the highest yield had 6.1 meq/100 g. At this rate there was an increase of 0.49 meq Ca per ton of lime applied (Table 5).

Exchangeable zinc was reduced significantly with increasing lime rates. At the optimum lime rate and pH level, exchangeable zinc was 4.6 ppm. Where lime was applied at 7 and 9 tons, it declined to 4.1 and 2.8 ppm, respectively (Table 5). Zinc deficiency symptoms were observed at the 9 tons lime rate as mentioned earlier.

Adding zinc to soils limed at 7 tons restored the zinc level to 5.38 ppm, but if this zinc treated soils is limed with 9 tons, exchangeable zinc is reduced again to 4.02 ppm confirming the adverse effect of high lime. Therefore, if a higher pH is required by crops on such lime soil, higher rate of zinc application would be necessary.

Soluble boron likewise decreased to 1.36 and 1.01 ppm with liming up to 7 and 9 tons/ha, respectively. At the treatment producing highest dry matter yield, there was 1.5 ppm boron. Boron application to soils limed at 7 tons increased the level to 1.82 ppm. The amount of soluble boron was lower where 9 tons lime was applied (Table 5).

The increase in exchangeable Ca was reflected in the significant increase in percentage Ca of the tissues. At the treatment producing the highest growth, Ca concentration was 0.37% (Table 5).

The serious problem affecting growth as lime was increased beyond 5 tons/ha was the reduction in zinc concentration. At 7 and 9 tons lime, zinc concentration was 18.6 ppm and 12.65 ppm, respectively. Zinc application at this lime rates increased the zinc concentration to 30.3 and 24.3 ppm, respectively. These were even above the zinc concentration of plants producing the highest yield.

Boron concentration in the tissues also decreased to as low as 3.94 ppm with high lime application. The plants producing the highest yield contained 8.01 ppm B. Boron fertilization on limed soil increased tissue boron to as much as 14.75 ppm.

The relationship of relative dry matter yield with pH, Zn and concentration of zinc can be used to establish the critical levels for these nutrients on Antipolo clay and in the corn plants. At 94% yield the optimum levels are pH 5.35, 4.0 ppm Zn and 18.5 ppm Zn in the tissue (Figs. 3, 4 and 5).

Influence of Lime, Zinc and Boron Applications on Soil pH and Amounts of Calcium, Zinc and Boron on Luisiana Sandy Clay and in Corn Plants

Soil pH increased from 4.75 to 6.51 as lime rate increased to 5 tons/ha (Table 6). The rate producing the highest yield had a pH of 5.3. Beyond this level yield decreased. The relationship between soil pH and lime rate is described by the equation $y = 4.43 + 4.10x$ ($r = .95^*$).

Concomitant with the increase in lime rate, exchangeable Ca significantly increased from 3.29 to 7.92 meq/100 g giving an increase of 0.9 meq Ca per ton lime. The initial level of Ca however was not considered inadequate as a growth factor in this soil.

Exchangeable zinc decreased from 3.95 to 1.86 ppm as the soil was limed to 5 tons/ha. At this rate, nutrient deficiency symptoms were observed. As pointed out earlier, since the poor growth at this lime rate was corrected or improved by zinc application, the nutritional problem was attributed to zinc deficiency rather than to boron deficiency. The treatment producing the highest dry matter yield had 3.5 ppm zinc. As a first approximation, this can be set as an adequate level considering the small variations in exchangeable zinc produced by liming.

On soils receiving five tons lime, zinc fertilization improved the exchangeable zinc to 3.45 ppm which was close to the adequate level indicated.

Soluble boron likewise decreased from 1.47 to 0.78 as the lime rate increased to 5 tons/ha. The limed soil producing the highest yield contained 1.38 ppm soluble boron. While soluble boron decreased, it was observed previously that the addition of boron had no significant effect on plant growth indicating the supply was still adequate in the limed soil. To restore the soluble boron to a higher level on limed soil, boron fertilization was necessary.

Boron fertilization increased soluble B to 1.6 ppm, which was above the critical level (Table 6).

The gradual improvement in Ca concentration of plants was obviously related to the increase in exchangeable Ca upon liming. However, since the initial soil supply was already adequate, the improvement did not have a strong influence on corn growth.

The decline of exchangeable zinc and soluble boron with liming was reflected in the diminishing concentration in the corn tissues. The concentrations decreased from 25.13 ppm to 11.85 ppm for zinc and from 8.40 ppm to 3.02 ppm for B. It may be emphasized also that deficiency symptoms were observed where the concentration was 11.8 ppm Zn. On soils limed to high pH, zinc and boron fertilization increased the concentrations to 22.12 ppm and 7.35 ppm, respectively (Table 6). These were above the critical levels. Thus, the attainment of high yields on red-yellow soils that are limed to maintain moderate to slightly acidic conditions would require the addition of zinc.

The relationship of relative dry matter yield with pH, exchangeable zinc and concentration of zinc would indicate the following optimal levels at 94% yield: pH 5.32, 3.0 ppm exchangeable Zn, 17.5 ppm Zn in the tissue (Figs. 6, 7 and 8).

Relationship of pH with Exchangeable Zinc and Soluble Boron

Exchangeable zinc decreased rapidly from 5.58 to 2.78 ppm on Antipolo sandy clay and from 3.95 to 1.86 ppm on Luisiana sandy clay as pH increased from 4.7 to 6.5 (Fig. 9). The decline was abrupt above pH 6.2. The overall decrease in exchangeable zinc was 46% or 1.0 ppm per unit pH increase. The significant negative relationship in both soils can be described by the following equations (Table 7):

= 7.8 - 0.79x in Luisiana sandy clay

= 10.54 - 1.07x in Antipolo sandy clay

The decline in soluble boron was slow and slight as the pH was increased to 6.5. For both soils soluble B declined from 1.56 pm to 0.90 ppm at the higher pH. The lower level was considered close to the critical level of boron in soils. The significant negative relationship are described by the equations given in Table 7.

Relationship of Zinc and Boron Concentration with Increase in pH Upon Liming

The concentration of zinc in corn tissues declined abruptly as the pH increased with liming (Fig. 10). The decrease on both soils was from 25.3 ppm to 12.25 ppm. At the lower level of zinc, deficiency symptoms were observed. The negative relationship may be described by the equations given in Table 8.

The same pattern may be observed for tissue boron as the concentration decreased significantly with an increase in pH. The soluble boron decreased from an initial level of 12.92 ppm on Antipolo soil and 8.4 ppm on Luisiana soil to lower levels of 3.94 ppm and 3.02 ppm, respectively, as the pH of both soils were increased by liming (Fig. 10).

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Table 1. Soil properties and methods of determination.

Soil Property	Method of Analysis	Reference
Soil pH	Potentiometric (soil:water, and soil:1N KCl, 1:1 ratios in both methods)	Jackson (1968)
Exch. Ca	1N NH_4OAc extraction buffered at pH 7 and versenate titration	Cheng and Bray (1951)
Boron	0.05 N HCl extraction and simplified curcumin procedure	Dible, *et al.* (1954)
Zinc	0.1 N HCl extraction and atomic adsorption spectrophotometry	Black (1965)

Table 2. Methods of determination of selected nutrient elements in the plant tissues.

Element	Method of Analysis	Reference
Ca	Dry ashing and versenate titration	Jackson (1965)
Boron	0.05 N HCl extraction and simplified curcumin procedure	Dible, *et al.* (1954)
Zinc	Dry ashing and atomic adsorption spectrophotometry	Jackson (1965) and Perkin Elmer Instruction Manual (1968)

Table 3. Effect of lime, Zn and B on plant height, shoot and root dry weights of corn grown on Antipolo sandy clay oil.

Treatment[1] (per ha)	Plant Height (cm)	Shoot Dry Weight (g/pot)	Root Dry Weight (g/pot)
0.0 Ton lime	73.67 f	13.36 f	7.32 e
1.0 Ton lime	96.83 d	17.78 def	10.36 de
2.0 Tons lime	97.67 cd	19.16 cde	10.92 cde
3.0 Tons lime	102.00 abcd	21.11 bcd	13.13 cd
5.0 Tons lime	105.00 ab	25.38 a	18.46 b
7.0 Tons lime	100.00 bcd	18.39 de	15.00 bcd
9.0 Tons lime	81.33 e	14.93 f	8.997 e
5.0 Tons lime + 9 kg Zn	107.50 a	26.19 a	19.87 ab
7.0 Tons lime + 8 kg Zn	106.00 a	21.97 bc	15.51 bcd
9.0 Tons lime + 8 kg Zn	102.70 abcd	21.06 bcd	16.04 bc
5.0 Tons lime + 8 kg Zn + 3.75 kg B	104.70 ab	23.92 ab	23.64 a
7.0 Tons lime + 8 kg Zn + 3.75 kg B	103.7 abc	20.76 bcd	15.73 bc
9.0 Tons lime + 8 kg Zn + 3.75 kg B	102.7 abcd	20.43 cd	15.18 bcd
Treatment	*	*	*
CV (%)	8.49	8.50	18.50

[1]Blanket application of 240-480-320 kg N-P_2O_5-K_2O/2 x 10^6 kg soil.

Means in a column followed by the same letters are not significantly different at 5% probability level.

* - Significant at 5% level.

Table 4. Effect of lime, Zn and B on plant height, shoot and root dry weights of corn grown on Luisiana sandy clay soil.

Treatment[1] (per ha)	Plant Height (cm)	Shoot Dry Weight (g/pot)	Root Dry Weight (g/pot)
0.0 Ton lime	100.0 d	24.16 d	7.62 a
0.75 Ton lime	116.0 cd	32.53 ab	10.58 c
1.5 Tons lime	121.7 abc	42.50 ab	10.74 c
3.0 Tons lime	128.0 a	60.55 ab	17.84 ab
4.0 Tons lime	121.2 abc	48.25 ab	9.89 c
5.0 Tons lime	94.0 e	38.31 c	2.98 d
3.0 Tons lime + 8 kg Zn	128.5 a	62.07 ab	18.82 a
4.0 Tons lime + 8 kg Zn	123.5 abc	54.51 ab	11.12 bc
5.0 Tons lime + 8 kg Zn	116.7 cd	53.03 ab	9.99 c
3.0 Tons lime + 8 kg Zn + 3.75 kg B	127.3 abc	64.27 a	16.78 ab
4.0 Tons lime + 8 kg Zn + 3.75 kg B	122.7 abc	55.76 ab	14.02 bc
5.0 Tons lime + 8 kg Zn + 3.75 kg B	121.0 abc	53.00 ab	10.16 c
Treatment	*	*	*
CV (%)	5.05	19.5	26.25

[1]Blanket application of 240-480-320 kg N-P_2O_5-K_2O/2 x 10^6 kg soil.

Means in a column followed by the same letters are not significantly different at 5% probability level.

* - Significant at 5% level.

Table 5. Effects of addition of lime, Zn and B on soil chemical properties and tissue Ca, Zn and B concentration in corn grown on Antipolo sandy clay.

Treatment (per ha)	pH (H^2O) (1:1)	Exch. Ca (meq/100g)	Exch. Zinc (ppm)	Soluble Boron (ppm)	Tissue Concentration Ca (%)	Zn (ppm)	B (ppm)
0.0 Ton lime	4.67 f	3.64 e	5.58 cd	1.64 c	0.32 f	25.40 b	12.92 b
1.0 Ton lime	4.93 e	4.02 e	5.28 def	1.62 cd	0.32 f	24.10 b	11.52 c
2.0 Tons lime	5.04 e	4.90 d	5.01 fg	1.57 cde	0.32 f	23.95 b	10.78 c
3.0 Tons lime	5.20 d	5.07 d	4.82 gh	1.53 de	0.37 de	22.62 b	9.25 d
5.0 Tons lime	5.32 c	6.10 c	4.61 h	1.50 c	0.37 de	21.36 bc	8.01 ef
7.0 Tons lime	6.20 b	6.79 b	4.08 i	1.36 f	0.40 c	18.60 c	6.75 g
9.0 Tons lime	6.45 a	7.73 a	2.78 j	1.01 h	0.51 a	12.65 d	3.94 h
5.0 Tons lime + 8 kg Zn	5.34 c	6.05 c	6.70 a	1.56 cde	0.36 e	32.50 a	8.75 de
7.0 Tons lime + 8 kg Zn	6.28 b	7.13 b	5.38 cde	1.32 f	0.39 cd	30.30 a	7.21 fg
9.0 Tons lime + 8 kg Zn	6.55 a	7.82 a	4.02 h	1.12 g	0.40 c	24.30 b	4.02 h
5.0 Tons lime + 8 kg Zn + 3.75 kg B	5.38 c	6.05 c	6.31 b	2.01 a	0.37 de	32.15 a	14.75 a
7.0 Tons lime + 8 kg Zn + 3.75 kg B	6.26 b	7.02 b	5.66 c	1.82 b	0.38 cde	29.16 a	12.92 b
9.0 Tons lime + 8 kg Zn + 3.75 kg B	6.50 a	8.16 a	4.78 gh	1.73 b	0.43 b	23.30 b	10.92 c
Treatment	**	**	**	*	**	*	*
CV (%)	6.36	4.46	6.02	8.34	5.88	8.73	6.3

Means in a column followed by the same letters are not significantly different at the 5% probability level.

** - Significant at 1% level
* - Significant at 5% level

Table 6. Effect of lime, Zn and B on soil chemical properties and concentration of Ca, Zn and B in corn grown on Luisiana sandy clay.

Treatment (per ha)	pH (H^2O) (1:1)	Exch. Ca (meq/100g)	Exch. Zinc (ppm)	Soluble Boron (ppm)	Tissue Concentration Ca (%)	Tissue Concentration Zn (ppm)	Tissue Concentration B (ppm)
0.0 Ton lime	4.75 d	3.29 g	3.95 c	1.47 bc	0.32 f	25.13 bc	8.40 b
0.75 Ton lime	4.89 d	4.91 f	3.88 c	1.44 bcd	0.40 e	23.95 d	7.82 c
1.50 Tons lime	5.22 c	5.96 e	3.62 d	1.41 cd	0.42 de	22.36 e	7.08 d
3.0 Tons lime	5.30 c	7.63 cd	3.48 def	1.38 cde	0.47 c	21.32 e	6.68 e
4.0 Tons lime	6.18 b	7.86 bcd	3.25 h	1.08 efg	0.48 bc	19.10 f	4.93 g
5.0 Tons lime	6.51 a	7.92 bc	1.86 i	0.78 h	0.55 a	11.85 g	3.02 i
3.0 Tons lime + 8 kg Zn	5.34 c	7.53 d	4.58 a	1.27 def	0.42 d	28.31 a	6.25 f
4.0 Tons lime + 8 kg Zn	6.21 b	8.13 ab	4.00 bc	1.10 ef	0.43 d	24.62 cd	4.76 g
5.0 Tons lime + 8 kg Zn	6.54 a	8.21 ab	3.45 def	0.82 h	0.47 c	18.52 f	3.85 h
3.0 Tons lime + 8 kg Zn + 3.75 kg B	5.33 c	7.66 cd	4.60 a	1.90 a	0.42 d	29.01 a	8.78 a
4.0 Tons lime + 8 kg Zn + 3.75 kg B	6.15 b	8.13 ab	4.12 b	1.74 ab	0.46 c	26.35 b	8.02 c
5.0 Tons lime + 8 kg Zn + 3.75 kg B	6.53 a	8.49 a	3.53 de	1.62 ab	0.51 b	22.12 e	7.35 d
Treatment	**	**	*	*	**	*	*
CV (%)	5.93	6.71	6.38	14.5	4.80	6.17	6.85

Means in a column followed by the same letters are not significantly different at the 5% probability level.

** - Significant at 1% level
 * - Significant at 5% level

Table 7. Equations for the relation of pH with exchangeable zinc and soluble boron in two acid soils.

Parameters Related	Regression Equation	Regression Coefficient (r)
Antipolo Sandy Clay		
pH and exchangeable Zn	$\hat{y} = 10.54 - 1.07\ x$	-0.86**
pH and soluble B	$\hat{y} = 2.85 - 0.25\ x$	-0.82**
Luisiana Sandy Clay		
pH and exchangeable Zn	$\hat{y} = 7.8 - 0.796\ x$	-0.92**
pH and soluble B	$\hat{y} = 2.92 - 0.296\ x$	-0.97**

**Significant at 1% level by F-test

Table 8. Equations for the relation of pH with zinc and boron concentration of corn grown on two acid soils.

Parameters Related	Regression Equation	Regression Coefficient (r)
Antipolo Sandy Clay		
pH and exchangeable Zn	$\hat{y} = 49.39 - 5.10\ x$	-0.97**
pH and soluble B	$\hat{y} = 23.53 - 2.43\ x$	-0.59**
Luisiana Sandy Clay		
pH and exchangeable Zn	$\hat{y} = 49.9 - 5.22\ x$	-0.96**
pH and soluble B	$\hat{y} = 15.28 - 14.96\ x$	-0.67**

**Significant at 1% level by F-test

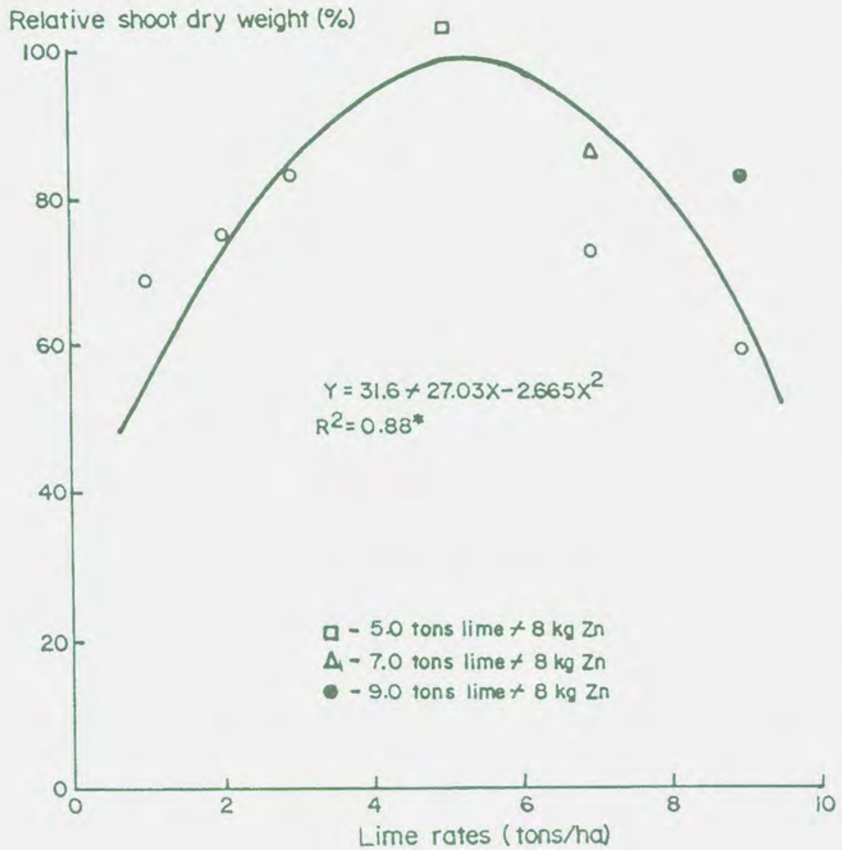

Figure 1. Relation between lime rates and relative shoot dry weight of corn grown on Antipolo sandy clay.

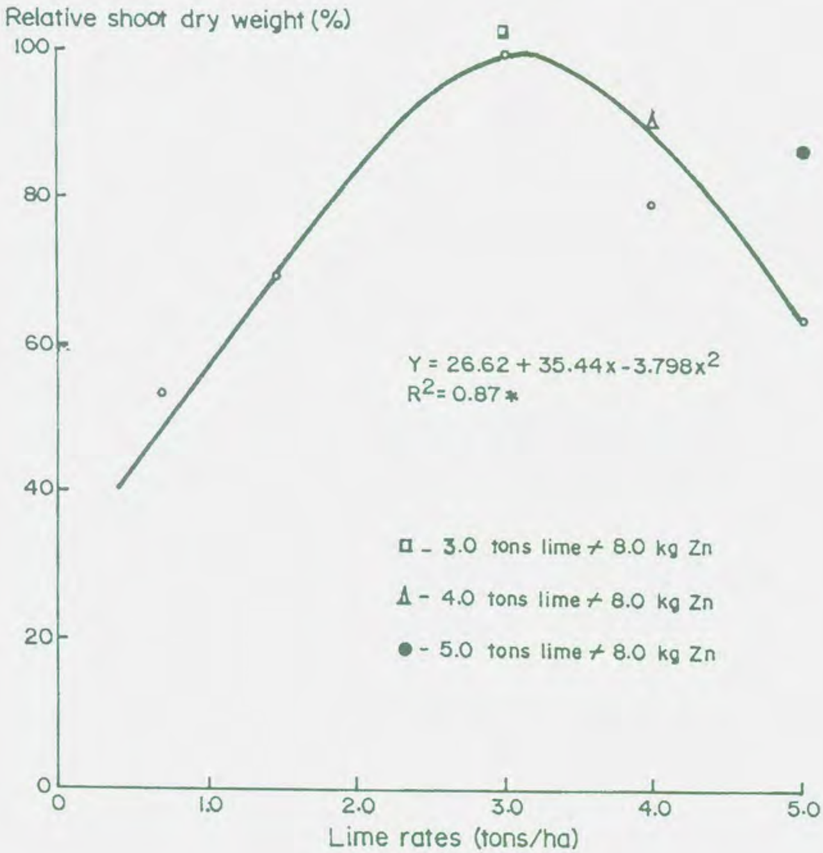

Figure 2. Relation between lime rates and relative shoot dry weight of corn grown on Luisiana sandy clay.

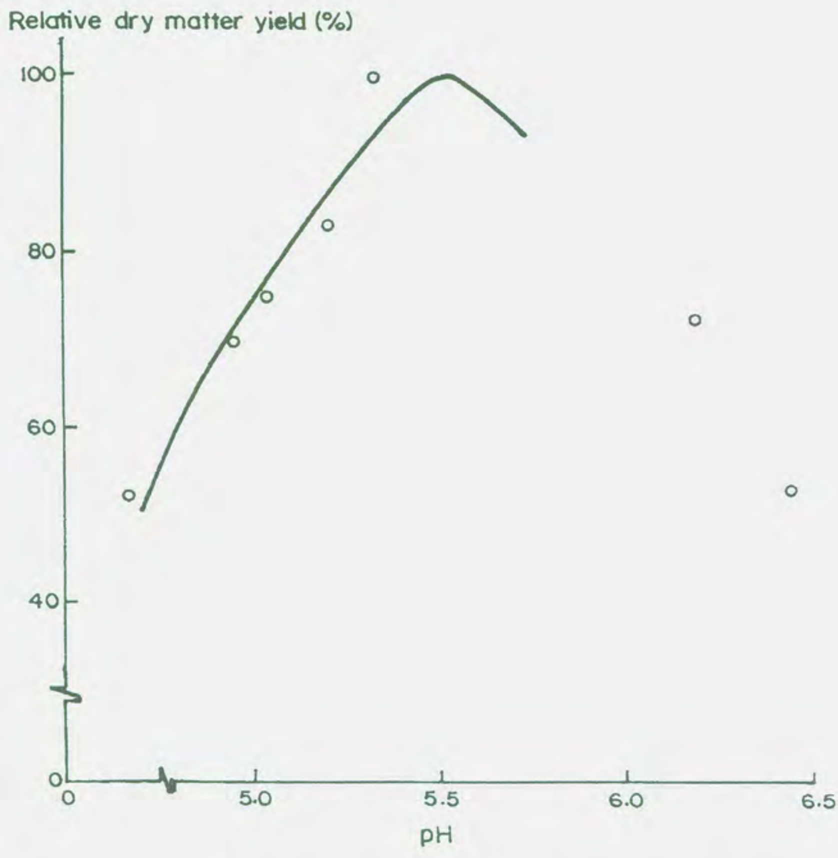

Figure 3. Relation between relative dry matter yield of corn and pH (H_2O) of Antipolo sandy clay upon liming.

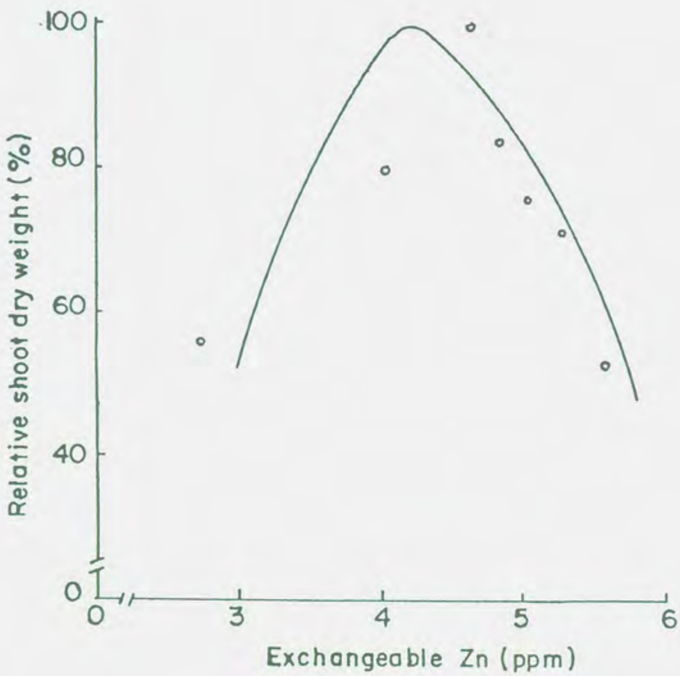

Figure 4. Relationship between relative shoot dry weight of corn and exchangeable Zn (ppm) of Antipolo sandy clay upon liming.

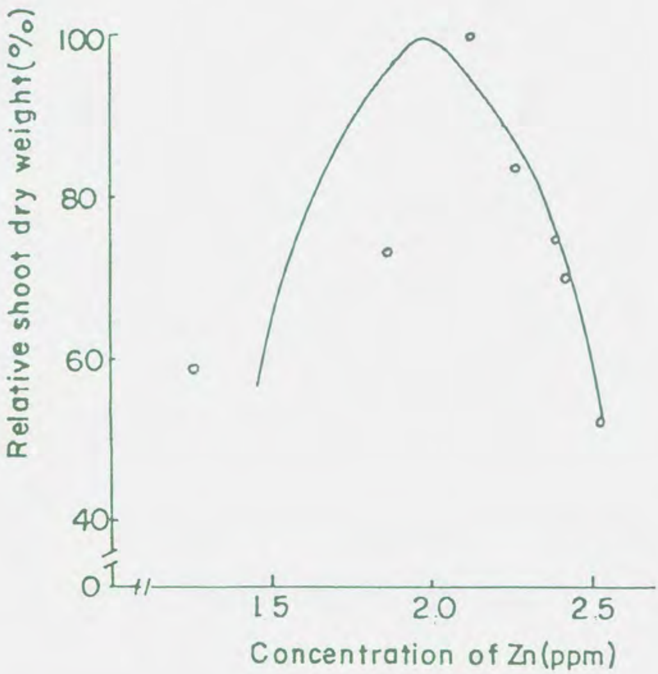

Figure 5. Relationship between relative shoot dry weight and concentration of Zn (ppm) in corn grown on Antipolo sandy clay.

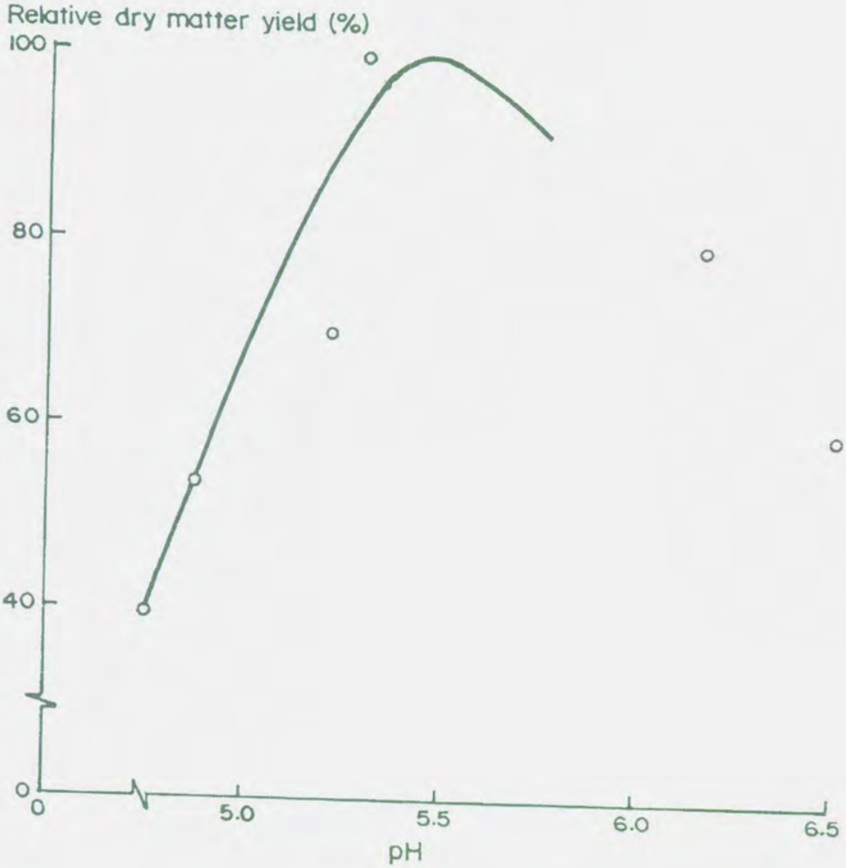

Figure 6. Relation between relative dry matter yield and soil pH (H_2O) of Luisiana sandy clay upon liming.

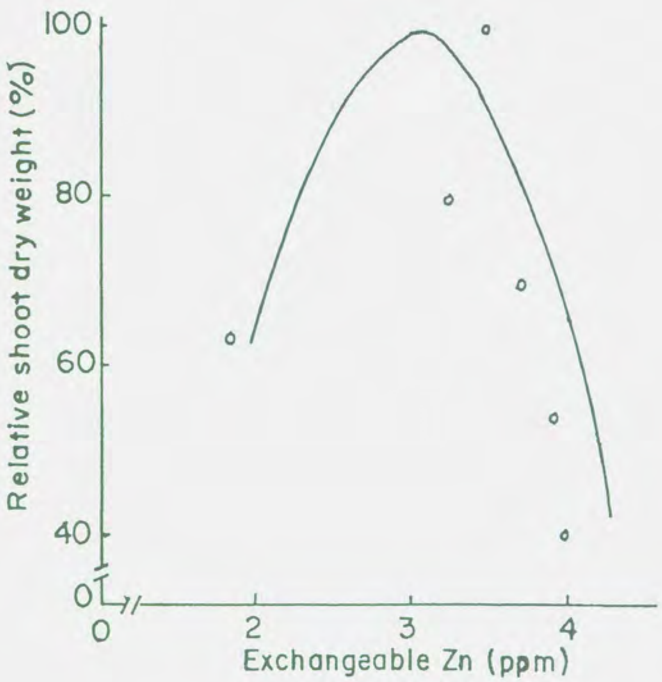

Figure 7. Relationship between relative shoot dry weight and exchangeable Zn (ppm) of Luisiana sandy clay.

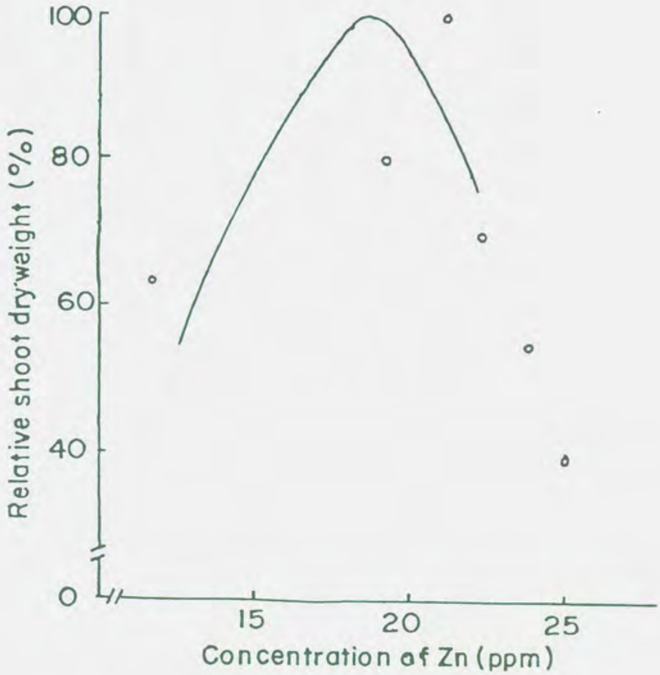

Figure 8. Relationship between relative shoot dry weight and concentration of Zn in tissue of corn grown on Luisiana sandy clay.

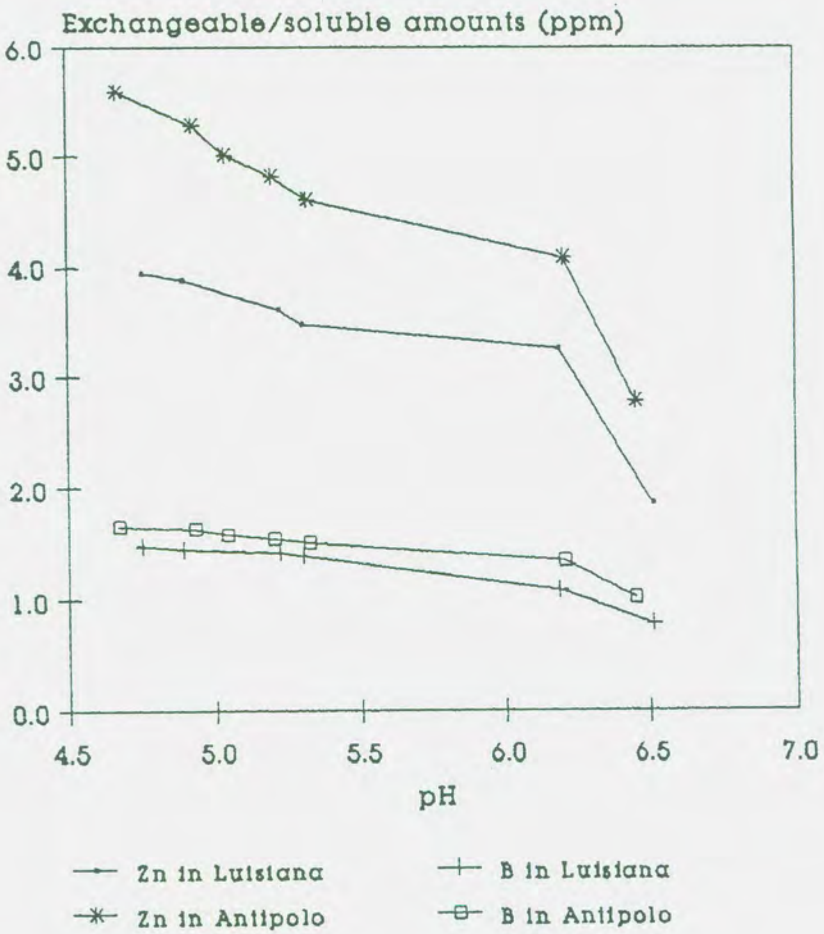

Figure 9. Soil exchangeable Zn and acid soluble B of Antipolo and Luisiana sandy clay soils as affected by soil pH.

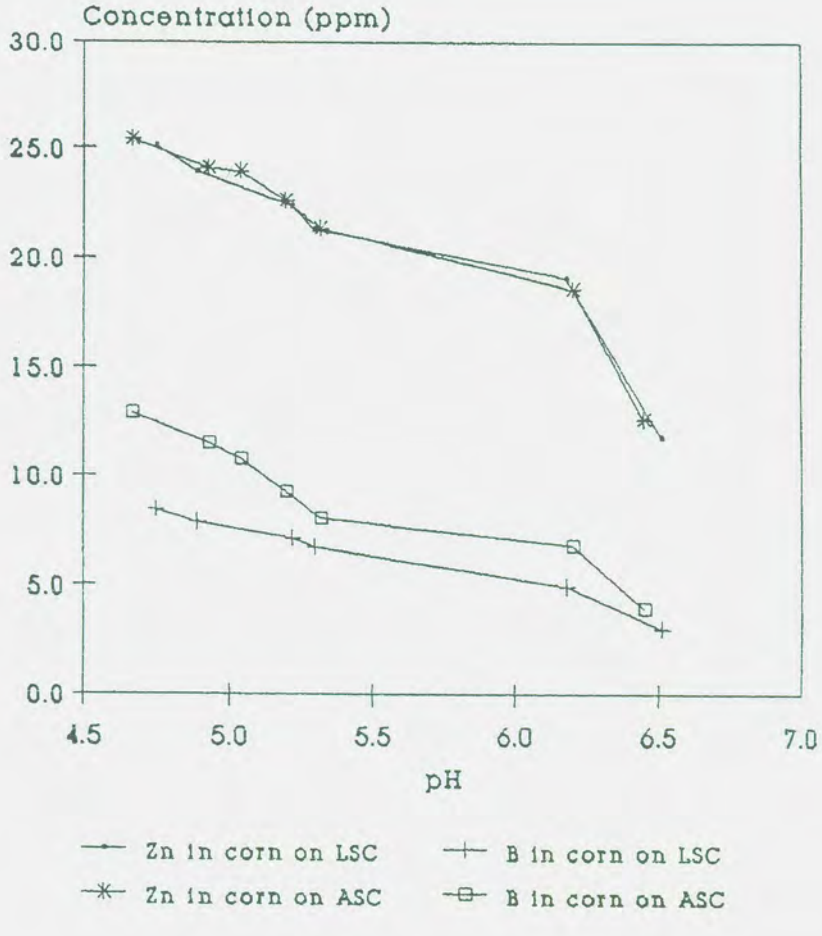

Figure 10. Shoot tissue Zn and B of corn grown on Antipolo and Luisiana sandy clay soils as affected by soil pH. (LSC = Luisiana sandy clay, ASC = Antipolo sandy clay).