Peanut yield response to micro and macronutrients of a Ferric Lixisol in the Guinea savanna zone of Ghana

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ABSTRACT

A field experiment was conducted on a Ferric Lixisol at the Savanna Agriculture Research Institute, Wa (10° 3ǀ N, 20° 50ǀ W) in the Guinea savannah zone of Ghana in 2010 and 2011, to study the effect of Cu, Mn, Zn, Ca, P and K on elemental uptake, peanut yield and yield components. Nine treatments were arranged in a randomized complete block (RCB) design with four replicates. Results from the study showed that nutrient application had a positive effect on nutrient concentration, nutrient uptake, pod yield, seed yield and total biomass. The PK + gypsum + Zn treatment had the highest pod yield, seed yield and total biomass. Increases in pod yield of the fertilized treatments ranged between 16.6 per cent and 47.8 per cent over the control. Where micronutrients were combined, some antagonism between micronutrients was also observed. Application of the macronutrients P and K and the micronutrient Zn had the greatest impact on yield.

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Introduction

The average yields of peanut (groundnut) in most parts of West Africa are lower (903 kg ha^{-1}) than those in South Africa (2000 kg ha^{-1}), Asia (1798 kg ha^{-1}) or the rest of the world (1447 kg ha^{-1}) (FAO 2005). Part of the reasons for the low yields of peanut in West Africa is the low inherent soil fertility, especially phosphorus (P) deficiency. Adequate supply of P and calcium (Ca) in these soils is essential for pod and kernel development (Sumner *et al*., 1988; Gascho & Davies, 1994, 1995). Also, most of the fertilizers used in West Africa provide mainly macronutrients. Thus, little attention is given to the role that micronutrients play in fertilizer use efficiency of the major nutrients and eventually on crop yield (Hikwa & Mukurumbira, 1995).

Micronutrients are essential plant minerals taken up and utilised by crops in very small quantities. Deficiencies of micronutrients have been diagnosed more frequently in soils in sub-Saharan Africa (Kamasho, 1980). When micronutrients become limiting, water, fertilizer and other production inputs may be wasted, since a plant will only grow and develop to the extent that its most limiting growth factor(s) will allow. Highly-weathered cultivated soils commonly suffer from multiple nutrient deficiencies, and nutrient balances are generally negative (Mokwunye, Jager & Smailing, 1996). Farmers who grow peanuts in the Guinea savanna zone of Ghana do not apply any nutrients at all. Soil fertility management on small holer farms in the tropics has become a major issue, as a result of continued land degradation and declining soil fertility.

Very little work has been done on the macronutrient Ca as well as the micronutrients Cu, Mn and Zn in the soils in peanut growing areas in northern Ghana. As a result, these nutrients in combination with the major nutrients P and K in these soils, and their effect on peanut yield are not very well known. Otherwise, the area has favourable climate and physical soil properties. Such conditions are favourable for relatively high yields of peanut once any limiting nutrients are corrected. The objectives of this study were to evaluate the levels of Ca, Cu, Mn and Zn in peanut fields and assess the addition of Cu, Mn, Zn, Ca, P and K fertilizers on the yield of peanut in the Guinea savanna zone of Ghana.

Materials and methods

Experimental site and design

The experiment was conducted on a sandy loam classified as a Ferric Lixisol (FAO, 2001) at the Savannah Agricultural Research Institute, Wa (10° 3^{l} N, 20° 50^{l} W) in 2010 and 2011. The area experiences a mono-modal rainfall pattern of 5 – 6 months yearly beginning from May to October, with a long term annual mean precipitation between 1000 and 1120 mm. Temperatures are generally high with maximum and minimum temperatures of 34.3 °C and 23.4 °C, respectively.

Prior to sowing, representative soil samples were collected for soil nutrient analysis. Ten replicate soil samples (about 250 g each) were taken from the top 20 cm of the site in a diagonal or zigzag pattern to provide a uniform distribution of sampling sites. The soil samples were placed in plastic bags and labeled before transporting to the laboratory. The replicates from the field were mixed thoroughly to give a composite sample. In the laboratory, the soil sample was air-dried, cleaned of any stones and plant residues and passed through a 2 – mm sieve. Sub-samples were then taken for analysis of organic carbon, total N, P, K, Ca, *p*H, Cu, Mn, and Zn. The *p*H was determined using a glass and reference electrode with a *p*H meter on a 1:1 suspension of soil to water ratio. Ca and K were extracted from the soil using neutral ammonium acetate (1N).

Total N and available P were determined by a modified Kjeldahl digestion method (Bremner, 1965) and Bray 1 method of Bray & Kurtz, (1945), respectively. Exchangeable K was determined by flame photometry. Organic carbon was determined by the Walkey-Black (1934) method. The elements Cu, Mn and Zn were also extracted by the diethylene triamine pentaacetic acid (DTPA) method of Lindsay & Norvell (1978), and their amounts in the samples determined by atomic absorption spectrophotometry. Triple superphosphate, murate of potash, $CuSO_4.5H_2O$, $ZnSO_4.7H_2O$ and $MnSO_4.3H_2O$ were used as sources of nutrients. The amounts of Cu, Mn and Zn were applied based on the suggested critical levels in soils (Lindsay & Norvell (1978). The elements Cu, Mn and Zn were applied at 1.25 kg Cu ha^{-1}, 2.5 kg Mn ha^{-1} and 2.5 kg Zn ha^{-1}, respectively. Ca in the form of gypsum ($CaSO_4.7H_2O$) was applied at a rate of 90 kg Ca ha^{-1}, with P and K applied at 60 and 30 kg ha^{-1} of P_2O_5 and K_2O, respectively. The Ca application rate took into account the amount of Ca supplied by triple superphosphate. The fertilizers were spread evenly on the soil surface and then incorporated into the soil before sowing

Nine treatments (Table 1) were established in a randomized complete block (RCB) design with four replicates. A peanut variety known as Chinese was used for the study. Seeds were sown in each plot (8 m × 4 m) at a spacing of 0.1 m within rows and 0.5 m between rows, giving a total plant population of 20 plants m^{-2}. Plots were kept free of weeds. Rainfall and temperature data were obtained during the growing season. At flowering, leaf and stem samples were collected by harvesting four plants from each plot. This was done when almost 50 per cent of peanut plants were at the flowering stage.

The leaf and stem samples were oven dried at 65 °C to constant weight, cut into small pieces, and ground to pass a 0.5 – mm sieve for chemical analysis. At the end of the season in 2010 and 2011, plants from the four inner rows were manually harvested and pods removed. A sub-sample of six plants was taken from the large plot yield sample. The plants were depodded and the fresh weights of pods, leaves and stems were recorded (excluding roots). The sub-samples were oven dried and the dry weights of the leaves, stems and pods that had not collapsed after drying were obtained. The dry matter yields and ratios of the sub-samples were then used to calculate pod yield, stem and leaf weight, and total biomass of each plot. Pod yield was computed from large plot harvest on a dry weight basis.

Uptake of nutrients was determined by determining the nutrient concentrations and seed, stem and leaf yields. Pod harvest index (PHI) was obtained by dividing the sub-sample pod mass by the total biomass of the sub-sample. The whole plot biomass was calculated by dividing the whole plot pod yield by the PHI.

Fifty oven-dried pods were randomly selected from the sub-sample and shelled. Shelling percentage was measured by dividing the seed dry weight by the weight of seed plus shell, expressed as a percentage. One hundred oven-dried seeds were randomly selected to determine the weight of 100 seeds and the weight per seed. Equations for the various calculations are shown in equations one to five. Analysis of variance (ANOVA) was conducted on pod yield, seed yield, biomass, unit seed weight, pod harvest index (HI) and shelling percentage using the procedures of SAS (SAS Institute, 2009).

$$\text{Whole plot pod yield dry weight (W)} = \frac{z}{x} \times y \qquad (1)$$

where x is the sub-sample fresh pod weight, y is the sub-sample oven-dried pod weight, and z is the whole plot fresh pod weight.

$$\text{Nutrient uptake} = \text{Nutrient concentration} \times \text{yield} \qquad (2)$$

$$\text{PHI} = \frac{\text{Subsample oven dry pod weight}}{\text{Subsample oven dry total biomass (leaf+stem+pod)}} \qquad (3)$$

$$\text{Whole plot biomass dry weight} = \frac{\text{Whole plot pod yield dry weight (W)}}{\text{PHI}} \qquad (4)$$

$$\text{Shelling percentage (\%)} = \frac{\text{Oven dry seed weight}}{\text{Oven dry pod weight}} \times 100 \quad (5)$$

TABLE 1

List of Treatments Used in the Field Experiment in 2010 and 2011 in Wa, Ghana

Number	*Treatment*	*Description and micronutrient used*
1	Control	No nutrient application
2	P	P only
3	K	K only
4	PK	P + K
5	PK + $CaSO_4.7H_2O$	P + K + $CaSO_4.7H_2O$
6	PK + $CaSO_4.7H_2O$ + Cu	P + K + $CaSO_4.7H_2O$ + Cu
7	PK + $CaSO_4.7H_2O$ + Mn	P + K + $CaSO_4.7H_2O$ + Mn
8	PK + $CaSO_4.7H_2O$ + Zn	P + K + $CaSO_4.7H_2O$ + Zn
9	PK + $CaSO_4.7H_2O$ + CuZnMn	P + K + $CaSO_4.7H_2O$ + Cu + Zn + Mn

Results and discussion

Chemical properties of the experimental soil

Some of the chemical properties of the soil at the experimental site are shown in Table 2. Soil *p*H was 6.1 and total N was low with a value of 0.11 per cent. Organic carbon was low with a value of 0.54 per cent. The Bray 1(Available) P, exchangeable Ca and exchangeable K were 8.6 mg kg^{-1}, 3.1 cmol kg^{-1} and 0.2 cmol kg^{-1}, respectively. The DTPA (diethylene triamine pentaacetic acid) extractable Cu was 0.13 mg kg^{-1}. According to Lindsay & Norvell (1978), the critical level of DTPA-extractable Cu in soil is 0.5 mg kg^{-1}; therefore, a DTPA-extractable Cu level of 0.13 mg kg^{-1} in the soil is low since it is below the soil critical level. The DTPA-extractable Zn in the soil was 0.36 mg kg^{-1}. Lindsay & Norvell (1978) suggested levels of 0.5-1.0 mg kg^{-1} to be the critical levels for Zn, therefore, the concentration of 0.36 mg Zn kg^{-1} is rated as low. The level of Mn (0.86 mg kg^{-1}) in the soil was also low compared to the critical level of 1.0 mg kg^{-1} (Lindsay & Norvell, 1978).

TABLE 2

Selected Chemical Properties of the Soil at the Experimental Site in Wa, Ghana

Property	*Value*
*p*H in water	6.10
Organic C(%)	0.54
Total N (%)	0.11
Bray 1 P, mg kg-1	8.60
Exchangeable Ca, cmol kg^{-1}	3.10
Exchangeable K, cmol kg^{-1}	0.20
DTPA-etractable Cu, mg kg^{-1}	0.13
DTPA-etractable Mn, mg kg^{-1}	0.86
DTPA-etractable Zn, mg kg^{-1}	0.36

Growth environment

Environmental conditions at Wa during the 2010 and 2011 growing seasons (June-October) are provided in Table 3. In 2010, Wa recorded a mean temperature of 27.1 °C. Total rainfall from June to October in 2010 was 956.4 mm which occurred in 59 rainfall events. During the 2011 growing season, a mean temperature of 27.2 °C was recorded. Total rainfall from June to October in 2011 was 724.1 mm which occurred in 60 rainfall events. Mean temperature and number of rainfall events during the growing season for 2010 and 2011 were similar. Total amount of rainfall in 2010 was 352.5 mm higher than in 2011. The 2010 growing season was, therefore, wetter than the 2011 season. For both the 2010 and 2011 growing seasons, the month of August had the highest amount of rainfall.

TABLE 3

Climate Data During the Growing Season (June-October) for Wa in 2010 and 2011

	2010	*2011*
Climate variable		
Mean temperature (°C)	27.1	27.2
Total rainfall (mm)	956.4	724.1
Rainfall events	59	60
Monthly rainfall (mm)		
June	198.4	117.6
July	162.1	116.8
August	352.5	270.6
September	209.8	193.2
October	33.6	25.9

Nutrient concentrations and uptake by peanut shoots and seeds

The concentrations of N, P, K, Ca, Cu, Zn, and Mn in peanut shoots and seeds are shown in Tables 4 and 5, respectively. Applications of P, K, Ca, Cu, Zn, and Mn had a positive effect on their concentrations in peanut shoots and seeds as their concentrations increased. The higher N concentration in the fertilized treatments could be due to enhanced N fixation. Application of Cu and Mn stimulated the concentration of P in peanut shoots. In most cases, application of nutrients significantly increased nutrient concentrations in both shoots and seeds over the control. Uptake of N, P, K, Ca, Cu, Zn, and Mn in peanut shoots and seeds are shown in Tables 6 and 7, respectively. Uptake of nutrients was higher for treatments where nutrients were applied compared with the control. This increased uptake is due to increased concentration of elements as well as increased shoot and seed yield of the fertilized treatments. Among all the nutrients, N was taken up in the largest amount in shoots followed by K, Ca, and P. Sahrawat *et al*. (1988) in a study on micro and macronutrient uptake by peanut, made a similar observation where N was assimilated in the highest amount (176.6 kg ha^{-1}) followed by K, Ca, Mg and P.

Additions of the micronutrients Cu, Mn and Zn alone or together, in most cases, contributed significantly to the increase in the concentration and uptake of these nutrients, and eventually to the increase in yield of the fertilized treatments. However, interaction among these micronutrients also affected their concentration and uptake. Some level of antagonism among micronutrients was also noted, for example, addition of Mn and Zn reduced Cu concentration and uptake in shoots and seeds which agrees with results of Hatem *et al*. (1990). For Zn, application of Cu and Mn also decreased its concentration and uptake in shoots and seeds, which also confirms the antagonistic effect of these elements and Zn as shown by Moussa *et al*. (1993) for Mn and Zn.

In the case of Mn, addition of Zn and Cu decreased Mn concentration and uptake in vegetative parts. This also reflects the antagonistic relationship between Mn and Zn (Moussa *et al*., 1993) and Mn and Cu (Karamonos, Hodge & Stewart, 1989). This antagonism was, however, less pronounced for seeds. Loneragan & Webb (1993) also observed Zn-Cu interactions and they noted that these interactions occur due to Cu and Zn sharing a common site for root absorption. According to Guzman & Romero (1988), these interactions may occur due to one nutrient competing with another to depress its function (Mn-Zn and Mn-Cu), or one nutrient may substitute for another (Zn-Cu), or one nutrient may be required for the assimilation or metabolism of another.

Yield and yield components

Pod yield, seed yield, total biomass, shelling percentage, unit seed weight and PHI

TABLE 4

Mean Concentration of Elements in Peanut Shoots (Leaf and Stem) at Flowering in 2010 and 2011

Treatments	*Concentration of elements*						
	N	*P*	*K*	*Ca*	*Cu*	*Zn*	*Mn*
	%	%	%	%	*p.p.m.*	*p.p.m.*	*p.p.m.*
Control	2.3e	0.12e	0.97c	0.8ef	1.8c	2.1abc	3.7e
P	2.7bc	0.22bc	1.02bc	0.7f	1.7cd	2.0bc	3.8de
K	2.4de	0.15de	1.12a	0.9def	1.8c	1.9c	3.9d
PK	2.8bc	0.16de	1.08ab	1.0cde	1.7cd	2.0bc	3.4f
PK +$CaSO_4.7H_2O$	2.7bc	0.18cd	1.12a	1.3ab	1.6d	2.1abc	4.3c
PK +$CaSO_4.7H_2O$+Cu	2.6cd	0.27a	1.02bc	1.1bcd	3.2a	2.0bc	4.6b
PK +$CaSO_4.7H_2O$+Mn	2.9b	0.28a	0.98c	1.2abc	1.7cd	2.4a	5.7a
PK +$CaSO_4.7H_2O$+Zn	2.7bc	0.19cd	0.96c	1.4a	1.2e	2.3ab	4.2c
PK +$CaSO_4.7H_2O$+CuZnMn	3.5a	0.25ab	1.13a	1.1bcd	2.4b	2.2abc	4.6b

Means followed by the same letter in a column are not significantly different at $P < 0.05$

TABLE 5

Mean Concentration of Elements in Peanut Seeds at Harvest in 2010 and 2011

Treatments	*Concentration of elements*						
	N	*P*	*K*	*Ca*	*Cu*	*Zn*	*Mn*
	%	%	%	%	*p.p.m.*	*p.p.m.*	*p.p.m.*
Control	3.8b	0.80b	0.92a	1.0ab	1.2c	1.3a	2.4d
P	4.1ab	1.16a	0.91a	0.9b	1.5bc	1.2a	3.4b
K	3.9b	0.84bc	1.22a	0.9b	1.4c	1.3a	2.9c
PK	4.2ab	0.89bc	1.08a	1.0ab	1.4c	1.1a	3.2bc
PK +$CaSO_4.7H_2O$	4.6ab	0.94bc	0.98a	1.1a	1.4c	1.4a	3.2bc
PK +$CaSO_4.7H_2O$+Cu	4.7ab	0.97b	1.09a	1.0ab	1.8ab	1.3a	3.3bc
PK +$CaSO_4.7H_2O$+Mn	4.3ab	0.92bc	1.12a	1.0ab	1.2c	1.2a	3.9a
PK +$CaSO_4.7H_2O$+Zn	4.8ab	0.92bc	1.06a	1.0ab	1.3c	1.7a	3.1bc
PK +$CaSO_4.7H_2O$+CuZnMn	5.2a	0.98b	1.09a	1.0ab	1.9a	1.5a	3.9a

Means followed by the same letter in a column are not significantly different at $P < 0.05$

TABLE 6

Mean Uptake of Elements in Peanut Shoots (Leaf and Stem) at Flowering in 2010 and 2011

	Uptake of elements						
Treatments	*N*	*P*	*K*	*Ca*	*Cu*	*Zn*	*Mn*
	kg ha^{-1}				*g ha*$^{-1}$		
Control	60.0a	3.1a	24.9a	20.5a	4.6a	5.4a	9.5a
P	84.2c	6.9de	31.8b	21.8a	5.3bc	6.2b	11.8b
K	68.0b	4.2ab	31.7b	25.5b	5.1b	5.4a	11.0b
PK	91.4e	5.2bc	35.3cd	32.7c	5.6c	6.5bc	11.1b
PK +$CaSO_4.7H_2O$	92.4e	6.2cd	38.3e	44.5f	5.5bc	7.2d	14.7c
PK +$CaSO_4.7H_2O$+Cu	88.4d	9.2f	34.7cd	34.0d	10.9e	6.8cd	15.6c
PK +$CaSO_4.7H_2O$+Mn	95.9f	9.3f	32.4b	39.7e	5.6c	7.9e	18.8d
PK +$CaSO_4.7H_2O$+Zn	94.2f	6.6d	33.5bc	48.8g	4.2a	8.0e	14.6c
PK +$CaSO_4.7H_2O$+CuZnMn	112.3g	8.0e	36.3de	35.3d	7.7d	7.1d	14.8c

Means followed by the same letter in a column are not significantly different at $P < 0.05$

TABLE 7

Mean Uptake of Elements in Peanut Seeds at Harvest in 2010 and 2011

	Uptake of elements						
Treatments	*N*	*P*	*K*	*Ca*	*Cu*	*Zn*	*Mn*
	kg ha^{-1}				*g ha*$^{-1}$		
Control	23.6a	5.0a	5.7a	6.2a	0.7a	0.8a	1.5a
P	31.3b	8.9e	6.9ab	6.9abc	1.1bc	0.9ab	2.6c
K	28.6ab	6.2b	8.9abc	6.6ab	1.0b	1.0bc	2.1b
PK	37.0c	7.8c	9.5bc	8.8bcd	1.2c	1.0bc	2.8cd
PK +$CaSO_4.7H_2O$	40.1cd	8.2d	8.5a	9.6d	1.2c	1.2d	2.8cd
PK +$CaSO_4.7H_2O$+Cu	41.6cd	8.6e	9.6bc	8.9c	1.6d	1.2d	2.9d
PK +$CaSO_4.7H_2O$+Mn	39.4c	8.4de	10.3c	9.2d	1.1bc	1.1cd	3.6e
PK +$CaSO_4.7H_2O$+Zn	45.1de	8.6e	10.0c	9.4d	1.2c	1.6f	2.9d
PK +$CaSO_4.7H_2O$+CuZnMn	47.1e	8.9e	9.9c	9.1d	1.7d	1.4e	3.5e

Means followed by the same letter in a column are not significantly different at $P < 0.05$

of all the treatments are shown in Table 8. Pod yields for the 2011 season were generally higher than for the 2010 season. The higher amount of rainfall in the 2010 season may have accounted for the relatively lower yields in 2010. Under more humid or wetter conditions, the fungal diseases, early leaf spot caused by *Cercospora arachidicola* and late leaf spot caused by *Cercosporidium personatum*, become critical yield-limiting diseases of groundnut in West Africa (Waliyar 1991; Waliyar, Adomau & Traore, 2000), accounting for yield reductions of 50 per cent to 70 per cent where fungicides

TABLE 8

Mean Performance for Pod Yield, Seed Yield, Biomass, Shelling Percentage, Seed Size and Pod Harvest Index (PHI) in 2010 and 2011

	Pod			*Seed*	*Biomass*	*Shelling percentage*	*Seed size*	*PHI*
Treatments	*2010* Kg ha^{-1}	*2011* Kg ha^{-1}	*Mean* Kg ha^{-1}	Kg ha^{-1}	Kg ha^{-1}	*%*	*g*	
Control	964d	830c	897de	620d	2565c	69.3b	0.273a	0.350a
P	982d	1216b	1099bc	763bcd	3117abc	69.5b	0.284a	0.353a
K	884de	1208b	1046cd	733cd	2833bc	70.1ab	0.276a	0.369a
PK	1200ab	1320ab	1260ab	881abc	3266ab	69.9ab	0.273a	0.386a
PK +$CaSO_4.7H_2O$	1274a	1238b	1256ab	871abc	3421ab	69.3b	0.276a	0.367a
PK +$CaSO_4.7H_2O$+Cu	1193ab	1293ab	1243abc	885abc	3400ab	71.0ab	0.289a	0.366a
PK +$CaSO_4.7H_2O$+Mn	1212ab	1346a	1279ab	916ab	3306ab	71.6a	0.284a	0.387a
PK +$CaSO_4.7H_2O$+Zn	1229ab	1423a	1326a	939a	3488a	70.8ab	0.284a	0.380a
PK +$CaSO_4.7H_2O$+CuMnZn	1148abc	1384a	1266ab	906ab	3209ab	71.6a	0.272a	0.395a

Means followed by the same letter in a column are not significantly different at $P < 0.05$

are not used (Waliyar 1991; Shokes & Culbreath, 1997).

Based on 2–year average, application of nutrients especially in combinations had a significant ($P < 0.05$) effect on peanut pod yield, seed yield and biomass. Increases in pod yield of the fertilized treatments ranged between 16.6 per cent and 47.8 per cent over the control. The highest pod yield of 1326 kg ha^{-1} which was observed for the PK +$CaSO_4.7H_2O$+Zn treatment was significantly higher ($P < 0.05$) than the control, K only and P only treatments. However, this did not differ statistically from the pod yield of the remaining treatments. Seed yield generally followed the same trend as pod yield such that, the treatments with higher pod yields recorded higher seed yields. In the case of biomass, the control and K only treatment had the lowest biomass production, with the remaining treatments all producing higher but statistically similar amounts of biomass.

Slightly higher shelling percentage (ratio of seed to seed plus shell) values were observed for the fertilized treatments over the control. This is likely due to the relatively higher unit seed weight (seed size) of the fertilized treatments compared with the control, though unit seed sizes were not significantly different. Alhough higher harvest index (HI) does not necessarily imply higher yield, HI is directly related to yield as it represents the proportion of total biomass partitioned into grain. As a result, increased HI has been a major factor of increased yield in many crops (Richards, 2000). Therefore, though there was no significant difference in PHI among treatments, the slightly higher PHI of the fertilized treatments may have contributed to their higher yields.

Conclusion

The study clearly demonstrated that addition of nutrients either alone or in combinations had a positive effect on nutrient concentrations, uptake and peanut pod yield. Application of PK+$CaSO_4.7H_2O$ with Zn had the greatest effect on pod yield, seed yield and biomass, whilst the control treatment gave the lowest values in all studied yield traits. Application of the macronutrients P and K and the micronutrient Zn had the greatest impact on yield. Where micronutrients were combined, some level of antagonism between micronutrients was also observed. Further studies are needed to cover the factors affecting such interrelationships between elements in different soils and or plants and how to minimize such interactions, for example, through the use of foliar fertilizers for antagonistic micronutrients.

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