I N S T I T U U T   V O O R   B O D E M V R U C H T B A A R H E I D

RAPPORT 4-1973

EFFECTS OF P-Zn INTERACTION AND LIME ON PLANT GROWTH IN THE PRESENCE OF HIGH LEVELS OF EXTRACTABLE ZINC

By

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1973

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Inst. Bodemvruchtbaarheid, Rapp. 4-1973

This report is the result of the research conducted by the author during his stay at the Instituut voor Bodemvruchtbaarheid (Institute for Soil Fertility) at Haren (Gr.) from 7 March to 31 August 1973 as a fellow of the International Agricultural Center at Wageningen, the Netherlands.

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industrial pollution and possibly to accumulation of this element in soils from various sources, it was thought that such a study might be useful in yielding practical information with regard to alleviating Zn toxicity caused by the high Zn levels of the above soils.

Hence, the purpose of this paper was to study the following:

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1) The effect of high P levels in combination with two levels of lime on dry matter yield and composition of maize, sudan grass, tomato and cotton grown on polluted soils containing toxic levels of 2.5% acetic acid extractable Zn.
2) The P-Zn interrelationship in the presence of high P and Zn levels.
3) The residual effect of applied P on dry matter yield and mineral composition of beans, lettuce and maize grown on the above soil in the presence of two levels of lime.

REVIEW OF LITERATURE

The effect of P on soil Zn availability

Many investigators have reported that P has a depressive effect on soil Zn availability. The first observation of this effect has been made by Mowry and Camp(1934), who found that Zn deficiency in citrus is rather apt to occur in soils heavily fertilized with P, or frequently containing high levels of soluble phosphates. Later, Barnette et al.(1936) showed that the application of superphosphate to the row with Zn, interfered with Zn deficiency symptoms, corrected with zinc sulfate. West(1938) reported that citrus plants grown on superphosphate treated plots in Australia, suffered from Zn deficiency apparently induced by phosphate ions. Similar results have been reported in the literature by Chapman et al.(1937), Powers and Pang(1947), Millikan(1947), Stukenholtz et al.(1966) Loneragen(1951), Morril(1956), Koukoulakis(1967), Burleson et al.(1961), Boawn and Legget(1964) and others.

However, some investigators, contrary to the above findings, have not been able to find any specific effect of phosphate on Zn availability, Millikan(1940), Viets et al.(1953) and Boawn et al.(1953). Yet, there is no doubt that residual or applied P may have an adverse effect on Zn availability on some soils and with some crops(Viets, 1966). This fact is supported by the results obtained with some more recent work. Thus, Paulsen and Rotimi(1968) found that the Zn content of two soybean varieties, differing in sensitivity to P nutrition, was decreased by high P applications and that added Zn overcame the effect of P in the tolerant variety but not in the sensitive one. Similarly, Sharma et al.(1968) reported that the Zn concentration of tomato and corn tops was reduced significantly due to P application and the magnitude of the reduction was greatest for the first increment of the added P.

The mechanism of P-Zn interaction

Attempts to explain the mechanism of P-Zn interaction have been made by some investigators, but it seems that the available data are rather conflicting and the presented evidence incomplete. Some workers support the view that phosphate precipitates Zn in the soil as $Zn_3(PO_4)_2$ rendering it unavailable to plants. It appears however from the work of Boawn et al.(1954) that this view does not agree with the fact that $Zn_3(PO_4)_2$ could as well be used as a good source of Zn(Boawn et al., 1957), and that according to JurinaK and Inouye(1962) Zn has a moderate solubility in $Zn_3(PO_4)_2$ systems, which as matter of fact, can yield a concentration of Zn equal to 1.02 ppm and 8 ppm of P even at pH 8.

On the other hand Stukenholtz et al.(1966), concentrated their attention to the possible occurenece of the P-Zn interaction in the plant. Thus, they reported that the P-Zn interrelationship is physiological in nature, occurring in the roots where, due to P accumulation, the translocation of Zn to the upper plant parts is inhibited. Koukoulakis (1967) found that the translocation of Zn from roots to tops of 40-day old maize plants was related to $CaCO_3$ content of the soil and that the depressive P effect on Zn concentration of tops was more pronounced in the soil of lower $CaCO_3$ content. These findings lead to the postulation that Ca inactivates P in the roots, reducing its tendency to inactivate Zn, and therefore even at high P levels more Zn is translocated to tops in the more calcareous soils.

Work of Keefer and Singh(1968) related to the mechanism of the P-Zn interaction as revealed by corn nutrition, indicated that P and Zn were not found to precipitate in the soil and neither did they interact in the plant. They postulated that the increase in soil P in some way changes the physiological ability of plants to absorb Zn. Further experimental evidence obtained by Pauli et al.(1968) indicated that the P-Zn interrelationship is influenced within the plant by the $CaCO_3$ content of the soil which also affects the solubilities of P and Zn compounds. They concluded that the P-Zn interaction problem is not in the soil external to plants. Also, Martin et al.(1965) reported that the soil temperature seems to be an important factor in determining whether or not massive P applications will induce Zn deficiency in tomatoes under controlled greenhouse conditions. Evidence obatained by Stanton et al.(1970) showed that Zn is sorbed in solution by two mechanisms, one involving OH^- and the other HPO_4^{--} and Ca^{++}. It was concluded from the above results that this theory explains adequately the effect of P on Zn availability. Finally, Christensen(1972) explained the effect of P on Zn uptake as a " dilution effect", for according to his results in no case was the total Zn uptake reduced by increasing the P levels.

The effect of lime and pH on Zn availability

Many studies have shown that the native as well as the applied Zn in the form of fertilizers is more available to plants from acid soil(Thorne, 1957). It has been found by Viets et al.(1957) that the availability of Zn in a buffered sandy soil as determined by plant Zn concentration, was almost doubled when the pH was reduced from 7 to 5. On the other hand an increase in pH reduced the availability of Zn. Addition of lime according to Wear(1956) decreased the Zn concentration of sorghum plants mainly due to the change in pH. He concluded that this was not a Ca effect but a pH effect. As a matter of fact liming may induce Zn deficiency(Thorne,1957). Generally, the pH effect on soil Zn availability has been well established even though the reasons are not well understood. Different theories have been advanced suggesting that with an increase in pH insoluble compounds are formed such as $Zn(OH)_2$, $ZnCO_3$, and $Zn_3(PO_4)_2$. But as it has already been mentioned, this theory does not agree with the findings of Boawn et al.(1957) at least with respect to the formation of $Zn_3(PO_4)_2$, for it was shown by these workers that it can be used as a good source of Zn for plant growth. More recent work of Prokhorov and Gromova(1971) points out that the sorption of Zn by clay minerals depends largely on soil pH. They reported that at low pH (acid range) Zn is adsorbed by ion exchange. With an increase in pH the competition with hydrogen decreases and the Zn sorption increases.

The above findings can not be overruled without further research and therefore the precipitation theory of P by Zn has to be further examined, for it appears that somehow the P-Zn interaction is also related to the soil.

Effect of P and lime on Zn availability

Shukla(1972) reported that liming resulted in decreased availability of both native and applied Zn, the decrease ranging from 32 to 34%. This was attributed to an increase in pH and perhaps to the formation of calcium zincate, as suggested by Jurinak and Thorne(1955). Contrary to lime, P application in the form of KH_2PO_4 resulted in an increased availability of both native and applied Zn. He explained this effect of P on Zn availability on the basis of pH changes brought about by the P fertilizer used. On the other hand, Spencer(1960) found that both superphosphate and lime applications considerably decreased the concentration of Zn in the roots, and the ratio of root Zn to leaf Zn, indicating that Zn was imobilized in the soil external to the root system, by phosphate and lime. Furthermore, he reported that growth of the trees which were treated with only phosphate or in combination with limestone, was sigificantly smaller than that receiving only limestone. Meuer et al.(1971) also found that increasing the soil pH to approximately 6.5 by liming reduced Zn uptake by 31% and that this reduction was sufficient enough to cause Zn deficiency symptoms. They further observed that liming had a much greater effect on Zn availability than P alone. It appears that the response to liming depended on the kind of plant. This is suggested by the work of Smilde(1971) who experimented with forest trees and found that conifer dry weight responded best to P applied in the absence of lime, whereas liming to pH 4.4 promoted the P response of broadleaved species. He also found that P interfered with root to shoot translocation of Cu, Fe and Al but not of Zn and Mn. Further experimental results obtained by Seatz et al.(1959), indicated that as the liming rate increased frm 2 to 8 tons/acre, the severity of Zn deficiency increased without Zn fertilization. Addition of P_2O_5 up to 1000 lbs/acre resulted in significant yield increases. They also reported that Zn fertilization decreased significantly the P content of plants along with the other elements. Similar results have also been reported for oats by Rogers and Wu(1948).

Effect of P and lime application on Zn toxicity

The toxicity of Zn to plants was known to agriculturists many years ago before its essentiality was established for normal plant growth(Thorne, 1957). The excessively high Zn content of some soils due to either pollution by Zn industry or to natural accumulation through the deposition of plant material as well as possible contamination through the extensive use of the Zn compounds for the control of soil borne fungal deseases, has stimulated scientific interest and some papers, limited in number, have appeared in literature. Thus, Henkens(1961) reported that the high Zn content of soils along the rivers Dommel and Neer in the Netherlands, was controlled by large dressings of lime(6.66 g/kg of soil $CaCO_3$ increased the pH from 5.4 to 6.9). Gall and Barnette(1940) found that P application in the form of monocalcium phosphate at a rate of 233 lbs/acre did not change the level of exchangeable Zn, toxic to maize or cowpeas. They stated that the presence of phosphate as a plant nutrient stimulated the growth of maize and cowpeas on the Orangeburg fine sand loam, while no effect was noted on the Norfolk sand.

From the experimental evidence received so far it is concluded that plants respond variably to toxic Zn levels. Thus, Polson and Adams(1970) reported that Salinac varieties of navy beans differ markedly in their response to excessive levels of Zn and Cu. Boawn and Rasmussen(1971) found that Zn concentration in tops associated with a 20% yield decrease, varied from 240 ppm for field bean to 740 ppm for sugar beet, with most crops falling in the 400 to 600 ppm range. Moreover, some crops such as swiss chard and spinach seem to tolerate extremely high levels of available soil Zn before accumulating toxic concentrations(Boawn, 1972). Similar studies conducted by Walsh et al. (1972), where excessive levels of Zn were used varying from 0 to 363 kg/ha on a loamy sand soil, indicated that generally, the yields of the snapbeans, cucumbers and maize were not reduced even at the higher rates of applied Zn. In relation to the ability of some plants to tolerate high amounts of metals Smilde(1973) states that internal plant tolerance, which is promoted possibly by P plays a more important part in neutralizing toxic concentrations of Zn and possibly Fe than exclusion mechanisms. The toxicity of high levels of Zn to plants may perhaps be explained on the basis of the findings of Lee et al. (1969) who reported that this element appears to interfere with the normal metabolism of Fe in some crops(flax).

MATERIALS AND METHODS

Six pot experiments were conducted in a glasshouse of the Institute for Soil Fertility, Haren (Gr.), the Netherlands. The following crops were studied: (a) tomato *Solanum lycopersicum* MILL. var. Moneymaker,(b) French bean *Phaseolus vulgaris* var. Prelude, (c) lettuce *Lactuca sativa* var. Reszia, (d) maize *Zea mays* L. var. Civona, (e) cotton[1] *Gossypium hirsutum* var. 4S, and (f) sudan grass[1] *Sorghum vulgare* , sweet sudan grass var. M-3011.

An additional experiment was set up, without crop, to study the effect of six levels of Zn and two levels of lime on the availability of added and indigenous soil P. The details of the above experiments are given in table 1.

Statistical design

A mixed factorial design of the type $3x2^2$ was used to study the effects of six P and two lime levels on dry matter yield of plants, mineral composition, residual P effect on dry matter and composition, and various Zn levels on the availability of indigenous and applied P, as suggested by Cochran and Cox, 1957, p. 224. This design has the advantage in that it confines the confounding to the highest order interactions, it includes by necessity a partial confounding of the least important interactions and sacrifices a small fraction of the important interactions(Yates, 1937). The statistical analysis was made in the Data Processing Center of the University of Groningen with a C.D.C. computer.

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[1]Cotton seeds were supplied by the Cotton Research Institute Sindos, Thessaloniki, Greece, and sudan grass by the Fodder Crops Research Institute, Larissa, Greece.

Table 1 : Pot experiments conducted in the glasshouse during the course of the study.

Project serial number	Number of replications	Date started	Date finished	Crop studied
VP-1115	3	29/3/73	15/5/73	Tomato
"	3	29/3/73	3/5/73	Maize
"	3	22/5/73	10/7/73	Cotton
"	3	26/6/73	24/7/73	S. grass
VP-1128	2	26/4/73	1/8/73	–
VP-1059	x	21/5/73	27/6/73	Lettuce
"	x	28/6/73	18/7/73	Maize

[x]This exploratory experiment started on 25/8/71 and original-it had two replications. With the addition of extra P it was actually split into two experiments each with one replicate.

Soils

Three soils were studied denoted as A, B and C. The A and B originated from Neerpelt, located in the Northern part of Belgium, and were sampled near the vicinity of a zinc factory. Soil A was used to study the P effect on plant dry matter yield and mineral composition, while B was used for the study of the residual P effect. The soil C originated from Someren, located in the N. Brabant province of the Netherlands. It was used to study the effects of added Zn on the availability of applied and indigenous P. Information on the physicochemical properties of these soils are given in table 2. It is shown that both A and B soils are rich in 2.5% acetic acid extractable Zn. This is due to pollution with ZnO, emitted by the nearby zinc smelter, which has been in operation in that area for the last hundred years. As a consequence, 400 hectares have almost become useless for any further agricultural use. The land around the smelter is barren and the existing scattered big trees are slowly drying due to Zn toxicity. This has actually been the cause of the initiation of the present study.

Table 2 : Some physicochemical properties of soils studied

Soil	Origin	Physicochemical Properties				
		texture	pH	Pw	O.M.%	Zn, ppm
A	Neerpelt, Belgium	Sand	4.5	51	4.4	171
B	"	Sand	4.3	20	5.9	167
C	Someren,Netherland	Sand	3.9	1	3.9	11

Pw is expressed in mg P_2O_5 per littre of soil.

Applied treatments

The levels of P and Zn used in the various experiments conducted(table 1), were 0, 250, 500, 750, 1000, and 1500 kg/ha P_2O_5 and 0, 75, 150, 300, 600, and 1200 ppm of Zn. The P was applied as $Ca(H_2PO_4)_2.H_2O$ and the Zn as $ZnSO_4.7H_2O$. The P treatments of the experiments VP-1059 were increased each year by half of the P quantity applied in the previous year. As to lime, two levels were used, namely 0 and 1, and it was applied in the form of $Ca(OH)_2$, the amount varying with the soil organic matter content. It corresponded to the quantity needed to raise the pH of soil by approximately one pH unit. Thus, the rates used in the various experiments were: VP-1115 1770 kgs, VP-1059 2170 kgs, and VP-1128 1620 kgs of CaO equivalent per hectare per 15 cm depth. These quantities were calculated on the basis of the information given by the handbook of the Ministry of Agriculture and

Fisheries(Ministerie van Landbouw en Visserij, Adviesbasis voor bemesting van landbouwgronden, 1962, p. 25).

Basic fertilization

Each pot of the experiment VP-1115 received a basic application consisting of 1.4 g N as NH_4NO_3, 2.0 g K_2O as KNO_3, 1.0 g MgO as $MgSO_4.7H_2O$, 0.15 g $CuSO_4.5H_2O$, 0,05 $Na_2B_4O_7.10H_2O$ and 0.015 g $Na_2MoO_4.2H_2O$. Every pot of VP-1059 was given a supplemental dressing of 0.7 g N as NH_4NO_3, 0.2 g MgO as $MgSO_4.7H_2O$ to account for the losses of these nutrients by the various crops grown during 1972 and 1971 periods. The basic fertilization of this experiment was applied at the time of its commencement, namely 25/8/71.

Supplemental dressing

After the harvest of maize(VP-1115), a supplemental dressing of 0.7 g N/pot as NH_4NO_3, 1.0 g K_2O/pot as KNO_3 and 0.5 g MgO/pot as $MgSO_4.7H_2O$ was administered, to satisfy the nutrient needs of the next crop(sudan grass), which also received an additional further dressing of 0.2 g N/pot as NH_4NO_3 on 17/7/73. Similarly, cotton following the tomato(VP-1115), received in total 0.8 g N/pot as NH_4NO_3 given in split applications of 0.2 g N/pot during its growth period from 8/6/73 to 28/6/73 to correct the N deficiency symptoms. Finally, maize(VP-1059), received a total supplemental dressing of 0.2 g/pot N as NH_4NO_3 in split applications of 0.1 g/pot over the period 5/7/73 to 9/7/73.

Preparation of pots

The pots of each experiment were prepared separately according to standard techniques followed at the Pot Experiment Department of the Institute. Thus, for the experiment VP-1115 36 plastic(polyethylene) pots of 10 litres volume, were filled with 11.385 Kgs of soil(weight determined on oven dry -105^{o}C-basis), previously mixed with the basic dressing(basic fertilization) and the corresponding P and lime treatments, according to the statistical design used. The seeding rates were 10 seeds/pot for maize tomato and cotton, and 40 seeds/pot for sudan grass. Thinning to 5 plants/pot was done only for the first three crops but not for the sudan grass. For the VP-1128 experiment, 24 plastic pots of 1.2 litres volume were filled with 1.000 kg of dry soil(oven dry basis), which had previously been mixed with the Zn applications according to the design employed. Also, on May 10, 1973 each of these pots was uniformly mixed with 0.4 g P_2O_5 as $Ca(H_2PO_4).H_2O$ along with two levels of lime, namely 0 level and ~~12.0~~ 1.32 g $Ca(OH)_2$. The pots of experiment VP-1059 were filled on on 25/8/71. To each pot of this experiment 10 lettuce plants were planted as first crop for 1973, followed by maize sown at a rate of 13 seeds/pot. After the preparation, the pots were placed in the greenhouse and arranged according to the statistical design used. The prevailing humudity and temperature in the glasshouse was continuously recorded by an automatic thermohydrograph(table 3).

Watering of pots

Pots were watered regularly with freshly prepared deionized water. Before each application of water, they were weighed separately and the amount of water added never exceeded the water capacity (W.C.). By this term, as it is used at the Institute is meant the amount of soil water corresponding with an equilibriated saturation state of soil, expressed as 100%. The amount of water each pot received during irrigation, was throughout the growth period in the range of 45 to 70% of the water capacity[1].

Glasshouse environmental conditions

The experiments VP-1115 and VP-1128 were conducted in a glasshouse which was permanently covered, while VP-1059(lettuce) was conducted in a glasshouse with a mobile roof. Thus, during most of the time this glasshouse was kept open, being closed only during rain or wind blow. The avarage temperature at 12 and 24 hours as well as the humidity are given in table 3.

Table 3 : Average temperature at 12 and 24 hours and relative humidity recorded during crop growth in the glasshouses.

Project serial number	Crop	Temperature		Humidity
		12hour	24hour	
VP-1115	Tomato	23.2	20.5	47.6
"	Maize	23.1	20.3	47.6
"	Cotton	26.7	24.3	62.2
"	Sudan grass	30.4	27.3	67.0
VP-1059	Lettuce	20.6	14.1	77.3
"	Maize	30.2	20.2	70.3
VP-1128	—	26.8	23.7	61.9

[1]The water capacity of a given soil is determined by saturating a known amount of soil(oven dry basis) over a period of three days for the attainment of the equilibrium and by subsequent determination of soil moisture(drying at 105°C). The amount of moisture so found represents the water capacity and is considered as 100%.

Harvesting and soil sampling

The crops were harvested on the dates indicated in table 1. Each pot of the experiment VP-1128, was sampled by means of aplastic sampler to the bottom of the pot in order to assure uniformity of the sample. Soil sampling for this particular experiment was done every month, starting from the date of the P application(10-5-73), for the determination of the Pw-value and following up the changes in available P due to the various Zn treatments. Soil samples were also taken from the other experiments for Pw determinations. The plant samples harvested were dried at 105°C for 24 hours, ground to pass a sieve of 2 mm, and stored in plastic boxes for chemical analyses.

Analytical methods

The chemical analyses of plant and soil samples, excepting determination of "available Zn of soil", were done in the Central Chemical Laboratory of the Institute and the methods used are as follows:

Plant Zn, Mn and Fe

A modified method[1] used in the Laboratoty, was employed, based on wet digestion of 1.0 g plant sample in a concentrated perchloric acid + nitric acid + sulfuric acid system. The elements were determined in the extract by means of a Perkin Elmer Atom. Absorption Spectrophotometer, model 306.

Plant P

P was determined by the method suggested by Rameau and Ten

[1]Personal communication by Messrs H. Vierveyzer and T. Lepelaar, Head and nanalyst, respectively, of the Central Chemical Laboratory of the Institute for Soil Fertility, Haren (Gr.).

Have(1951), employing mono-methiopara-amidophenol sulfate (metol) as a reducing agent for the development of the blue color.

Plant N

The method of Deijs(1961) was employed for the determination of total plant N.

Available P (Pw-value)

This was determined according to the method of Sissingh (1971). Ascorbic acid was used as a reducing agent for the development of the blue color.

Fractionation of soil P

The Fe-P, Ca-P and Al-P fractions of the soil from VP-1059 experiment were determined by means of the method of Chang and Jackson(1957).

"Available soil Zn"

Soil "available Zn" was extracted by five extractants and Zn was determined in the extracts by means of an atomic absorption spectrophotometer in the research laboratory of the Glasshouse Research and Experiment Station, Naaldwijk, the Netherlands. The methods of extraction employed were: M ammonium acetate, suggested by Shaw and Dean(1952), 0,01M EDTA + M ammonium carbonate(Trierweiler and Lindsay, 1969), 0.02M EDTA(Jensen and Laam, 1961), 0.05M EDTA as used in the above laboratory, and 2.5% acetic acid(Davies, 1971).

RESULTS AND DISCUSSION

Effect of P and lime on dry matter yields

Applied P in the presence of lime had a positive and statistically significant effect on dry matter yields of tomato, maize, and sudan grass, but not on cotton(fig. 1, table 4). In the absence of lime, tomato and cotton failed almost completely to respond to added P, while maize and sudan grass responded significantly, maximum yields being attained for both crops with the third level of P, the mean yield leveling off with further increase of P. It was also found that in the limed soil, maize and sudan grass could not produce maximum dry matter yields with the applied P levels. This was most probably due to fixation of P by lime.

The effect of lime was negative at the low levels, of P for maize and sudan grass, and positive for cotton and tomato, suggesting that liming may not be a limiting factor for maize and sudan grass production, but only for cotton and tomato. On the other hand the positive, highly significant PxL interaction in tomato, maize and sudan grass indicated that both P and L must be at high levels for tomato and lower levels for the latter crops, if maximum growth is to be realized, the negative and significant P^2 effect suggesting that the slope of the response curve is diminishing with additional P increments. The general P and lime effect on tomato and beans(experiment VP-1059) is shown in photo 1, 2 and 3.

Effect of P and lime on P concentration of tops

The range of the applied P levels included amounts that are normally added to agricultural soils as well as quantities which

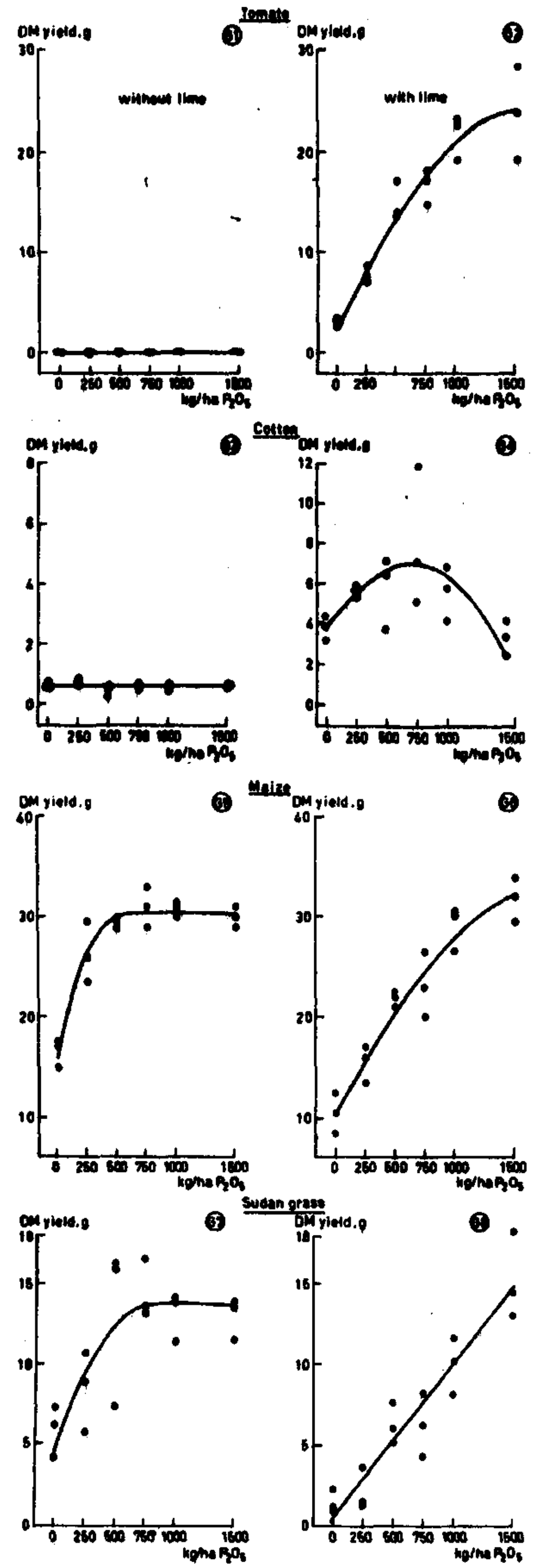
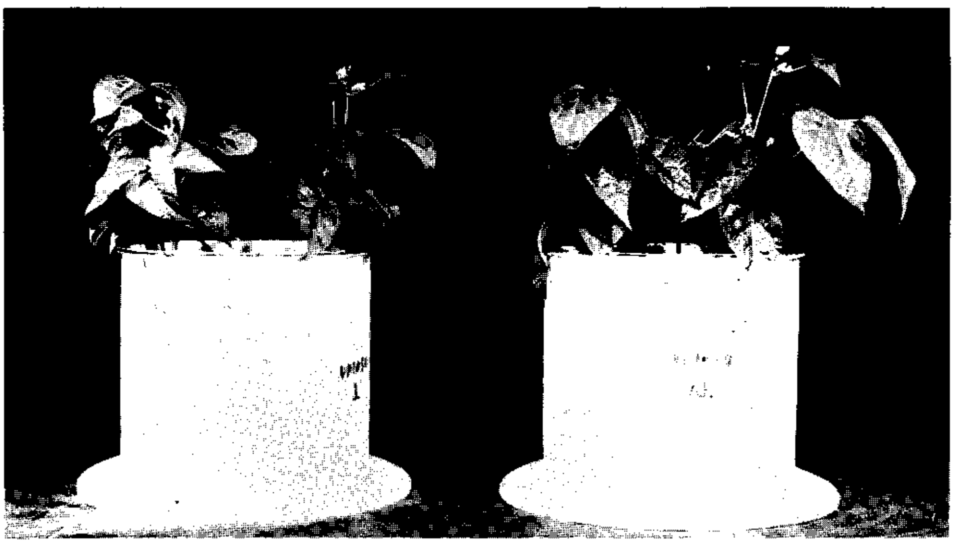
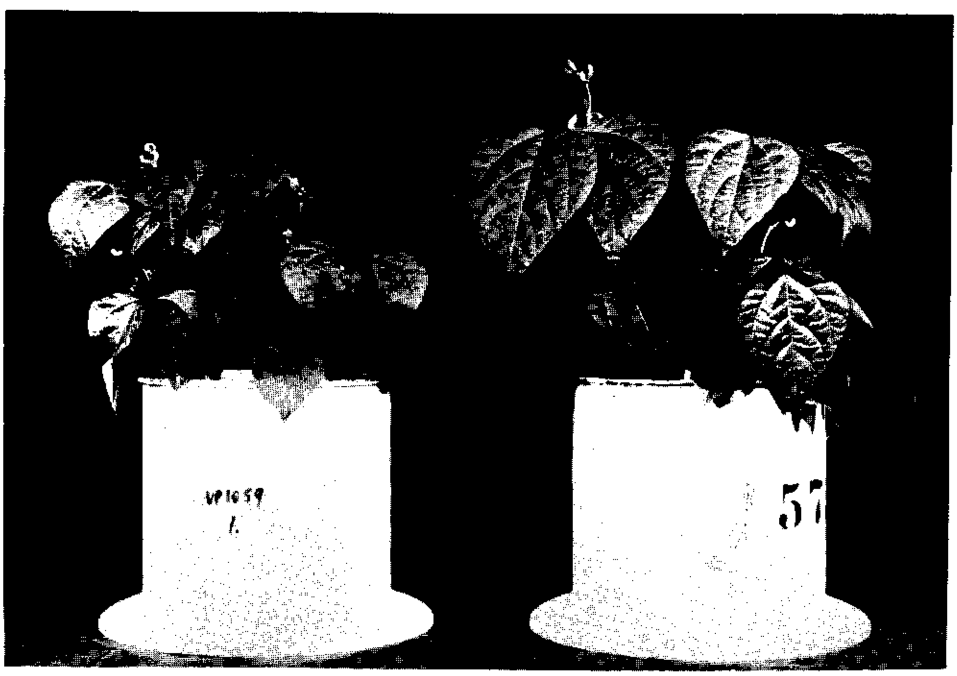


Fig. 1. Effect of applied P on dry matter yield of tomato, cotton, maize and sudan grass grown in the presence of two levels of lime.

LIME P_1 LIME P_2



LIME P_3 LIME P_4



LIME P_5 LIME P_6

Photo 1. Effect of phosphate levels (P1 to P6) on growth of bean in the presence of lime.

LIME P_1 LIME P_2

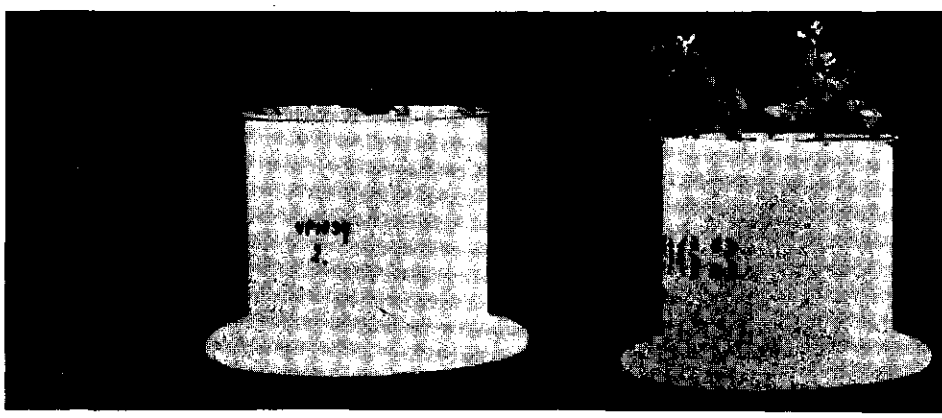
LIME P_3 LIME P_4

LIME P_5 LIME P_6

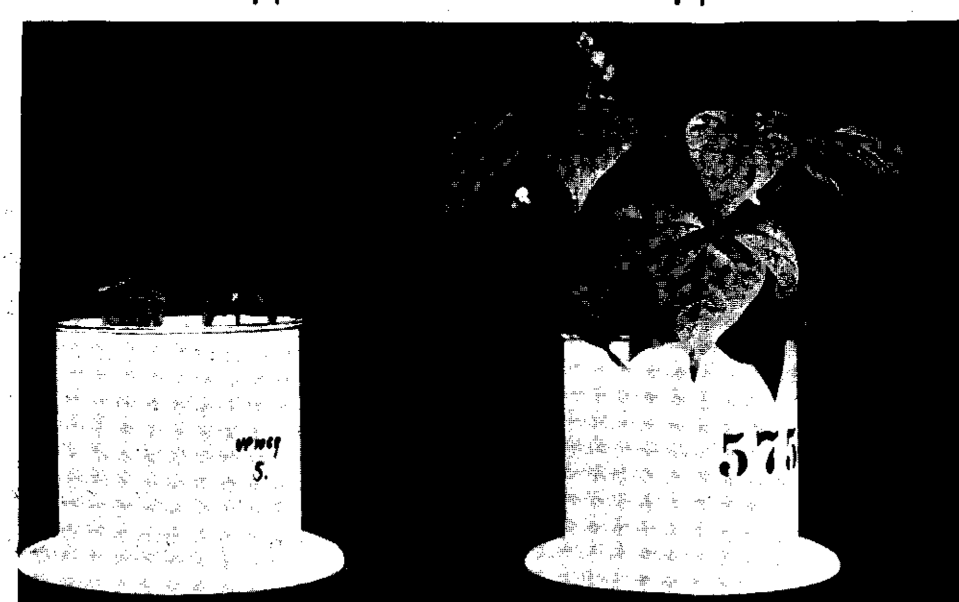
Photo 2. Effect of phosphate levels (P1 to P6) on growth of tomato in the presence of lime.

NO LIME P_1 | LIME P_1

NO LIME P_6 | LIME P_6



NO LIME P_1 | LIME P_1



NO LIME P_6 | LIME P_6

Photo 3. Effect of lime on growth of tomato and bean in the presence of P1 and P6 phosphate levels.

may be considered relatively high. This was necessitated by the high Zn content of the soil studied. Thus, it was found that P had a positive effect on P concentration of tops of tomato, cotton, maize and sudan grass, and the differences among treatments were highly significant(table 5).

Table 4 : Regression coefficients and F values for dry matter yields of tops of the crops studied.

Terms	Tomato		Cotton		Corn		Sudan grass	
	regression coeffic.	F value	regression coeffic.	F value	regression coeffic.	F value	regression coeffic.	F value
P	0.589	170.0***	-0.013	0.12	0.914	196.6***	0.585	113.4***
L	7.268	740.2***	2.392	119.7***	-2.69	48.8***	-2.23	46.8***
P^2	-0.249	12.2**	-0.174	8.9**	-0.63	37.4***	-0.19	5.0*
PxL	0.588	169.8***	-0.014	0.1	0.29	19.4**	0.200	13.3**
R^1	0.9889		0.9204		0.9616		0.9404	

[1]Multiple correlation coefficient. *** , ** , * = 1‰ , 1% and 5% level of significance,respectively.

The general P level of the plants investigated was lower for limed soil than for unlimed(fig. 2 and 4). This showed that lime had a negative effect on P concentration of tops which was highly significant, indicating the role of lime in inactivating soil P. The negative and highly significant PxL interaction in maize showed that maximum P concentration of tops was attained with high P and low lime, and that the curvature was stronger at the lower lime rate as suggested by the negative and highly significant P^2 effect. On the other hand,

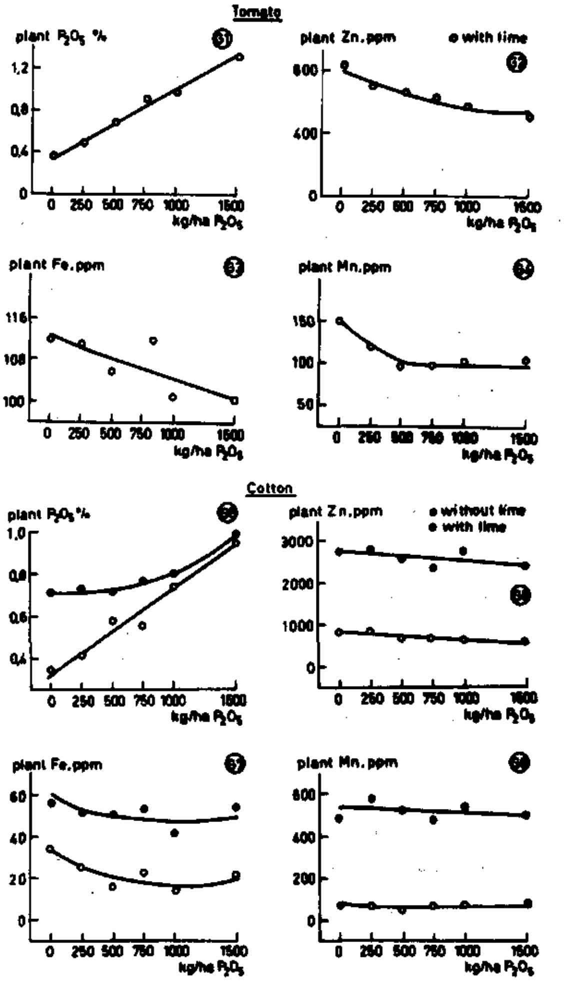


Fig. 2. Effect of applied P on P, Zn, Fe and Mn concentration of tomato and cotton grown in the presence of two levels of lime.

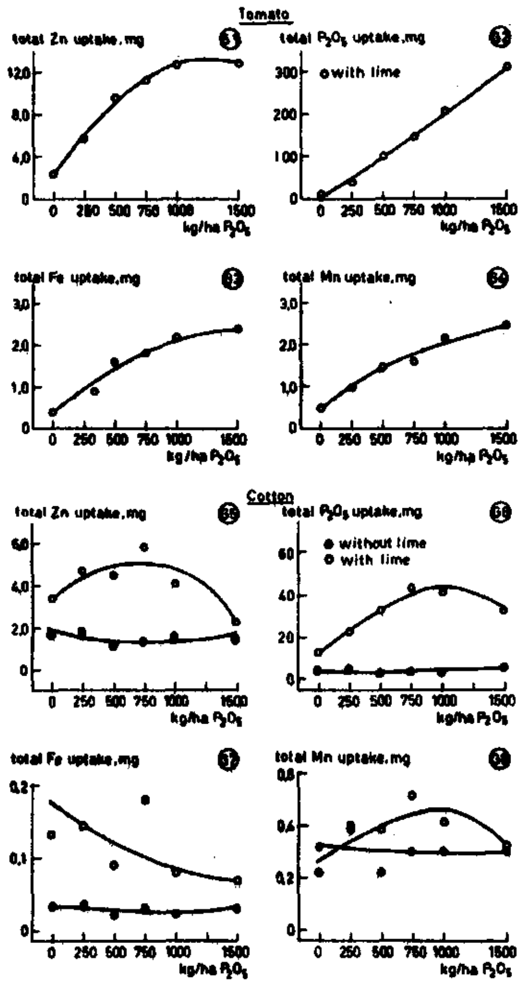


Fig. 3. Effect of applied P on total uptake of P, Zn, Fe, and Mn of tomato and cotton grown in the presence of two levels of lime.

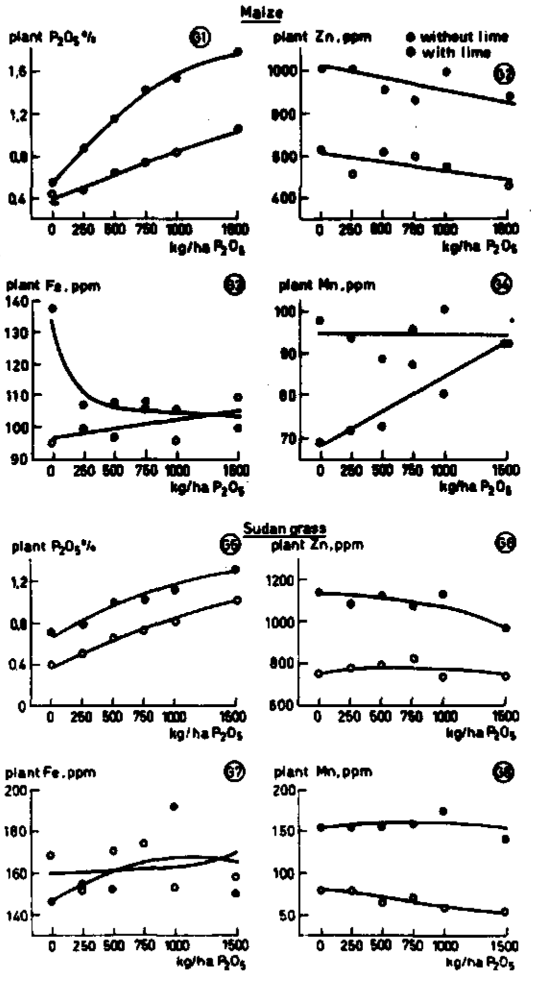


Fig. 4. Effect of applied P on P, Zn, Fe and Mn concentration of maize and sudan grass grown in the presence of two levels of lime.

the positive and highly significant PxL interaction in cotton indicated that maximum P concentration was possible at a ~~lower~~ higher lime rate.

Table 5 : Regression coefficients and F values for P concentration of tops of crops studied

Terms	Cotton		Maize		Sudan grass	
	regression coefficient	F value	regression coefficient	F value	regression coefficient	F value
P	0.022	130.2***	0.051	1238.4***	0.033	758.4***
L	-0.086	58.6***	-0.26	865.9***	-0.147	410.7***
P^2	0.004	1.84	-0.01	25.3**	-0.002	1.2
PxL	0.012	38.54**	-0.02	121.7***	0.009	0.6
R[1]	0.9872		0.9987		0.9974	

[1]Multiple correlation coefficient. ***, **, * = 1‰, 1% and 5% level of significance, respectively.

The effect of the applied P treatments on the total P uptake was as expected, positive and highly significant for all crops studied(table 6, fig. 3 & 5). Similarly, the lime effect was positive and highly significant for cotton, but negative and highly significant for maize and sudan grass. The PxL interaction, on the other hand, was positive for cotton and negative for maize, but highly significant in both cases, suggesting that for the former crop both P and lime must be at high level, while for the latter P must be at high and lime at low level for maximum total P uptake.However, the slope of the P response curve in both of the above crops is decreasing as suggested by the negative and highly significant P^2 effect.

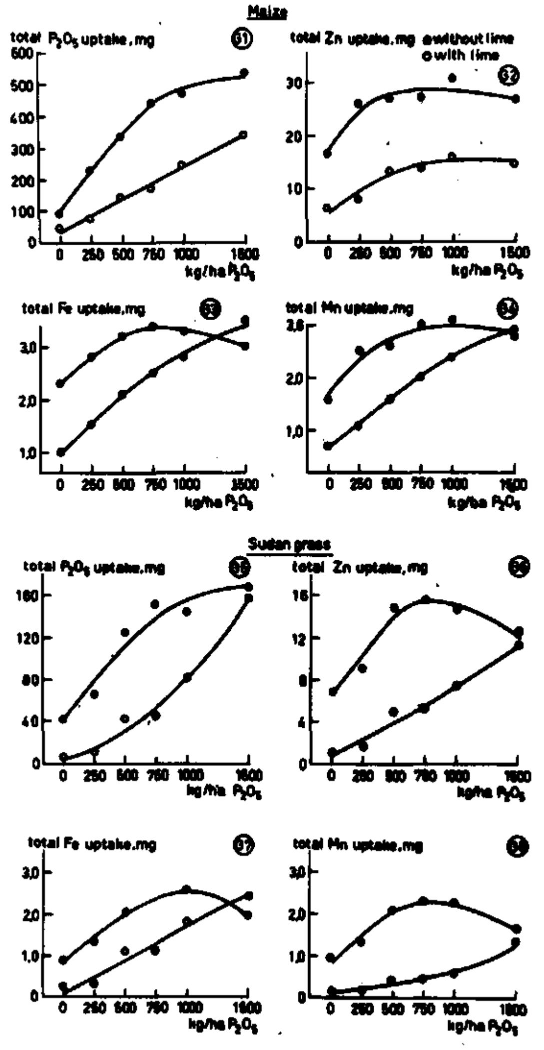


Fig. 5. Effect of applied P on total uptake of P, Zn Fe and Mn of maize and sudan grass in the presence of two levels of lime

Table 6 : Regression coefficients and F values for total P uptake of tops of crops studied.

Terms	Cotton		Maize		Sudan grass	
	regression coefficient	F value	regression coefficient	F value	regression coefficint	F value
P	0.629	39.8***	20.43	1097.6***	7.81	187.0***
L	13.325	509.3***	-90.92	621.1***	-29.8	77.5***
P^2	-0.988	39.2***	-5.92	36.9**	-0.50	0.3
PxL	0.560	31.6**	-3.95	40.9***	0.67	1.4
R[1]	0.9955		0.9984		0.9896	

[1]Multiple correlation ceofficient. ***, **, * = 1‰, 1% and 5% level of significance, respectively.

Effect of P and lime on Zn concentration of tops

As it has been pointed out in the review of literature, P has been found to have a depressive effect on Zn concentration of some plants. In the present work it was found that added P treatments had indeed a negative effect on plant Zn concentration as suggested by the negative regression coefficients. This effect was however, only statistically significant at the 10% level(table 7). Similarly, the effect of lime was also negative but higly significant, indicating the important function of lime in controlling soil Zn availability. It is also suggestive of the need for liming of the Zn polluted soils.

The effect of P and lime on Zn concentration of tops is demonstrated in fig. 2. Contrary to the effect of the applied P treatments on plant Zn concentration, total Zn uptake of maize and sudan grass was increased by P(fig. 5) as shown by the positive regression coefficients, the differences being significant at 1% and 1‰ level, respectively.(table 8). The effect of lime on total Zn uptake was similarly negative for maize and sudan grass, and positive for cotton, but highly significant for all crops, indicating that liming is necessary for high Zn accumulating crops.

Table 7 : Regression coefficients and F values for Zn concentration of tops of crops studied.

Terms	Cotton		Maize		Sudan grass	
	regression coefficient	F value	regression coefficient	F value	regression coefficien.	F value
P	-14.24	4.37[e]	-6.19	4.51[e]	-4.13	4.85[e]
L	-916.0	516.51***	-191.5	123.32***	-156.4	198.5***
P^2	4.84	0.20	-1.33	0.08	-5.56	3.5[e]
PxL	3.39	0.25	-0.62	0.05	2.79	2.2
R[1]	0.9943		0.9775		0.9860	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5% and 10% level of significance, respectively.

Effect of P and lime on Fe and Mn concentration

The effect of P on Fe concentration of tops was generally negative, but the differences were not statistically significant (table 9). Lime, as expected, had a strong negative effect as revealed by the corresponding negative regression coefficient for cotton and maize, being highly significant for the former and significant for the latter crop. On the other hand, the general Fe level of sudan grass was not affected by P application, and neither by lime(fig. 4). The PxL interaction in maize

Table 8 : Regression coefficients and F values for total Zn uptake of tops of crops studied.

Terms	Cotton		Maize		sudan grass	
	regression coefficient	F value	regression coefficient	F value	regression coeffiecient	F value
P	-0.041	2.78	0.484	31.6**	0.459	80.8**
L	1.300	81.1**	-6.792	177.6***	-3.492	133.6***
P^2	-0.113	8.5*	-0.618	20.6**	-0.295	13.4*
PxL	-0.028	1.3	0.014	0.0	0.119	5.48^{e}
R[1]	0.9792		0.9873		0.9883	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5% and 10% level of significance, respectively.

was positive and significant suggesting that liming neutralizes to some extent the adverse effect of high P treatments on Fe concentration of plants. In general P increased the total Fe uptake, except in cotton. Lime had opposite effect on all crops, while on cotton plants it had a positive effect(table 10). It may be stated here that the trend of the P effect on Fe concentration and total uptake is similar to that demonstrated for Zn.

With respect to the P effect on Mn concentration of crops studied, it was found that this was positive and significant at 5% and 10% level for maize and sudan grass, respectively(table 11). similarly, the effect of lime was negative and highly significant as shown by the negative coefficients for cotton, maize and sudan grass. The significant effect of the positive PxL interaction in maize, suggested that when limed, P must be at high level to have a positive net effect on Mn concentration. On the other hand the application of P treatments had a positive effect on total Mn uptake in all crops studied and this effect was highly significant for maize and sudan grass(table 12), but not for cotton.

Table 9 : Regression coefficients and F values for Fe concentration of tops of crops studied.

Terms	cotton		Maize	
	regression coefficient	F value	regression coefficient	F value
P	-0.429	3.67[e]	-0.452	1.54
L	-14.49	119.34***	-5.250	5.94*
P^2	0.892	6.34*	0.851	2.18[e]
PxL	-0.231	1.06	1.086	8.89*
R^1	0.9778		0.8739	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5%, and 10% level of significance, respectively.

The negative and highly significant P^2 effect on maize and sudan grass, indicated however that additional P increments have a smaller effect. Furthermore, the trend of the lime effect on total Mn uptake for maize and sudan grass was similar to its effect on plant Mn concentration, that is negative and highly significant. However, in cotton lime had a positive effect on total Mn uptake significant at 10% level.

Table 10 : Regression coefficients and F values for total Fe uptake of tops of crops studied.

Terms	Cotton		Maize	
	regression coefficient	F value	regression coefficient	F value
P	-0.002	1.33	0.087	853.5***
L	0.042	21.11**	-0.383	466.8***
P^2	-0.001	0.16	-0.052	122.0***
PxL	-0.002	1.16	0.050	283.3***
R[1]	0.8955		0.9983	

Table 11: Regression coefficients and F values for Mn concentration of tops of crops studied,

Terms	Cotton		Maize		Sudan grass	
	regression coefficient	F value	regression coefficient	F value	regression coefficient	F value
P	0.085	0.00	0.671	6.77*	+0.910	5.45[e]
L	-221.830	534.98***	-7.917	26.88**	-44.00	362.23***
P^2	-0.166	0.00	-0.018	0.00	-0.76	1.54
PxL	1.062	0.43	0.681	6.96*	-0.67	3.02[e]
R[1]	0.9944		0.9334		0.9921	

[1]Multiple correlation coefficient. +++, ++, +, e = 1%o. 1%, 5% and 10% level of significance, respectively.

Table 12 : Regression coefficient and F values for total Mn uptake of tops of crops studied.

Terms	Cotton		Maize		Sudan grass	
	regression coefficient	F value	regression coefficient	F value	regression coefficient	F value
P	0.001	0.14	0.093	295.0***	0.061	126.6***
L	0.033	4.62e	-0.408	161.4***	-0.638	395.3***
P^2	-0.007	3.28e	-0.054	39.7**	-0.035	16.23**
PxL	0.001	0.31	0.032	34.5**	0.005	0.93
R[1]	0.8487		0.9945		0.9950	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5% and 10% level of significance, respectively.

The P-Zn interrelationship in soil

Preliminary determinations of the extractable Zn of soil from experiments VP-1059/72(beans) and VP-1115(maize), with five extractants, aiming at finding a suitable method for " available soil Zn " determination, indicated that the Zn taken up by maize and bean plants was significantly correlated with M NH_4Ac extractable Zn(Shaw and Dean, 1952). The relationship obtained between Zn extracted by the various extractants and plant Zn concentration of maize and beans, are shown in fig. 6 and 7, respectively. It can be also seen that EDTA+$(NH_4)_2CO_3$ extractable Zn(Trierweiler and Lindsay, 1969), has also given a good correlation with plant Zn concentration, but this was better for maize than for bean(table 13). It is suggested by the

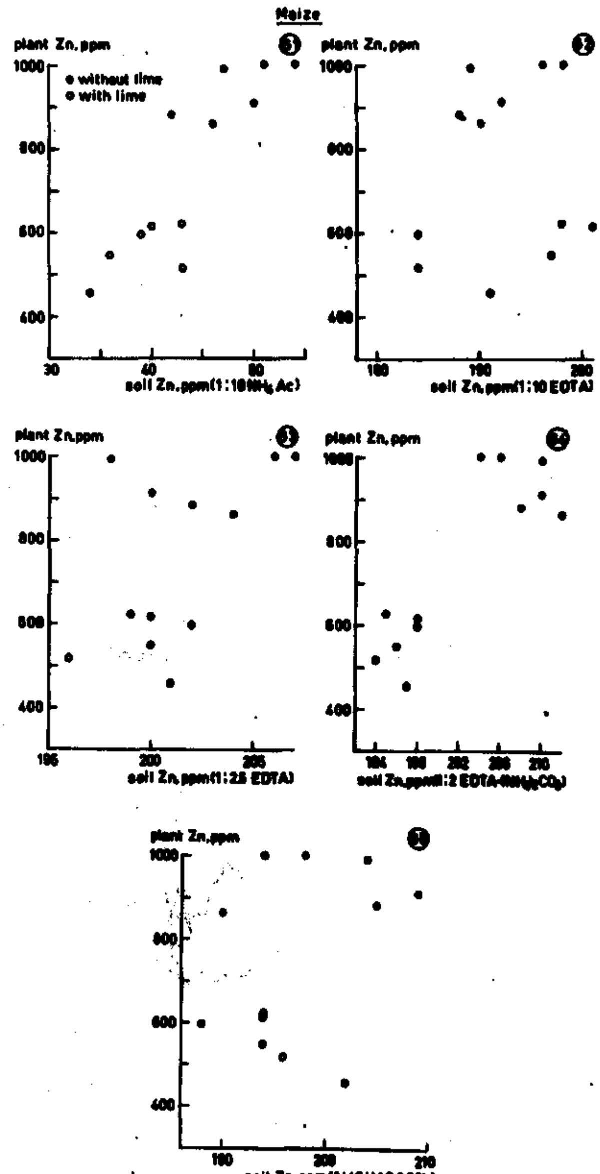


Fig. 6. Relationships between soil Zn extracted with various extractants and Zn concentration of maize plants grown in the presence of two levels of lime.

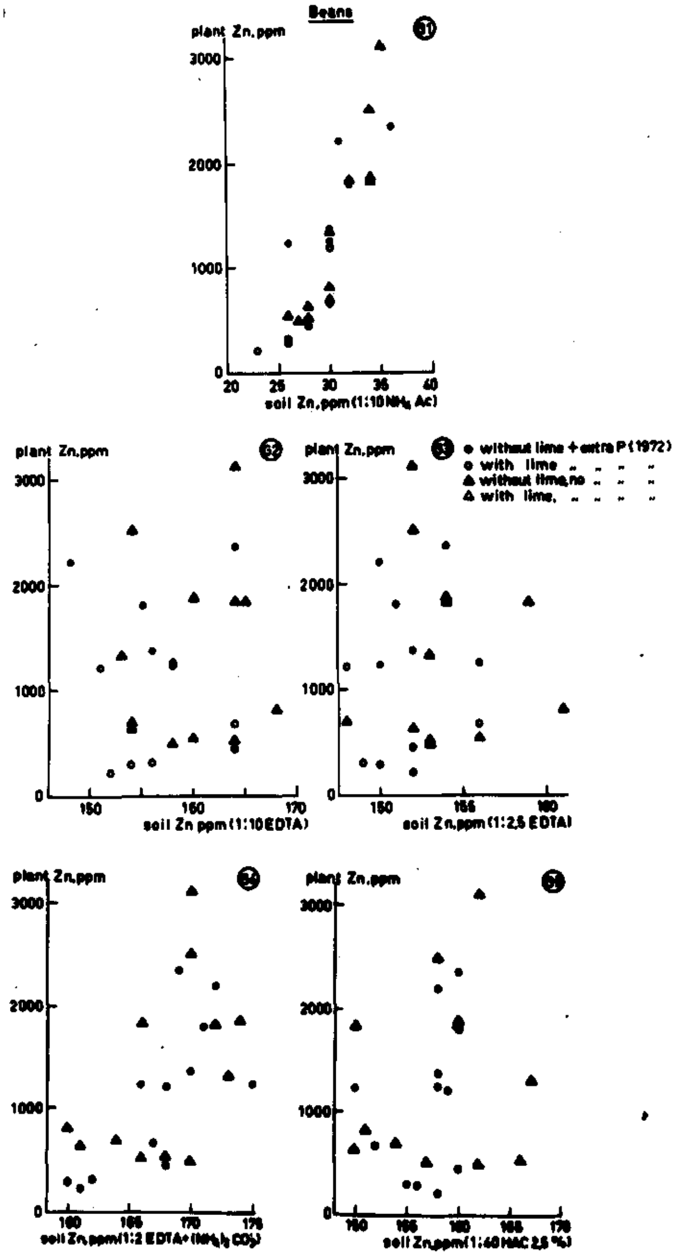


Fig. 7. Relationships between soil Zn extracted with various extractants and Zn concentration of bean plants grown in the presence of two levels of lime.

above results that the M NH_4Ac extractable Zn could be considered a relatively good estimation of the "available" soil Zn.

It was found furthermore, that the applied P had a strong negative and highly significant effect on soil Zn, extracted with M NH_4Ac(table 14). These preliminary results suggested that a possible interaction between P and Zn in the soil may take place, even though many workers have excluded this possibility(Viets, 1966). The effect of P on soil Zn is shown for the various soils studied, in fig. 8.

Table 13 : Coefficients of correlation for the relatioship between plant and soil Zn as determined by various extractants.

Experiment	Crop studied	1:10 M NH_4Ac	1:10 E D T A	1:2½ E D T A	1:2 EDTA+NH_4CO_3	1:40 HOAc
VP-1059	beans	0.8375*	-0.0713	0.0870	0.7253	0.3197
VP-1059	beans	0.9168*	0.1481	-0.0526	0.4857	0.1290
VP-1115	maize	0.8664*	0.1086	0.5377	0.8651*	0.3365

In order to prove that excessive Zn content of soil under investigation could fix P in the soil, as it was revealed by the strong P deficiency symptoms in tomato plants, an experiment (VP-1128) was initiated to study the effect of added excess Zn on the availability of P added to soil. The Someren soil (C) was used for this experiment(table 2). No crops were grown. Instead, soil sampling was carried out about every thirty days and the Pw-value was determined(table 15). It is shown

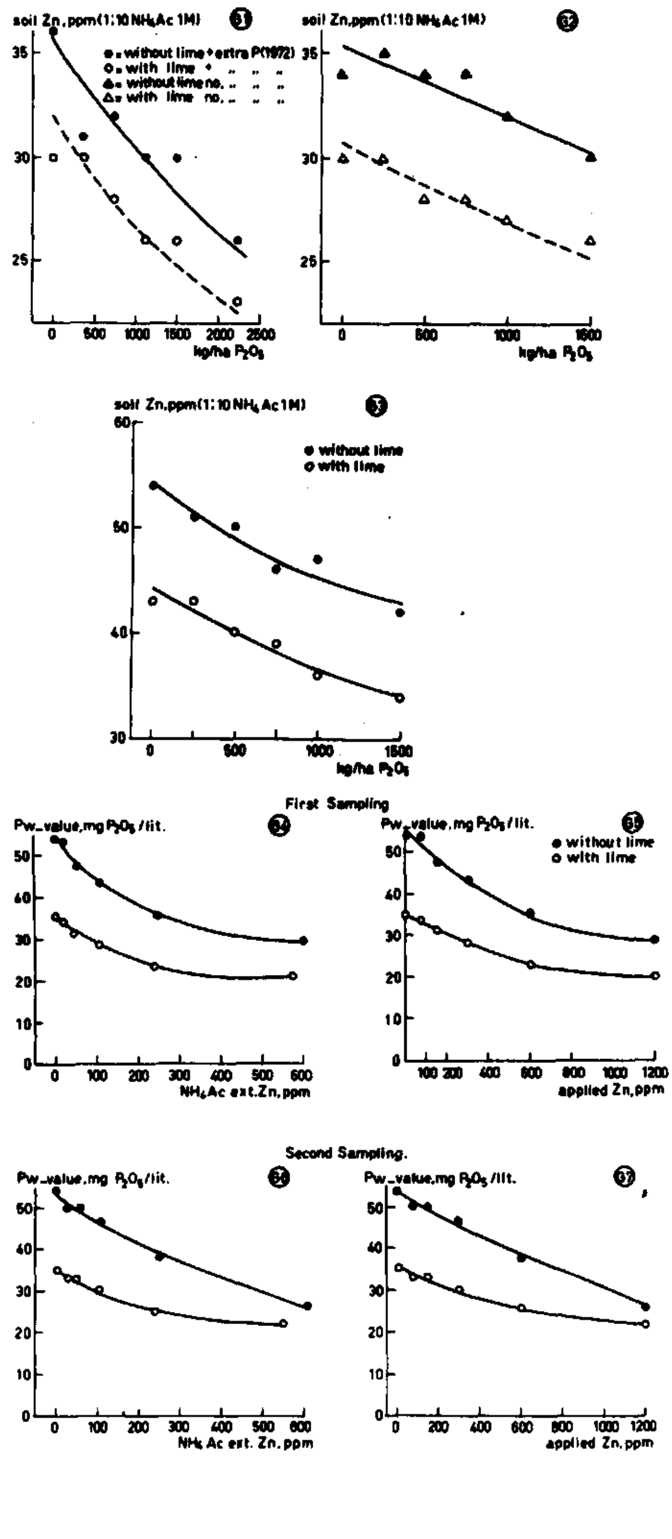


Fig. 8. Effect of applied P or Zn on M NH_4Ac extractable soil Zn and water extractable soil P (Pw-value), respectively.

in fig. 8(1st and 2nd sampling) that Zn has a definite negative effect on P water(Pw-value). Statistical analysis indicated that the Zn effect was negative as suggested by the corresponding regression coefficients, and highly significant. Similarly, the effect of lime was negative and highly significant, the magnitude of the regression coefficient being however smaller than that of Zn(table 16). It is also shown in this table that the ZnxL interaction effect was positive and statistically significant indicating that the fixation of P by Zn was intensive at the lower lime rate. It must be noted that the results were consistent throughout the three samplings, suggesting that equilibrium was attained in the soil, at least, till the time of the first sampling from the date of Zn application.

Table 14 : Regression coefficients and F values for the effect of applied P on M NH_4Ac extractable Zn of soil.

Terms	VP-1059 French beans				VP-1115 Maize	
	RI (Extra P)		RII (No extra P)			
	regr. coef.	F value	regres. coeffic.	F value	regres. coeffic.	F value
P	-0.435	50.7***	-0.245	77.9***	-0.529	117.4***
L	-1.833	25.6**	-2.500	231.3***	-4.583	200.4***
PxL	0.026	0.18	0.007	0.1	0.040	0.6
R[1]	0.9630		0.9907		0.9907	

[1]Multiple correlation coefficinet. ***, **, *, = 1‰, 1% and 5% level of significance, respectively.

Table 15 : Effect of applied Zn on water extractable P (Pw-value) of soil C.

Treatments		Pw in mg P_2O_5/litre			Zn extracted, ppm in M NH_4Ac
lime	zinc levels ppm	1st sampling	2nd sampling	3rd sampling	1st sampling
0	0	55	54	54	1.5
0	75	54	50	50	24.0
0	150	48	50	45	54.0
0	300	44	47	40	110.0
0	600	36	38	36	251.0
0	1200	30	31	28	608.0
1	0	35	35	37	3.3
1	75	34	33	31	23.0
1	150	32	33	29	48.0
1	300	29	30	29	107.0
1	600	23	26	25	241.0
1	1200	21	22	21	575.0

0 = no lime , 1 = lime added.

Table 16 : Regression coefficients and F values for the effect of applied Zn on Pw-value of soil.

Terms	soil samplings			
	1st		2nd	
	regression coef.	F value	regresiion coef.	F value
Zn	-1.197	150.9***	-1.014	118.7***
L	-7.550	171.7***	-7.517	186.5***
ZnxL	0.316	10.6*	0.279	8.9*
R	0.9911		0.9907	

The residual P effect on yields and mineral composition

In 1971 an exploratory experiment(VP-1059) with soil B (table 2) was set up in order to investigate the effects of added P and lime on bean dry matter yield and composition. The soil studied contains excess Zn as determined by extraction with 2.5% acetic acid. This experiment was continued till 1973 and the results obtained are discussed below:

Experiment VP-1059/71

Beans were used as a test crop. The results obtained show that application of lime induced a yield response to applied P levels, the effect being positive and highly significant as indicated by the positive regression coefficient(table 17, fig. 9). Similarly, the effect of lime in the presence of P is positive and highly significant(photo 1 and 3). The positive effect of P was intesified by the higher lime levels and conversly, as shown by the positive and highly significant PxL interaction.

Since there was not enough material for analysis of plants grown on the unlimed soils(table 18), it has been impossible to statistically evaluate the effect of P and lime on the mineral composition of beans. However, the available chemical analysis for P and Zn of plants grown on the limed soil reveal the following: P has a definite positive effect on P concentration and a negative effect on Zn concentration of plant tops.

Experiment VP-1059/72

During 1972 beans were also used as test crop. All pots

Table 17: Regression coefficients and F values for dry matter yields of beans grown during 1971.

Terms	Dry matter yields g. regression coefficient	F value
P	0.291	48.5***
L	2.410	95.3***
P^2	0.044	0.5
PxL	0.231	30.0**
Mean yield	3.22	
R^1	0.957	

[1]Multiple correlation coefficient. ***, **, * = 1‰, 1% and 5% level of significance, respectively.

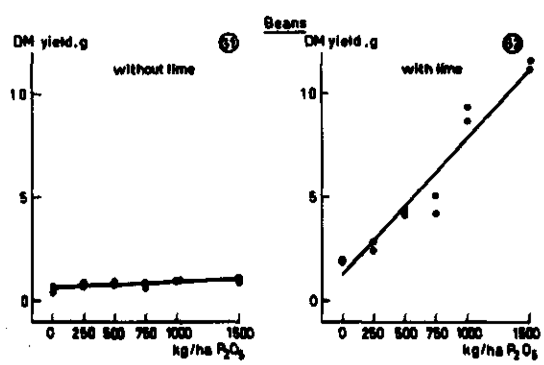


Fig. 9. Effect of applied P on dry matter yield of French beans grown in the presence of two levels of lime

of replicate I(RI) received half of the P_2O_5 quantity added in 1971. This was done in order to evaluate the residual effect on plant growth and mineral composition. Thus, the data obtained during the second year showed that the effect of freshly added P on dry matter yield and P concentration was positive and highly significant. Residual P had a similar positive effect, but the yield response was not significant(table 19 and 20). Both,**freshly** applied and residual P had a significant ne-

Table 18 : Yield and composition of French beans grown in 1971 as affected by P and lime application.

Treatments		Dry matter, g.		Composition	
lime	P_2O_5 kg/ha	RI	RII	P_2O_5%	Zn, ppm
0	0	0.43	0.64	-	-
0	250	0.71	0.82	-	-
0	500	0.81	0.86	-	-
0	750	0.65	0.86	-	-
0	1000	0.98	0.98	-	-
0	1500	0.90	1.09	-	-
1	0	1.85	1.96	0.38	850
1	250	2.88	2.43	0.45	683
1	500	4.14	4.33	0.48	549
1	750	4.20	5.06	0.57	465
1	1000	9.32	8.66	0.61	355
1	1500	11.18	11.57	0.81	287

0 + No lime, 1 = Lime added.

gative effect on plant Zn concentration. The effect of lime on dry matter yield was positive but only highly significantly so in plant receiving additional P, while significant at 10% level in plants growing on residual P. Plant Zn and P concentrations were negative and highly significantly affected by lime irrespective of freshly added or residual P(fig. 10).

It is interesting to note that the PxL interaction is rather similar for residual and freshly added P, differing only in the level of significance and in the magnitude of the regression coefficient. Thus, the PxL effect is highly significant for dry matter yields of plants grown on additional but not on residual P. The negative PxL interaction on P concentration indicates that optimum P uptake occurs at a high P and low lime rate, the slope of the P response curve being diminishing with additional P increments, as shown by the highly significant and negative P^2 effect on dry matter yield and concentration of plant P for plants given additional P. The observed low residual P effect on dry matter yield could be explained on the basis of the mineral composition data. It is shown in table 19 and 20 that the mean P concentration of beans given additional P is higher than that of plants grown on residual P(0.677 vs 0.505 %), whereas the opposite holds for Zn(fig. 10) These differences in composition probably reflect a reduction in Zn toxicity.

Attempts to explain the observed low residual P effect lead to the postulation that P might have been fixed. Fractionation of soil P by the method suggested by Chang and Jackson (1957) disclosed that a considerable amount of P had been fixed in the form of Fe-phosphate, a smaller fraction as Ca-phosphate and a negligible amount as Al-phosphate. Statistical analysis indicated that the main effect of P on Fe-phosphate formation was positive and significant at 1%。 and 5% level for soils with additional and residual P, respectively(table 21). On the other hand, lime had a negative and highly significant effect on soils with additional P, indicating that there was a competition between Ca and Fe for P fixation. This competition seems to occur at its maximum when lime is at higher rate as suggested by the negative and significant at 5% level PxL interaction for soils with additional P(fig. 11).

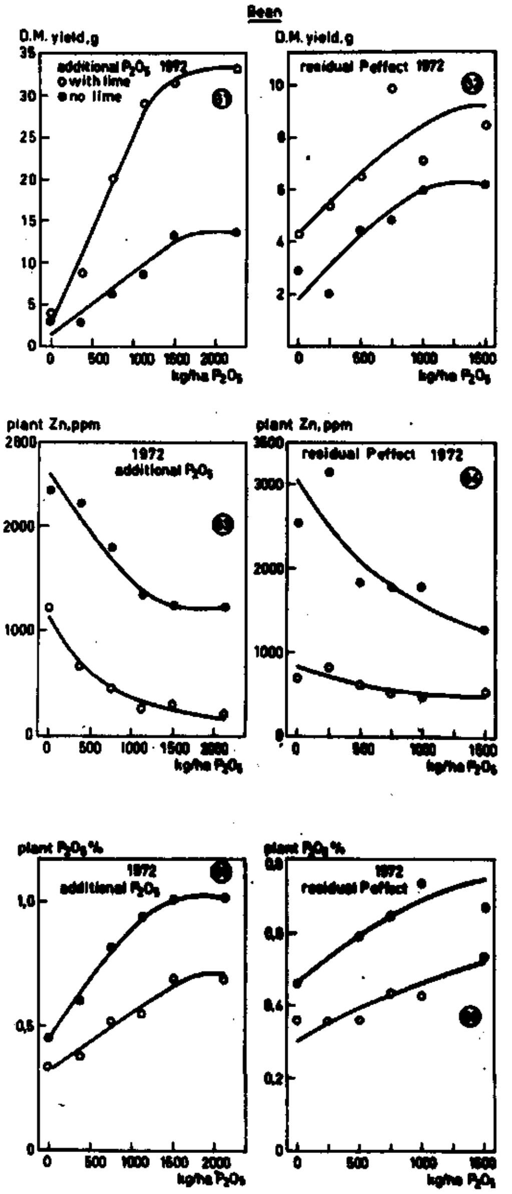


Fig. 10. Effect of additionally applied or residual P on dry matter yield, Zn and P concentration of bean plants grown in the presence of two levels of lime.

Table 19 : Regression coefficients and F values for dry matter yields, plant Zn and P_2O_5 concentration of beans grown on pots with extra phosphate added in 1972.

Terms	Dry matter, g.		Plant Zn, ppm		Plant P_2O_5%	
	regres. coeffic.	F value	regres. coeffic.	F value	regres. coeff.	F value
P	1.242	130.9***	-60.160	101.4***	0.029	278.9***
L	6.595	105.5***	-587.58	276.3***	-0.148	205.8***
P^2	-0.581	11.5*	42.79	20.5**	-0.013	21.7**
PxL	0.520	22.9**	10.38	3.0^e	-0.008	19.2**
Mean yield	14.600		1116.8		0.677	
R[1]	0.9890		0.9930		0.994	

Table 20 : Regression coefficients and F values for dry matter yields, plant Zn and P_2O_5 concentration of beans grown on pots without extra phosphate in 1972.

Terms	Dry matter, g.		Plant Zn, ppm		Plant P_2O_5 %	
	regres. coeff.	F value	regres. coeff.	F value	regres. coeff.	F value
P	0.241	3.11^e	-47.380	8.8*	0.012	48.6***
L	1.753	4.72^e	-733.580	60.3**+	-0.092	80.1***
P^2	-0.262	1.48	8.640	0.1	-0.003	1.2
PxL	0.006	-	33.600	4.4^e	-0.002	1.7
Mean yield	6.200		1348.8		0.505	
R[1]	0.791		0.9620		0.979	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5% and 10% level of significance, respectively.

Table 21 : Regression coefficients for Fe-phosphate[2] content of soil as affected by various phosphate treatments

T e r m s	Fe-phosphate, ppm			
	extra P added		residual P	
	regression coefficient	F value	regression coefficient	F value
P	2.2267	100.8***	1.4821	15.3*
L	-6.3375	22.5**	3.2875	2.1e
P^2	-0.5521	2.3e	-0.7247	1.5
PxL	-0.4714	4.2*	0.0750	0.0
Mean	35.1		37.6	
R[1]	0.978		0.878	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5%, and 10% level of significance, respectively.

[2]Soil was sampled after the growth of beans 1972.

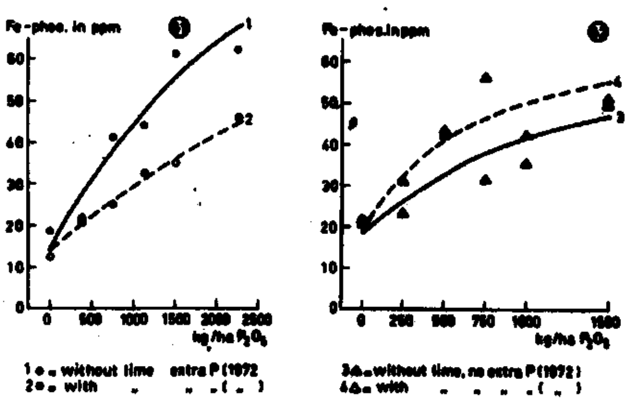


Fig. 11. Effect of additionally applied or residual P on Fe-phosphate formation of a Zn polluted soil in the presence of two levels of lime

However, fixation by Fe only can not account for the observed low residual P effect. It has already been shown that excess soil Zn can fix considerable amounts of added P. Furthermore, P may also be fixed by the organic matter of soil. According to unpublished data[1] of Sissingh(1973), the organic P fraction of a similar soil with comparable pH, organic matter, and texture, was about 30% of the total P content of soil.

Thus, fixation can possibly explain at least partially, the low residual P effect found. More work is necessary however, in order to get a better insight into the nature of the problem.

Experiment VP-1059/73

In 1973 the pots of the replicate II(RII) of the afore mentioned experiment, received half of the P_2O_5 quantity added in 1971. The pots of RI were left untreated for purposes of comparison and evaluation of residual P effect.

It was found that the mean yields of maize plants grown on the additionally applied P was slightly lower than that of plants grown on residual P. This is reflected in the mineral composition of plants(fig. 12). It can be seen that the mean plant Zn concentrations were almost equal(see also tables 22 and 23). There is however a small positive difference in P composition for plants given additional P. The main P, lime and PxL effects largely follow the same trend as shown for beans (tables 19 and 20), the differences being in the level of significance and in the magnitude of the regression coefficients, which were higher for additional than for residual P. This indicates that with the time, somehow P is inactivated(fixed), thus becoming less available to plants. There is also a similarity with the P effect in the change of the regression coefficients for the lime effect on dry matter yield, with additional and

[1]Personal communication by Dr. H.A.Sissingh, Department of Soil Chemistry, Institute for Soil Fertility, Haren (Gr.) the Netherlands.

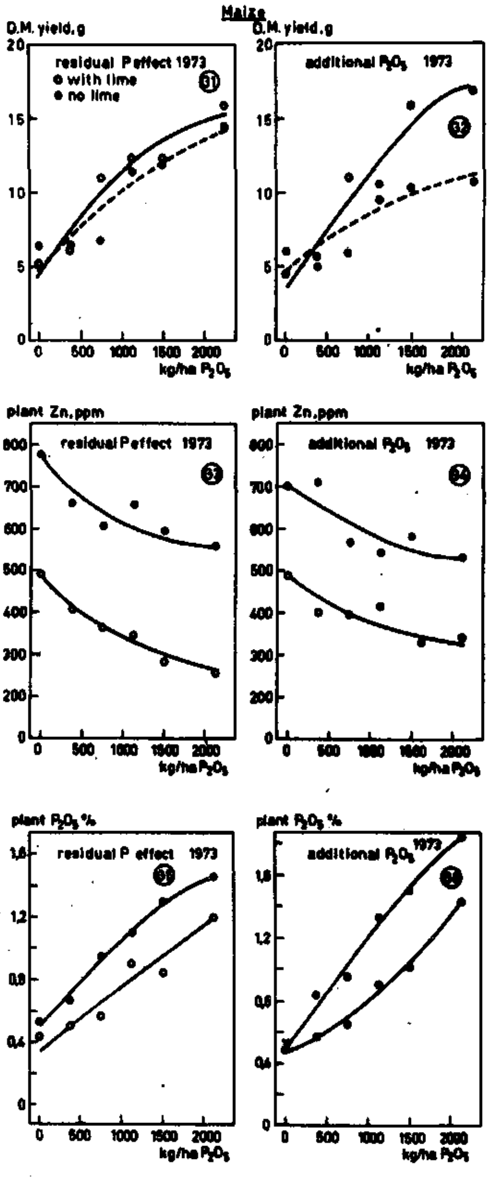


Fig. 12. Effect of additionally applied or residual P on dry matter yield, Zn and P concentration of maize plants grown in the presence of two levels of lime.

residual P. This fact lends further support to the postulation that P is most probably fixed by Ca.

Table 22 : Regression coefficients and F values for dry matter yield, plant Zn and P_2O_5 concentration of maize grown on pots without extra phosphate in 1973.

Terms	Dry matter, g.		Plant Zn, ppm		Plant P_2O_5%	
	regres. coeff.	F value	regres. coeff.	F value	regres. coeff.	F value
P	0.5426	78.2***	-11.220	50.3***	0.048	33.7**
L	0.2617	0.5	-141.83	229.7***	-0.128	166.5***
P^2	-0.1891	3.8e	4.89	3.8e	-0.006	1.0
PxL	0.0855	1.9	-1.3700	0.8	-0.005	1.5
Mean	11.48		500.0		0.865	
R[1]	0.967		0.989		0.986	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5%, and 10% level of significance, respectively.

Contrary to beans and maize, the results obtained with lettuce are suggestive of the existence of strong residual effect. This is inferred from the higher mean value for dry matter yield of plants grown on residual P than for plants grown on freshly added P(table 24). The observed difference however, should be treated with caution, because as it has already been emphasized the general purpose of the experiment was exploratory and therefore further experimentation is necessary to substantiate the above results.

Unfortunately, since there was not enough material from the lettuce plants grown on the unlimed soil, statistical evaluation of the additionally applied or residual P effect on mineral composition was impossible. However, examination of fig. 13 discloses that the average Zn concentration of plants grown on the residual P was lower than that of plants grown on freshly added P. It can be also seen that the average P concentration of plants was about the same for both freshly added and residual P. Furthermore, the analysis of variance for lettuce dry matter yields indicated that the main P and lime effects as well as their interaction were similar to those demonstrated earlier for maize and beans.

Table 23 : Regression coefficients and F values for dry matter yields, plant Zn and P_2O_5 concentration of maize plants grown on pots with extra phosphate added in 1973.

Terms	Dry matter, g.		Plant Zn, ppm		Plant P_2O_5 %	
	regres. coeff.	F value	regres. coeff.	F value	regres. coeff.	F value
P	1.228	27.0**	-106.00	17.3**	0.063	1345.4***
L	0.582	3.4e	-8.42	78.1**	-0.169	281.4***
P^2	-0.091	0.3	4.89	2.3e	-0.003	0.9
PxL	0.228	4.1e	1.14	0.3	-0.009	29.0**
Mean	9.98		503.5		0.998	
R[1]	0.924		0.971		0.998	

[1]Multiple correlation coefficient. ***, **, *, e = 1‰, 1%, 5%, and 10% levels of significance, respectively.

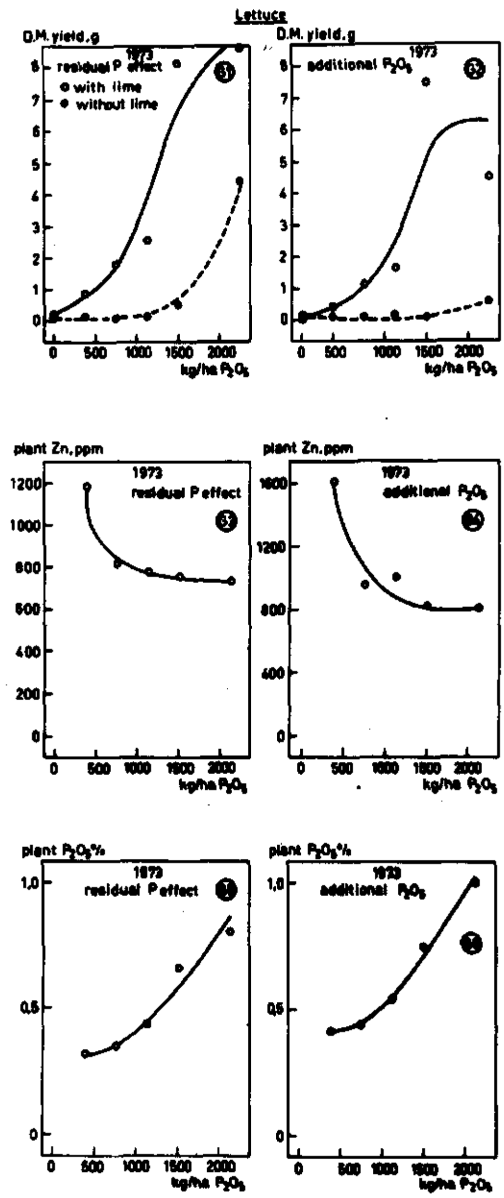


Fig. 13. Effect of additionally applied or residual P on dry matter yield, Zn and P concentration of lettuce plants grown in the presence of two levels of lime.

Table 24 : Regression coefficients and F values for dry matter yields of lettuce grown on pots without and with extra phosphate in 1973.

Terms	Dry matter, g.(No extra P)		Dry matter, g(Extra P)	
	regression coefficient	F value	regression coefficient	F value
P	0.3774	35.9***	0.1239	61.2***
L	1.3183	12.5*	0.6817	52.9***
P^2	0.1176	1.4	0.0652	6.8*
PxL	0.1633	6.7*	0.1042	43.2**
Mean	2.93		0.86	
R[1]	0.951		0.982	

[1]Multiple correlation coefficient. ***, **, * , e = 1‰, 1%, 5%, and 10% level of significance, respectively.

The results of the present study show that the plants investigated respond differently to excess Zn in the Neerpelt soil. It is suggested that the yield response to applied P depends on the ability of plants to selectively exclude or accumulate Zn in their tissues. Thus, high Zn accumulator plants, such as cotton, tomato, and beans, failed almost completely to grow on the unlimed soil, while maize and sudan grass, having accumulated lower amounts of Zn, responded positively to P application. This finding suggests that maize and sudan grass and perhaps other members of the Gramineae family could grow successfully on such soils with excess Zn, provided there is a good supply of P, while tomato, cotton and beans could grow only if the soil is properly limed.

The evidence obtained in this study with respect to Zn accumulation and consequent growth retardation of plants, seems to be in line with the results reported by Boawn(1971). He found that swiss chard and spinach tended to accumulate Zn and that these two crops were the only ones out of the twelve studied, suffering from growth depression when grown on plots treated with high Zn levels(800 lbs/acre Zn). Furthermore, there is no real evidence that Zn accumulator plants have any greater tolerance to excess soil Zn, though it may be true for some tree species(Stone, 1968). In fact, this Zn accumulating tendency of some plant species appears to limit yields under the stress of excess soil Zn. It seems that cotton, tomato and beans, belong to this category of plants.

The concept of Zn toxicity is not yet well understood. According to some workers Zn toxicity may be due to direct poisonous effect of excess Zn in plant tissues on metabolic processes. Chapman(1966) reports that 526 - 1486 ppm of Zn in tomato leaves is considered excessive and eventually growth retarding. On the other hand other investigators believe that Zn may interfere with the metabolism of Fe(Brown and Tiffin, 1962) and (Polson and Adams, 1970), and perhaps Mn, thus, manifesting its toxicity to plants in an indirect way.

The results of the present work also show that excess soil Zn interfers with the uptake of P by the tomato plants, whose average leaf P composition was below the sufficiency limits reported by Smilde and Roorda van Eysinga(1968). However, the inability of cotton, tomato and beans to grow on the unlimed soil and their high leaf Zn concentration suggests that Zn affected its toxicity through a direct poisonous effect rather than an indirect interference with the P uptake. The importance of the latter effect should however not be underestimated, for it has been stated by Boawn and Rasmussen(1971) that excess soil Zn may cause P deficiency symptoms, thus retarding growth.

The mineral composition data show that applied P had in general a negative effect on Zn concentration, but trends for Fe and Mn were less pronounced. On the other hand total metal uptake was increased by applied P, except in cotton. Lime generally decreased both metal concentration and total uptake , except in cotton. It has been suggested that the negative effect of P on Zn concentration of plants is caused by the " dilution" induced by the growth promotive effect of applied P(Smilde, 1973) and (Christensen, 1972). However, the data obtained indicated that the observed depressive effect of P on plant Zn concentration could not be explained on the basis of a mere "dilution effect" only. As a matter of fact the excess Zn of soil studied interferred with the P concentration of tomato leaves causing severe P deficiency symptoms. Furthermore, there was a negative and statistically significant effect of added P on M NH_4Ac extractable soil Zn. Finally, the observed depressive Zn effect on soil P availability is also suggestive of the complicated nature of the P-Zn interaction. It can thus be postulated, in the light of the above findings that the following three factors may sufficiently explain the P-Zn antagonism: (a) The mutual depressive effect in the soil leading to fixation of these elements (b) The dilution effect due to growth promotive effect of P , and (c) The mutual depressive effect in the roots of plants as reported in the literature(Stukenholtz et al.,1966) and (Koukoulakis 1967).

The residual P effect varied with the plant species investigated, and that there was a good agreement between the mineral composition of crops and the attained yields. The plant Zn concentration was an important factor in controlling plant growth and yields. The results are suggestive of the continuation of the present experimental work in order to get a better insight into the nature of the problem, for it has not been possible to fully account for the observed low residual P effect on dry matter yield of crops investigated.

SUMMARY

Six glasshouse experiments were conducted in order to study (a) the effect of P and lime on dry matter yield and mineral composition of tomato, cotton, maize and sudan grass grown on a Zn polluted soil(containing 170 ppm of 2.5% acetic acid extractable Zn).(b) The effect of residual P on dry matter yield and mineral composition of beans, lettuce, and maize grown on a similar soil and (c) The effect of various Zn treatments on the availability of indigenous and added P of a soil low in Zn(11 ppm)

It was found that the yield response to applied P of maize and sudan grass was independent of lime, while cotton tomato and beans failed almost completely to respond in the absence of lime. The crops investigated, responded differently to the excess soil Zn and the dry matter yields were related to the ability to accumulate Zn. High Zn accumulator plants failed to respond to applied P in the absence of lime, while low Zn accumulating plants responded positively. The positive and highly significant effect of P on total Zn uptake of plants, masked the depressive effect of P on Zn concentration. However, the results indicated that the P-Zn interrelationship is far more complicated than a mere "dilution effect" caused by the promotive effect of applied P. Studies of the effect of applied Zn levels on available soil P and conversely, indicated that a strong mutual fixation, probably coprecipitation takes place in the soil, which may account for a considerable part of the depressive effect of P on plant Zn, in addition to the effects like coprecipitation in roots and dilution,reported in the literature.

Finally, the residual effect of P varied with the plant species, and the plant Zn concentration was found to be a determinant factor in controlling dry matter yields.

ACKNOWLEDGEMENTS

I express my gratitude to Dr K.W.Smilde for his encouragement, numerous suggestions made throughout the course of the present study, as well as for the critical reading of the manuscript. Thanks are also extended to Ing. B. van Luit for his valuable help in performing the experiments and drawing the graphs. Furthermore, appreciation is expressed to Ir. J.T.V. Venekamp and D.K. van Mullem for statistical analysis and computer programming, Mr H.C. Vierveijzer for chemical analysis of the plant samples, Mr. S.S. de Bes, head of the Research Laboratory of the Glasshouse Research and Experiment Station, Naaldwijk, the Netherlands, for soil analyses, and Mr. P.C. Siebelink for supervising the publication of this report, as well as all those staff members of the Institute, namely, research officers, technicians, analysts and labourers, who helped in the timely completion of the present work.

I also feel indebted to the Director of the Institute for Soil Fertility Ir. C.M.J. Sluijsmans for making available all the necessary facilities during my work at the Institute.

The present work however, would have been impossible without the financial support of the International Agricultural Centre, Wageningen, the Netherlands to which I express my sincerest appreciation for granting me the study fellowship. Finally, I wish to extend my thanks to Mr. P. Tziolas, head of the Agricultural Research Station for Soils and Fertilization of Thessalia, Larissa, Greece, Dr V. Bekiaris, Director of the Agricultural Research Service and the Secretary General of the Department of Agriculture, Ministry of National Economy, Athens, Greece, Mr. D. Dimopoulos for making possible my educational mission to the Netherlands.

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