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EFFECT OF PLANT HORMONES ON THE GROWTH AND NUTRIENT UPTAKE OF MAIZE IN ACIDIC SOILS OF THE HUMID TROPICS

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ABSTRACT: An experiment was conducted in a greenhouse to investigate the availability of phosphate fertiliser in acidic soils, and to evaluate the effects of phosphorous and synthetic plant hormones on yield and nutrient uptake of maize (cv. Golda FAO-240). The soil was limed with 1.05 g of $Ca(OH)_2$ and 12.2 g of $CaSO_4.2H_2O$ 1.7 kg^{-1} soil according to Jensen Curve. Phosphorus was applied as Mono-ammonium dihydrogen phosphate at the rate of 0, 26 and 52 mg P 1.7 kg^{-1} soil by placed application using neutral compost as a buffering material. Benzyladenine (BA) and gibberellin (GA) were applied as exogenous plant hormones. Nitrogen, K, Mg, Cu, Mn, Zn, B and Mo were applied uniformly to all pots. In treatments that received P fertiliser without BA the dry matter yield and P uptake by plants were higher by 15.9 and 19.5%, respectively, compared to the results of P with BA. Similarly, in treatments that received P fertiliser without GA the dry matter yield and P uptake by plants were higher by 9 and 15.4%, respectively.

Key words/phrases: Acidic soils, exogenous plant hormones, liming, neutral compost, placed application

INTRODUCTION

Besides genetic and climatic factors, the growth and yield of crops are mainly determined by the amount of nutrients available in the soil (Jungk and Rademacher, 1983). The vast area of tropical soils of the humid tropics are acidic. A number of studies have shown that high proportions of soils which belong to the great soil groups of Oxisols and Ultisols have a marked ability to fix applied inorganic P, and usually have low extractable P (Sanchez and Salinas, 1981). Higher soil acidity is associated with increases in precipitation, leaching, weathering, hydrolysis, organic matter, nitrification, fertiliser application, oxidation of sulphides, uptake of ions, and more (Adams, 1984).

Phosphate can readily be rendered unavailable to plant roots because it is the most immobile of the major plant nutrients and whose efficiency can be affected by P fertiliser distribution and distance of application from the plant (Eghball and Sander, 1989). The quantity of P in soil solution is in the range of 0.3 to 3 kg P_2O_5 ha^{-1} as growing crops absorb about 1 kg P_2O_5 ha^{-1} per day. The labile fraction in the topsoil layer of 20 cm is in the range of 150 to 500 kg P_2O_5 ha^{-1}, which could replenish soil solution P (Mengel and Kirby, 1996). The phosphate concentrations of the soil solution and its buffering capacity are the most important parameters governing the P supply to plant roots. Thus, the rate of desorption is higher in soils with a higher phosphate buffer capacity (Dear *et al*., 1992). The consideration of significant varietal and species differences in tolerating low available P_2O_5 and low pH effect is also important. At similar yield levels, upland rice usually requires less P than maize. The general recommendation for these crops, in acidic soils, ranges from 100 to 150 kg P_2O_5 ha^{-1} for maize and 0 to 60 kg ha^{-1} for upland rice (Sanchez, 1976).

The low productivity and yields of crops, in acidic soils, can mainly be attributed either to the deficiency of nutrients such as P, Ca and Mg or to low pH and toxicity of Al, Fe and Mn (Soon, 1991; Marschner, 1995). Consequently, the application of lime to acid soils can displace P_2O_5 from precipitates of Al and Fe-phosphate, making the exchange sites more active through the improvement in physico-chemical properties of such soils and culminates in the replenishment of Ca and Mg (Sommer, 1979; Crizaldo, 1981). The first observable effect of Al on plants is a limitation in root growth. Root tips and lateral roots become thickened and turn brown and the uptake and translocation of P to the upper plant parts are affected. The toxicity in the tops is often characterised by symptoms similar to those of phosphate. In the plant Al may interfere with the P metabolism by the formation of stable Al-phosphate complexes (Sommer, 1979; Marschner, 1995).

Plant growth regulators make plants use nutrients more efficiently by exploiting their genetic and physiological potentials on a higher level (Jungk and Rademacher, 1983). Plant hormones are able to influence growth and differentiation in plants without having a nutritive character. By promoting, inhibiting or modifying the physiological processes of plants, results might be gained which directly or indirectly lead to higher yields (Koter *et al*., 1983). Caldiz *et al*. (1991) found that foliar application of N and benzyladenine (BA) on wheat delayed chlorophyll loss and increased grain protein but not yield. Similarly, the application of Gibberellins (GAs) has remarkable effects on the elongation of primary stalk, on the growth of dwarf plants and development of side branches (Nickell, 1983; Ross *et al*., 1993). This effect occurs in the young tissues and growth centres and is caused by an increase in the rate of cell division (Nickell, 1983). Therefore, the objectives of this study were to optimise the availability of phosphate fertiliser using buffering material and plant hormones for acidic and P deficient soils, and to investigate the effect of exogenous plant growth regulators on the relative dry matter yield and nutrient uptake of maize.

MATERIALS AND METHODS

Greenhouse experiment

An experiment was conducted in a greenhouse at the Institute of Agricultural Chemistry, University of Bonn, Germany to study the response of maize *Zea mays* L. (cv. Golda FAO-240) to phosphorus fertiliser and plant hormones on acidic soils of Liberia. The temperature of the growing room was kept constant at 20°C. Sub-samples of 1.7 kg of air dried soil, screened through a 4 mm sieve, were placed into plastic pots of 18 and 10 cm upper and lower diameter size, respectively. Each pot was watered to 70% water holding capacity of the soil. The treatments included 7 structurally selected combinations of 3 levels of phosphorus (0, 26 and 52 mg P 1.7 kg^{-1} soil) in the form of Mono-ammonium dihydrogen phosphate ($NH_4H_2PO_4$) with 1 mg benzyladenine (BA) and 2 mg gibbberellin (GA) applied as depot 10 cm deep in the soil after mixing with 10 g neutral compost. The experiment was laid out in completely randomised design with four replications. The pH of the experimental soil was 5.0 in the 0.05 M K_2SO_4 which was attained by liming before planting on the basis of 200 mg exchangeable Ca 100 g^{-1} soil by adding 1.05 g $Ca(OH)_2$ and 12.2 g $CaSO_4 \times 2H_2O$ 1.7 kg^{-1} soil according to Jensen curve.

Nitrogen (N), potassium (K) and magnesium (Mg) were applied uniformly to all pots in two split applications, *i.e.*, 0.200 g N 1.7 kg^{-1} soil at planting in the form of $CO(NH_2)_2$ and ammonium from $NH_4H_2PO_4$ and 0.200 g N 1.7 kg^{-1} soil 3 weeks after planting as $Ca(NO_3)_2$. Likewise, 0.249 g K and 0.09 g Mg 1.7 kg^{-1} soil were applied at planting as K_2SO_4 and $MgSO_4 \times 7H_2O$, respectively, and 0.166 g K and 0.06 g Mg 1.7 kg^{-1} soil in the same form 3 weeks after planting (Table 1). The required micronutrient elements, namely copper (Cu), manganese (Mn), zinc (Zn), boron (B) and molybdenum (Mo), were also applied uniformly to all pots after mixing 3 ml of the original solution from each element. Fifteen ml per pot was applied from the mixture prepared in the proportion of 7.21 g $CuSO_4.5H_2O$, 24.60 g $MnSO_4.H_2O$, 35.19 g $ZnSO_4$, 11.43 g H_3BO_3 and 3.68 g $(NH_4)_6Mo_7O_{24}.4H_2O$ each in 2000 ml water. Eight seeds were sown in each pot at a depth of 2.5 cm. The date of emergence, in which 50% of the seedlings appeared above the surface of soil and plant height scores as the mean of 4 randomly selected plants from each pot were recorded just prior to harvesting. Fifty-five days after planting the aboveground portion of each plant was harvested, and the dry weight was recorded.

Table 1. Plant nutrients applied as elemental and fertiliser form.

Nutrient elements*	Amount (g pot^{-1})	Fertiliser form	Amount (g pot^{-1})
P	0.026	$NH_4H_2PO_4$	0.0972
P	0.052	$NH_4H_2PO_4$	0.194
N	0.194	$CO(NH_2)_2$	0.416
N	0.188	$CO(NH_2)_2$	0.404
K	0.249	K_2SO_4	0.560
Mg	0.090	$MgSO_4.7H_2O$	0.920
Ca	0.565	$Ca(OH)_2$	1.05
Ca	2.840	$CaSO_4.2H_2O$	12.20
N	0.200	$Ca(NO_3)_2.7H2O$	1.686
K	0.166	K_2SO_4	0.38
Mg	0.060	$MgSO_4.7H_2O$	0.61

*15 ml pot^{-1} mixture of micronutrient elements were added.

Plant and soil analysis

After harvesting, the plant materials were dried in an oven at 70ºC to 95ºC up to a constant weight. Oven dried samples were ground to pass a 1 mm sieve for macronutrient analysis. One gram of finely ground sub-samples were ashed at 550ºC for 4 hours in a muffle furnace. After dry oxidation, the samples were treated with concentrated NH_4NO_3, evaporated to dryness at 100ºC and placed back carefully in the muffle furnace at 550°C for 2 hours. After cooling, the samples were boiled by adding 5 ml HCl and transferred to a 100 ml measuring flask. Then, the samples were filled up to 100 ml with distilled water, mixed thoroughly and filtered with ash free filter paper. The aliquots from this were used for the determination of P, K, and Mg after suitable dilution. Then, phosphorus was determined colorimetrically following the ascorbic acid method (John, 1970). Potassium was determined by flame photometer and Mg by atomic absorption spectrophotometer. The total uptake of nutrients was calculated by multiplying the percent nutrient concentrations with dry matter yields on oven dried weight basis.

After harvesting the aboveground portions of plants at soil level, the roots were picked from the soil and samples of all soils were collected. Air dried soil samples were ground to pass through a 2 mm sieve and kept for analysis. The measurements of pH were conducted in H_2O, 0.01 M $CaCl_2$ and 0.1 N K_2SO_4 solutions with a liquid to solid ratio of 2.5:1 by using glass electrode. The concentrations of P and K in the soil were determined following CAL (Calcium Acetate Lactate) method (Schüller, 1969). Then, P and K were determined by colorimeter and flame photometer, respectively. Likewise, the concentration of Mg was determined according to Schachtschabel (1976) by using atomic absorption spectrophotometer. The concentrations of P and K 100 g^{-1} soil were evaluated by deducting the measured values of the checks from the samples.

Data analysis

The data were subjected to analysis of variance using the SAS statistical package version 8.2 (SAS Institute Inc., 1999–2001) and presented as means separated by the Duncan's Multiple-Range Test (DMRT). Coefficients of correlation and orthogonal contrasts were performed using the standard procedures from SAS programs at $P < 0.01$ probability level. To evaluate the effects of treatments on plant growth and nutrient uptake six single degrees of freedom (df) orthogonal contrasts were partitioned from seven structured treatments.

RESULTS AND DISCUSSION

Dry matter yield and nutrient uptake

The placement of phosphorous as mineral fertiliser with 10 g neutral compost at a depth of 10 cm in the soil resulted in a substantial increase in plant height and shoot dry matter yield (Table 2). The use of neutral compost to apply P-fertiliser reduces the absorption of phosphate thereby improves the root-fertiliser contact and optimises P availability to plants. Analysis of variance indicated that plant height, dry matter yield and uptake of nutrients by plants were significantly ($P < 0.01$) affected by phosphorus application but not by plant hormones. Plant height and shoot dry matter yields were higher by about 32 and 38%, respectively, due to P application than the control. However, a lower increase in plant height (19%) and dry matter yield (26%) occurred due to the treatment of both phosphorous and plant growth regulators as benzyladenine (BA) and gibberellin (GA) over the control as compared to only the same rate of P application. Similarly, Koter *et al.* (1983) reported that the application of kinetin on maize plants prolonged vegetative growth, which resulted in decreased grain yield. The investigation of Caldiz *et al.* (1991) also indicated that foliar application of BA and nitrogen on wheat plants delayed chlorophyll loss in the flag leaf but modified neither yield nor yield components. Benzyladennine (BA) increased only grain protein. Plant P-uptake efficiency from fertiliser increased when phosphate was applied as depot close to the plants, because this increased the contact between P and roots of plants at an early stage of growth. Higher plant P from fertiliser when P was applied close to plants as depot was due to the fact that the contact between roots and fertiliser increased at early stage of growth and as a result contact is maintained for a longer period of time. This agrees with the findings of Eghball and Sander (1989) which indicated the positive response of maize plants to placed application of phosphate fertiliser.

Table 2. Effects of phosphorous and plant hormones on plant height and total shoot dry matter yield of maize in acidic soils of the humid tropics.

No.	Treatment	Plant height (cm)	Dry matter (g)
1	Control (without P and plant hormone)	78.7c	5.3c
2	26 mg P	93.0b	6.1bc
3	52 mg P	104.0a	7.3a
4	26 mg P+1.0 mg benzyladenine (BA)	93.6b	6.3abc
5	52 mg P+1.0 mg benzyladenine (BA)	93.9b	6.3abc
6	26 mg P+2.0 mg Gibberellin (GA)	88.7b	5.6bc
7	52 mg P+2.0 mg Gibberellin (GA)	91.3b	6.7ab
SE		1.75	0.25
CV (%)		3.80	8.15

Means in a column with different letters are significantly different ($P < 0.01$)

It was anticipated that the application of 1 mg BA and 2 mg GA pot[-1] after emergence might increase biomass yield and shoot nutrient content, particularly of phosphorus. This is due to the fact that plant hormones make plants use nutrients more efficiently by exploiting their genetic and physiological potentials on a higher level (Jungk and Rademacher, 1983). However, analysis of variance indicated that total biological yield and nutrient uptake were significantly ($P < 0.01$) affected by P fertilisation but not by plant hormones, which were low compared to the results without an exogenous supply of these synthetic plant hormones (Table 3). The overall effect of treatments on plant growth and nutrient uptake was highly significant. Phosphorus rate was highly correlated ($r = 0.85^{**}$, 0.99^{**}, 0.98^{**} and 0.99^{**}) with shoot dry matter yield and P, K and Mg concentrations in the plant, respectively (Table 4). Phosphorus and plant hormone treated plants resulted in lower P uptake and concentration.

Partitioning of treatments into logical orthogonal contrasts showed that plant height and aboveground shoot dry matter yield were significantly ($P < 0.01$) affected by P application, but not P with BA and GA compared to P alone. The comparison also showed that there was no significant difference in the growth of plants between the two types of plant hormones when combined independently with phosphorous. Mean shoot dry matter yield was not significantly altered by the application of P with plant hormones. The highest plant height and total biological yield was obtained from the application of P (Table 5). Nevertheless, the uptakes and concentrations of P, K and Mg in the plant were significantly affected both by P fertilisation and P with plant hormone applications (Table 5). The investigation of Moskaleva and Polevoi (1985) showed that the addition of kinetin to the medium markedly increased the growth of maize coleoptile, while GA increased the growth of mesocotyl and leaf. Kinetin and GA increased the growth of both coleoptile and mesocotyl, but not leaf growth. Thus, they concluded that interaction of above and underground parts of the maize seedlings are accomplished by growth regulators produced by the aboveground parts (indole acetic acid) and the root (cytokinins and gibberellins).

Table 3. Effects of phosphorus and plant hormones on uptake and nutrient concentration in the shoot dry matter yield of maize.

Treatment	Nutrient concentration (%)			Nutrient uptake (mg)		
	P	K	Mg	P	K	Mg
Control	0.14	4.9	0.44	7.4f	257.2f	23.1e
26 mg P	0.18	4.9	0.46	10.9cd	295.9d	28.0b
52 mg P	0.19	5.1	0.46	13.5a	369.5a	33.4a
26 mg P + 1mg BA	0.16	5.2	0.44	10.0e	324.0b	27.4b
52 mg P + 1 mg BA	0.18	4.8	0.42	11.3bc	299.9d	26.5c
26 mg P + 1 mg GA	0.17	4.6	0.39	10.7d	286.8e	24.4d
52 mg P + 1 mg GA	0.18	4.8	0.41	11.7b	318.5c	27.5b
SE				0.10	1.27	0.14
CV(%)				1.81	0.83	0.99

Means in a column with different letters are significantly different ($P < 0.01$).

Table 4. Correlation coefficients (r) of plant height, shoot dry matter yield and nutrient uptake (P, K and Mg) of maize as affected by P-fertilisation.

Character	Plant height	Dry matter	Plant P	Plant K	Plant Mg
Phosphorus rate	0.86 **	0.85 **	0.99 **	0.98 **	0.99 **
Plant height		0.74 **	0.86 **	0.85 **	0.86 **
Dry matter			0.85 **	0.86 **	0.86 **
Plant P				0.96 **	0.99 **
Plant K					0.98 **

** Significant at $P < 0.01$.

A number of investigators have reported a high correlation between mineral nutrient status, particularly N and P, and endogenous levels of cytokinins in which the decrease in their levels is more in N-deficient plants than P-deficient ones (Kuiper and Staal, 1987; Thorsteinsson and Eliasson, 1990). The growth stimulating effects of exogenous applications of cytokinins to plants grown in N-deficient medium indicate that cytokinins mediate the plant response to changes in nutrient supply. The types of N-fertilisers, in particular, have also been reported to affect cytokinin levels (Sattelmacher and Marschner, 1978). In this study, urea was used as a source of N-fertiliser. Smicklas and Below (1992) have investigated the role of cytokinin in the enhanced productivity of maize supplied with NH_4^+ and NO_3^-. They have found that plants treated with ammonium and nitrate nitrogen without the addition of any plant hormone increased grain yield by 11% and whole shoot N content by 6% predominantly when compared with nitrate. On the other hand, cytokinin application to nitrate grown field plants increased grain yield to that of ammonium and nitrate grown plants. During vegetative growth, ammonium and nitrate treated plants had higher concentrations of endogenous cytokinins in root tips than nitrate grown plants (Smicklas and Below, 1992). Similarly, the study of Getachew Agegnehu and Sommer (2000) showed that the application of ammonium nitrate resulted in greater shoot dry matter yield and higher uptake of P, K and Mg as compared to urea regardless of rate and method of application. It is, therefore, suggested that endogenous cytokinin supply may be associated with the type and combination of N fertiliser supply. Thus, based on the results of this study, it is not possible to give a definitive inference about the role of these synthetic plant hormones, and further study should be carried out regarding the role of these plant growth regulators in order to obtain a definitive conclusion.

Nutrient concentration in the soil

The pH values observed in this study ranged between 6.5 and 7.2 (Table 6). The pH measurements in H_2O were between 6.6 and 7.2, while in $CaCl_2$ between 6.5 and 6.8 and in K_2SO_4 between 6.6 and 7.2. There was no significant difference ($P < 0.05$) among pH values measured in different media. The maximum pH value 7.2 was observed in experimental pots treated with 52 mg P as $NH_4H_2PO_4$ and BA and GA as synthetic plant hormones, whereas the minimum buffer area was pH 6.5 obtained from experimental pots treated only with 52 mg P of the same type of fertiliser. High pH values were observed, relatively, in plant hormone treated soils compared to those with only phosphate fertiliser treated ones. Greater total shoot dry matter yield and high nutrient content in the dry matter were obtained in the relatively lower pH values (pH < 6.6) in comparison with the minimum results obtained in the relatively higher pH values (pH > 6.6). Hence, it is evident from the results of this study that at different pH levels maize shoot dry matter yield dropped off progressively more with increased pH (pH > 6.6). Likewise, the study of Adams (1984) showed that liming soils, high in Fe and Al-oxides, to pH 6–6.5 increased the availability of added P fertiliser.

Table 5. Probabilities of variance ratios, and residual mean squares of single degrees of freedom orthogonal contrasts for P rate and P with plant hormones on growth and nutrient uptake of maize.

Contrast	Plant height	Dry matter	Plant nutrient uptake			Soil nutrient concentration		
			P	K	Mg	P	K	Mg
Control vs. P fertilised	**	**	**	**	**	**	**	**
26 mg P vs. 52 mg P	*	**	**	**	**	**	**	**
P fertilised vs. (P+BA) (P+GA)	*	NS	**	**	**	**	**	**
P fertilised vs. P + BA	NS	NS	**	**	**	**	**	**
P fertilised vs. P + GA	*	NS	**	**	**	**	**	**
P + BA vs. P + GA	NS	NS	**	**	**	**	**	**
Residual mean square (21df)	41.80	0.31	0.04	9.08	0.07	0.00	0.00	0.04

NS = Not significant; *, ** = Significant at $P < 0.05$ and $P < 0.01$ probability level, respectively.

Table 6. Soil pH and nutrient concentration in the soil as affected by phosphorus fertilisation and plant hormone application.

Treatment	pH Value			Nutrient concentration 100 g^{-1} soil (mg)		
	H_2O	0.01M$CaCl_2$	0.1N K_2SO_4	P	K	Mg
Control	6.6	6.5	6.6	0.97f	25.15a	9.83a
26 mg P	6.8	6.6	6.9	1.94e	20.92d	8.08d
52 mg P	6.6	6.5	6.6	2.82b	15.77f	8.50c
26 mg P + 1mg BA	6.7	6.6	6.8	2.24d	19.01e	8.50c
52 mg P + 1 mg BA	6.8	6.6	6.8	2.86a	22.08c	8.92b
26 mg P + 1 mg GA	7.1	6.8	7.2	1.94e	24.07b	9.65a
52 mg P + 1 mg GA	7.2	6.8	7.2	2.68c	22.24c	9.71a
SE				0.02	0.02	0.10
CV(%)				0.30	0.12	1.35

Means in a column with different letters are significantly different ($P < 0.01$).

After extraction, available soil phosphorus ranged from 0.97 mg in the control to 2.86 mg P 100 g^{-1} soil in soils treated with 52 mg P. It is apparent that significant yield increase was caused by the application of P fertiliser in the soils. The results of the investigation showed that an increased shoot dry matter yield, high nutrient uptake by plants and maximum P content in the dry matter were accompanied with lower nutrient concentrations in the soil. Orthogonal contrasts indicated that the levels of soil nutrient concentrations were significantly affected both by P and plant hormone applications (Table 5). The rate of application of K and Mg as mineral fertilisers was the same in all-experimental potted soils. However, the results indicated that relatively higher concentrations of soil K and Mg were observed in the control (25.15 mg K and 9.83 mg Mg 100 g^{-1} soil) and in plant hormone treated soils compared to the treatments that received only phosphate fertiliser. Hence, higher yield and nutrient uptake by plants were accompanied with lower nutrient concentrations in the soil.

CONCLUSION

The results of this study indicated that acidic-ferralitic soils of the humid tropics are deficient in available P for maize plants. The placement of 52 mg P 1.7 kg^{-1} soil with 10 g neutral compost as depot 10 cm deep in the soil in the form of Mono-ammonium dihydrogen phosphate ($NH_4H_2PO_4$) without an exogenous supply of synthetic plant hormones increased nutrient uptake and shoot dry matter yield of maize plants. The use of plant growth regulators as benzyladenine (BA) and gibberellin (GA) with the same phosphorous rate and method of application decreased plant height, shoot dry matter yield and nutrient uptake of maize plants. Therefore, this study needs further investigation to be confirmed in the future.

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REFERENCES

1. Adams, F. (1984). Crop response to lime in the Southern United States. Soil acidity and liming. **In:** *Adams, F. (ed.), Am. Soc. Agron.*, Madison.
2. Caldiz, D.O., Beltrano, J., Fernandez, V. and Favoretti, C. (1991). Effects of foliar applied benzyladenine on grain yield and grain protein in wheat. *Plant Growth Regulation*. **10**:197–204.
3. Crizaldo, L.V. (1981). Phosphate potential of acidic and limed soils and its relation to corn yield. Ph.D. Thesis, University of the Philippines at Los Banos, Laguna, Philippines.
4. Dear, B.S., Helyar, K.R, Muller, W.J. and Loveland, B. (1992). The phosphate fertiliser requirements of subterranean clover, and the soil P_2O_5 status, sorption and buffering capacities from two phosphate analyses. *Aust. J. Soil Res*. **30**:27–44.
5. Eghball, B. and Sander, D.H. (1989). Distance and distribution effects of phosphate fertiliser on corn. *Soil Sci. Soc. Am. J.* **53**:282–287.
6. Getachew Agegnehu and Sommer, K. (2000). Optimisation of the efficiency of phosphate fertilisers in acidic-ferralitic soils of the humid tropics. *Ethiopian Journal of Natural Resources* **2**:63–77.
7. John, M.K. (1970). Colorimetric determination of phosphorus in soil and plant materials with ascorbic acid. *Soil Sci*. **109**:214–220.
8. Jungk, J. and Rademacher, W. (1983). Chemical growth regulation in cereal grains. *Plant Growth Regulating Chemicals* **1**:253–271.
9. Koter, M., Czapla, J., Nowak, G. and Nowak, J. (1983). Effect of GA3, IAA and Kinetin on growth and development of bean, maize and flax. *Plant Physiol. and Biochem*. **36**:17–27.
10. Kupier, D. and Staal, M (1987). The effects of exogenously applied plant growth substance on the physiological plasticity in P*lantago spp*. *Plant Physiol*. **69**:651–658.
11. Marschner, H. (1995). *Mineral Nutrition of Higher Plants*. Institute of Plant Nutrition, University of Hohenheim, Academic Press, Harcour Brace, London.
12 Mengel, K. and Kirby, E.A. (1996). *Principles of Plant Nutrition*. 4th ed., Panima Publishing Corporation, New Delhi, Banglore.
13. Moskaleva, O.V. and Polevoi, V.V. (1985). Effect of growth regulators on growth of maize seedlings. *Biol.* **10**:84–90.
14. Nickell, L.G. (1983). Chemical growth regulation in sugarcane. *Plant Growth Regulating Chemicals* **1**:185–205.
15. Ross, J.J., Murfet, I.C. and Reid, J.B. (1993). Distribution of gibberellins in *Lathyrus odoratus* L. and their role in leaf growth. *Plant Physiol*. **102**:603–609.
16. Sanchez, A.P. (1976). *Properties and Management of Soils in the Tropics*. John Wiley and Sons, New York, London.
17. Sanchez, P.A. and Salinas, G. (1981). Low input technology for managing Oxisols and Ultisols in Tropical America. *Advances in Agron.* **34**:280–406.
18. SAS (2001). *SAS Statistical Package Version* 8.2. Copyright (c) 1999–2001 by SAS Institute Inc., Cary, NC, USA.
19. Sattelmacher, B. and Marschner, H. (1978). Nitrogen nutrition and cytokinins activity in potato. *Plant Physiol*. **42**:185–189.
20. Schactschabel, P. (1976). Beziehungen zwischen dem Phosphorgehalt im Boden und jungen Haferpflanzen. *Z Pflanzenernähr. u. Bodenk*. **135**:31–43.
21. Schüller, H. (1969). The CAL-Method, a new method for the determination of available phosphate in soils. *Z. Pflanzenernähr. u. Bodenk*. **123**:48–63.
22. Smicklas, K.D. and Below, F.E. (1992). Role of cytokinin in enhanced productivity of maize supplied with ammonium and nitrate. *Plant and Soil* **142**:307–313.
23. Sommer, K. (1979). *Interactions between Sulphate and pH Values in Humid Tropical Soils*. 3rd ed.,

Agriculturchemisches Institut der Universität Bonn, Germany.

24. Soon, Y.K. (1991). Solubility and retention of phosphate in soils of the North western Canadian Prairie. *Canadian Soil Sci. J.* **71**:453–463.

25. Thorsteinsson, B. and Eliasson, L. (1990). Growth retardation induced by nutritional deficiency or abscisic acid in *Lemna gibba*: The relationship between growth rate and endogenous cytokinin content. *Plant Growth Regulation* **9**:171–182.