Identification of nutrient limitation for development and yield of cowpea (*Vigna unguiculata*), intercropped with maize, on an Alumi-Haplic Acrisol

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Abstract

Within the WAVES program, the working group „Plant Nutrition“ has the objective to identify the limitation of mineral nutrients for plant development and production under the soil and climatic conditions of the semi-arid regions in Piauí and Ceará. Therefore, on an Alumi-Haplic Acrisol, an experiment with the following treatments was carried out: Complete fertilization; Complete fertilization without nitrogen; complete fertilization without phosphorus; complete fertilization without potassium; complete fertilization without lime and control. Phosphorus was the most limiting nutrient in the growing period of 1998. The biomass accumulation in the treatment with phosphorus omission was only superior to the control treatment. At flowering, the magnesium concentration in cowpea was higher in the treatment with potassium omission, which was probably caused by the antagonism between potassium and magnesium in the other treatments, and smaller in the treatment with complete fertilization without lime compared to the other treatments. This indicated that, at this site, the application of dolomitic lime is necessary for an adequate supply of magnesium to the crop.

Keywords: Northeast Brazil, Cowpea, Plant Nutrient.

Introduction

More than 60 % of the soils in Piauí state (Brazil) show a high acidity, with limitation in calcium and magnesium availability (Bezerra & Salviano, 1995). This factor associated with the normally low precipitation in this area, is one of the most important constraints for the agricultural production in the region.

Cowpea is an important source of protein for a large population in developing countries (Ratchie, 1974; Wien et al., 1984) and Brazil is one of the most prominent cowpea grain producing countries (Summerfield et al, 1983). The main reasons for low yields are water deficiency, limited fertilization, incidence of pests and diseases in traditional cropping systems. Phosphorus deficiency is one of the major limitation to the growth of cowpea in many soils, particulary those in tropical areas with high capacity for P-fixation (Kellog et al., 1969; Araujo et al., 1984).

Cowpea is generally considered to be an acid-tolerant legume (Sanches et al., 1981; Alva et al., 1990). Improved plant growth of Al-tolerant cowpea cultivars under acid conditions has been reported (Hohenberg et al., 1984; Malkanthi et al., 1995). This phenomenon may be due to the distinct ability of cowpea to adapt to an unfavorable root environment (H^+ and Al^{3+}) by promoting root growth, thereby maintaining higher uptake of water and nutrients under such conditions (Malkanthi et al., 1995). However, a reduction in plant growth and nutrient uptake in cowpea under low pH conditions was reported when plants depend on symbiotic nitrogen fixation (Alva et al. 1990).

Effects of Al on P uptake by plants can vary from sensitive (Konishi et al., 1985; Tan et al., 1990) to supressive (Lee, 1971; Mugwira et al., 1976). Malkanthi et al. (1995) has found an increasing tendency in P content in plants in Al presence compared with Al ausence. It has been also reported that Al does not interfere appreciably with K nutrition (Aniol, 1983) and H^+ presence was not inibitory for K uptake in cowpea shoots and promotory for roots, but was inibitory for Ca and particularly for Mg uptake. However, this reduction in cation uptake under low pH conditions and in the presence of Al did not result in a reduction of growth of cowpea (Malkanthi et al., 1995).

Biomass production, P uptake and yield of cowpea is highly increased with P application and this increase is much higher in shoots than in roots. The concentrations of K, Cu and Zn decrease, Ca and Fe are unaffected and Mg increases by increasing P availability (Fagéria, 1991).

The objective of this study was to evaluate the nutrient limitation for cowpea development and production under the climatic conditions and highly acid soils of Piauí State (Brazil).

Material and methods

The experiment was carried out in Picos , Brazil, in 1998, on a Latossolo Amarelo Álico (Alumi-Haplic Acrisol) (pH ($CaCl_2$): 3,7; aluminium saturation of 95%).

The area has been used as cashew plantation before the experiment. The land was cleared about 40 days before planting. The trees and roots were removed and the land was prepared with a disk bedder. Liming was broadcast 20 days before planting and incorporated manually by hoeing.

Cowpea was intercropped with maize. The variety of maize was "São Vicente" and of cowpea was "EPACE 10". Both varieties were breeded in order to be more adapted to semi-arid conditions. The spacing for the crops was 1 m between the rows of maize, and also 1 m between the cowpea rows, that were placed between the rows of maize. It was planted 4-5 holes per meter with 2 seed per hole for both crops and after germination the plant population was reduced to 1 plant of maize per hole. After this proceeding the stand was 4,5 plants of maize and 9 plants of cowpea per square meter.

Only the results of the cowpea crop are presented in this paper.

The statistical layout was a RCB design (Randomized Complete Blocks) with 4 replications. Each plot had the dimension of 8 per 6 meters with an effective area of 7 per 5 meters. There were 1 meter space between the blocks and between the plots.

Planting depth was 5 cm and the fertilizer was banded about 7 cm away from the seed at 5 cm depth.

The following treatments were used: 1) Complete fertilization (nitrogen, phosphorus, potassium and dolomitic lime); 2) Complete fertilization without nitrogen; 3) Complete fertilization without phosphorus; 4) Complete fertilization without potassium; 5) Complete fertilization without lime and 6) Control (without fertilizer application)

Nitrogen was applied at the rate of 30 kg per ha as ammonium sulphate. 10 kg nitrogen per ha were applied at planting, 5 kg to maize and 5 kg to cowpea. The rest of the nitrogen was applied only to maize in 2 splits: 7,5 kg per ha 42 days after planting and 12,5 kg per ha at flowering of maize. Phosphorus and potassium were applied at the rate of 40 kg P_2O_5 per ha as superphosphate and 40 kg K_2O per ha as KCl. The total amount was applied at planting, 20 kg per ha for each crop. For liming, dolomitic lime was used (40% Ca,MgO), at the rate of 3.000 kg per ha applied as mentioned above.

Cowpea samples were collected at 42 days after planting ("vegetation" time harvest); at flowering (56 days after planting) and at harvest (75 days after planting). At vegetation and flowering 4 pockets per plot were randomly selected (8 plants per plot) and at harvest 40 randomized holes per plot (80 plants) in order to determine dry matter production. All above ground parts of the plants were harvested.

The concentration of nitrogen was determined with a Heraeus Macro N Autoanalyzer (DUMAS method). Phosphorus, potassium, calcium (Absoption Atomic Spectrophotometer) and magnesium (Flame Photometer) were measured in HCl extracts after ashing.

Results

Biomass production

There was no difference in dry matter production between the treatments 42 days after planting. Differences appeared at flowering and at harvest (Table 1).

Although the variation within the treatments was very high, the total dry matter at flowering and the grain yield shows that the most limiting nutrient was phosphorus followed by potassium, although there was no statistical difference between the treatment with potassium omission and complete fertilization.

Although, there was no statistical difference between the treatment with nitrogen omission and complete fertilization both at flowering and harvest, the treatment with nitrogen omission shows a slightly higher biomass production than the treatment with complete fertilization. It seems that as the land was recently cleared, the nitrogen mineralized in the soil was enough to start the biological nitrogen fixation.

The amendment of the soil with dolomitic lime didn't show any effect in biomass production. This can be due to the fact that the lime was applied just 20 days before planting and, as it was a year with low rainfall, there was not enough time for the reaction between soil and lime.

Independent of the various fertilizer treatments the harvest index was quite low (0.17-0.28), obviously due to water shortage during the critical period of early yield formation.

Table 1: Dry matter production of cowpea in different treatments and at different development stages

Treatment	**Dry matter (kg/ha)**				
	Sampling time				
	Vegetation	***Flowering***	***Harvest***		
			Total	***Crop residues***	***Grains***
Control	183	298	1117	956	161
Complete	432	981	2706	2050	656
Complete - N	317	859	2980	2223	757
Complete - P	350	433	1783	1443	341
Complete - K	248	700	2085	1598	487
Complete - lime	247	623	2559	2021	538
LSD=	327	415	939	709	254

Nitrogen

Nitrogen availability was not a limiting factor for development of cowpea in this year. The nitrogen concentrations at flowering, for all treatments, were above the threshold that indicates deficiency (3.0 % N) (Table 2).

At flowering there was a statistical difference in nitrogen concentration, showing the smallest nitrogen concentration in the treatments with complete fertilization and with nitrogen omission and highest in the treatments with phosphorus omission and no fertilization (control). Probably this results is due to the higher biomass production by these treatments, with major dilution effect of the nutrient in the tissue.

Table 2: Nitrogen concentration in cowpea in different treatments and at different development stages

Treatment	**N(%)**			
	Sampling time			
	Vegetation	***Flowering***	***Harvest***	
			Crop residues	***Grains***
Control	4,88	4,37	2,91	4,08
Complete	4,48	3,58	1,92	4,10
Complete - N	4,53	3,54	1,81	3,95
Complete - P	4,78	4,21	2,37	4,07
Complete - K	4,68	3,91	2,29	4,03
Complete - lime	4,71	3,93	2,20	4,09
Threshold		3,00		
LSD=	0,81	0,58	0,64	0,26

Phosphorus

Phosphorus was clearly the major limiting nutrient for cowpea development in this soil. All treatments show a concentration lower than threshold indication at flowering (0.25 % P) (Table 3).

Like the nitrogen concentration, the phosphorus concentration in the tissue showed statistical differences at flowering, but theses differences were not detected in crop residues against a strong difference in grains, showing a quite higher concentration than in crop residues.

The translocation of phosphorus to grains seems to be highly affected by phosphorus availability at flowering, since the treatments with highest phosphorus concentration at this period shows also highest concentrations in grains at harvest.

Table 3: Phosphorus concentration in cowpea in different treatments and at different development stages

Treatment	**P(mg/g DM)**			
	Sampling time			
	Vegetation	***Flowering***	***Harvest***	
			Crop residues	***Grains***
Control	1,93	1,57	1,48	2,08
Complete	2,40	1,68	1,23	2,22
Complete - N	2,40	1,77	1,32	2,34
Complete - P	2,03	1,47	1,17	1,90
Complete - K	2,28	1,79	1,38	2,25
Complete - lime	2,39	1,73	1,84	2,21
Threshold		2,50		
LSD=	0,69	0,26	0,97	0,24

Potassium

In contrast to nitrogen, phosphorus and calcium, potassium concentration showed statistical differences already at the first harvest (42 days after planting). It seems that this nutrient is also an important limiting factor, but not as strong as phosphorus, because all treatments with potassium application are equal or above the threshold indication at flowering (Table 4).

Excluding the treatment with lime omission, potassium concentration showed a negative correlation with biomass production at flowering and at the final harvest in crop residues. This result indicate that potassium availability, even with potassium application, was not enough to follow biomass production.

Compared to complete fertilization, a higher potassium concentration was found in the treatment with lime omission although biomass production was similar at flowering. This maybe due to the antagonism between potassium and magnesium/calcium. In the treatment with complete fertilization, the higher magnesium plus calcium concentration may cause smaller potassium uptake by the crop.

As expected, the potassium content in the tissues was quite lower and bellow the deficiency threshold in the treatment with potassium omission compared to treatments with potassium application.

Table 4: Potassium concentration in cowpea in different treatments and at different development stages

Treatment	**K(mg/g DM)**			
	Sampling time			
	Vegetation	***Flowering***	***Harvest***	
			Crop residues	***Grains***
Control	25,93	19,05	17,20	10,39
Complete	29,67	17,65	12,42	9,97
Complete – N	28,83	19,59	12,13	10,59
Complete – P	32,67	24,20	18,80	10,47
Complete – K	17,23	11,09	8,29	8,50
Complete – lime	34,39	22,67	18,82	9,61
Threshold		18,00		
LSD=	8,94	3,97	6,37	0,91

Calcium

Probably because of liming has been done just 20 days before planting, there was no effect on calcium supply for the crop. But, in all case, it seems that supplementation of calcium is also important in this soil, since all treatments showed calcium deficiency at flowering (Table 5).

Calcium concentrations showed differences between the treatments only in crop residues, in which the highest concentration was found in control and smallest in complete fertilization, perhaps due the dilution of the element according to the biomass production.

The only recognized effect in calcium supply was found in the treatment with potassium omission, in which there was highest calcium concentration at flowering, showing again a very important relationship between the cations calcium and magnesium against potassium in the uptake by the crop.

Table 5: Calcium concentration in cowpea in different treatments and at different development stages

Treatment	**Ca (mg/g DM)**			
	Sampling time			
	Vegetation	***Flowering***	***Harvest***	
			Crop residues	***Grains***
Control	13,48	12,53	8,99	0,62
Complete	12,26	11,43	5,90	0,55
Complete - N	12,47	11,49	6,16	0,60
Complete - P	13,09	11,46	6,89	0,59
Complete - K	14,32	13,46	7,51	0,56
Complete - lime	12,02	11,49	7,14	0,54
Threshold		15,00		
LSD=	3,62	3,21	2,73	0,12

Magnesium

There was a remarkable difference between the complete fertilization and the treatment with potassium omission in magnesium concentration already at the first time harvest (42 days after planting), showing a strong effect of potassium reducing magnesium concentration in the tissue in all periods analised (Table 6).

In contrast to the calcium supply, liming showed an effect in magnesium supplementation already in the first year. The lowest magnesium concentration was in the treatment with lime omission in all periods and also in grains. But, it seems that this element was not a strong limiting factor in this year, because for all treatments, the magnesium concentrations were above the deficiency threshold at flowering.

Again the results, show a strong antagonism between potassium and magnessium in the plant uptake.

Table 6: Magnesium concentration in cowpea in different treatments and at different development stages

Treatment	Mg (mg/g DM)			
	Sampling time			
	Vegetation	*Flowering*	*Harvest*	
			Crop residues	*Grains*
Control	3,71	4,30	3,07	1,29
Complete	4,58	4,43	2,91	1,23
Complete - N	4,36	4,35	3,18	1,33
Complete - P	4,58	4,90	3,41	1,36
Complete - K	6,95	6,01	4,43	1,19
Complete - lime	3,17	3,23	2,72	1,13
Threshold		2,50		
LSD=	1,62	1,12	1,35	0,11

Conclusions

- Phosphorus is the most limiting nutrient for cowpea development and yield at this site;
- If phosphorus is supplied adequately, calcium and potassium become most limiting;
- An antagonism between potassium and magnesium/calcium is observed under these; condition
- The application of dolomitic lime reduces potassium uptake by cowpea;
- Dolomitic lime application is necessary in order so supply sufficient magnesium to the crop;

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