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MICRONUTRIENTS USE EFFICIENCY IN TROPICAL COVER CROPS AS INFLUENCED BY PHOSPHORUS FERTILIZATION[1]

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ABSTRACT - Deficiency of micronutrients is increasing in the recent years in cropping systems in many parts of the world and cover crops are important components of cropping systems. A greenhouse experiment was conducted to evaluate copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) use efficiency in 14 tropical legume cover crops grown on an Oxisol. The P levels used were low (0 mg kg^{-1}), medium (100 mg kg^{-1}) and high (200 mg kg^{-1}). The P X cover crops interactions were significant for Cu, Fe, Mn, and Zn use efficiency (tops dry weight/unit nutrient uptake). Hence, cover crop species varied in nutrient use efficiency with change in P levels. The micronutrient use efficiency was in the order of Cu > Zn > Mn > Fe. Higher Cu use efficiency was associated with lower uptake of this element, in the cover crop tops compared to other micronutrients. Similarly, lower efficiency of Fe and Mn was associated with their higher uptake in the tops of cover crops. Overall, Cu and Mn use efficiency was decreased when P level was raised from low to medium level and then it was constant. Iron use efficiency was increased with increasing P level but Zn use efficiency was constant with the addition of P fertilizer.

Keywords: Green manure. Crotalaria. Mucuna. Cajanus.

EFICIÊNCIA DE USO DE MICRONUTRIENTES EM PLANTAS DE COBERTURA TROPICAIS INFLUENCIADA POR DOSES DE FÓSFORO

RESUMO – Em muitas partes do mundo a deficiência de micronutrientes no solo está aumentando e as plantas de cobertura do solo são componentes importantes dos sistemas de produção. Um experimento de casa-de-vegetação foi conduzido para avaliar a eficiência de uso de cobre (Cu), ferro (Fe), manganês (Mn) e zinco (Zn) por 14 leguminosas tropicais usadas como plantas de cobertura, crescidas em um Latossolo sob três doses de fósforo (P): baixa (0 mg kg^{-1}), média (100 mg kg^{-1}) e alta (200 mg kg^{-1}). As interações P X plantas de cobertura foram significativas para a eficiência de uso de Cu, Fe, Mn e Zn. Assim, a eficiência de uso de micronutrientes variou entre as plantas de cobertura em função das doses de P. A eficiência de uso de micronutrientes ocorreu na ordem Cu > Zn > Mn > Fe. Maior eficiência de uso de Cu foi associada à menor concentração desse elemento na parte aérea das plantas em comparação com outros micronutrientes. De forma similar, menor eficiência de uso de Fe e Mn foi associada à maior concentração destes na parte aérea das plantas de cobertura. De forma geral, a eficiência de uso de Cu e Mn diminuiu com o aumento da dose de P, sendo constante a partir da dose média. A eficiência de uso de Fe aumentou com o aumento das doses de P; contudo, as doses de P não provocaram mudanças na eficiência de uso de Zn.

Palavras-chave: Adubo verde. Crotalária. Mucuna. Guandú.

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INTRODUCTION

Micronutrient deficiencies in crop production are reported worldwide (ALLOWAY, 2008). Deficiency of micronutrients in crop plants is associated with number of factors. These factors include (i) increased micronutrient demands from intensive cropping practices and adaptation of high yielding cultivars which may have higher micronutrient demand, (ii) enhanced production of crops on marginal soils that contain low levels of essential nutrients, (iii) increased use of high analysis fertilizers with low amounts of micronutrients, (iv) decreased use of animal manures, composts, and crop residues, (v) use of many soils that are inherently low in micronutrient reserves, and (vi) involvement of natural and anthropogenic factors that limit adequate supplies and create element imbalances (FAGERIA et al., 2002).

Plant acquisition of micronutrients is affected by numerous soil, plant, microbial, and environmental factors. Parent material, minerals containing micronutrients, and soil formation processes influence micronutrient availability to plants. Solid phase materials are important in determining solubility relationships of nutrients in soils (LINDSAY, 1991; CHAVES et al., 2007). Available micronutrients in soil are derived from weathering of underlying parent materials, natural processes (e.g., gases from volcanic eruption, rain/snow, marine aerosols, continental dust, forest fires), and anthropogenic processes (industrial and automobile discharges, addition of fertilizers, lime, pesticides, manures, sewage sludges). Soil micronutrients exist in solid phases like primary minerals, secondary precipitates, and adsorbed on clay surfaces (SHUMAN, 1991; LINDSAY, 1991). Soil adsorption reactions are important in determining bioavailability of B, Cu, Mo, and Zn. Micronutrients associated with solid phases are often not available to plants. Only about 10% of micronutrients in soil are in soluble and/or exchangeable forms for plant acquisition (LAKE et al., 1984). Fluctuating temperatures, moisture, and anthropogenic factors change micronutrient concentrations, forms, and distribution between various phases of soil.

Micronutrients are normally constituents of prosthetic groups that catalyze redox processes by electron transfer such as with the transition elements Cu, Fe, Mn, and Mo, and form enzyme-substrate complexes by coupling enzyme with substrate (Fe and Zn) or enhance enzyme reactions by influencing molecular configurations between enzyme and substrate (Zn) (RÖMHELD; MARSCHNER, 1991). In addition, micronutrients also improve root growth which is related to nutrient and water absorption by crop plants and consequently improving yields (IBRAHIM; FARYAL, 2014).

Cover crops are important components of cropping systems to improve soil quality and consequently crop yields. The role of cover crops in improving soil physical, biological and chemical properties is well established (CUNHA et al., 2011a; 2011b; 2012). Phosphorus is one of the most yield limiting nutrients in tropical Oxisols for crop production (FAGERIA; BALIGAR, 2003; YANG; POST, 2011), and, especially for tropical legume cover crops data about the influence of P on the nutrient use efficiency by these plants are limited. The objective of this study was to evaluate the influence of P on Cu, Fe, Mn and Zn use efficiency in tropical legume cover crops grown on a Brazilian Oxisol.

MATERIALS AND METHODS

A greenhouse experiment to evaluate micronutrients use efficiency (Cu, Fe, Mn and Zn) was conducted at the EMBRAPA - National Rice and Beans Research Center, Capivara farm, Santo Antônio de Goiás county, state of Goiás, located at the latitude 16º29’40“ S, longitude 49º17’30” W and 823 m above sea level. The experimental design used consisted of a completely randomized block in a factorial arrangement 3 x 14 (3 P levels and 14 cover crops) with four replicates. The common and scientific names of these cover crops are given in Table 1.

Table 1. Common and scientific names of 14 legume cover crop species used in the experiment. Santo Antônio de Goiás, 2012.

Common name	Scientific name
Shortflower rattlebox	*Crotalaria breviflora* DC.
Sunn hemp	*Crotalaria juncea L.*
Smooth crotalaria	*Crotalaria mucronata* Desv.
Showy rattlebox	*Crotalaria spectabilis* Roth.
Slender leaf rattlebox	*Crotalaria ochroleuca* G. Don.
Calopo	*Calopogonium mucunoides* Desv.
Tropical kudzu	*Pueraria phaseoloides* (Roxb.) Benth.
Pigeon pea (black)	*Cajanus cajan* (L.) Millsp.
Pigeon pea (mixed color)	*Cajanus cajan* (L.) Millsp.
Lablab bean	*Lablab purpureus* (L.) Sweet
Dwarf velvet bean	*Mucuna deeringiana* (Bort) Merr.
Black velvet bean	*Mucuna aterrima* (Piper & Tracy) Holland
Gray velvet bean	*Mucuna cinereum* L.
Jack bean	*Canavalia ensiformis* (L.) DC.

Soil used in the experiment was Oxisol with following chemical and physical properties before imposing acidity treatments: pH in H_2O 5.8, Ca 1.17 $cmol_c$ kg^{-1}, Mg 0.6 $cmol_c$ kg^{-1}, Al 0.1 $cmol_c$ kg^{-1}, P 0.9 mg kg^{-1}, K 33 mg kg^{-1}, Cu 1.2 mg kg^{-1}, Zn 1.1 mg kg^{-1}, Fe 35 mg kg^{-1}, Mn 8 mg kg^{-1} and organic matter 20 g kg^{-1}, clay 569 g kg^{-1}, Silt 140 g kg^{-1} and sand 291 g kg^{-1}. Soil analysis methodology used is described in manual of soil analysis (EMBRAPA, 1997).

The experiment was conducted in plastic pots with 9 kg soil in each pot. The P levels used were 0 mg kg^{-1} of soil (low), 100 mg kg^{-1} of soil (medium), and 200 mg kg^{-1} of soil (high), applied as triple superphosphate at the sowing time. Each pot received 10 g dolomitic lime 4 weeks before sowing the cover crops and pots were subjected to dry and wet cycling. The liming material used was having 32.9% CaO, 14.0% MgO and neutralizing power of 85%. At the time of sowing basal fertilizers rates used were 200 mg N kg^{-1} of soil and 200 mg K kg^{-1} of soil. Nitrogen was applied as urea and K was applied as potassium chloride as recommended by Fageria and Baligar (2003). After germination, 4 plants were maintained in each pot. All plants were harvested at an age of 35 days after sowing. Harvested material was washed in distilled water several times and was dried in an oven at 70 ^{0}C to a constant weight, and milled together to perform the plant tissue analyses (CARMO et al., 2000).

Data were analyzed by analysis of variance to evaluate treatment effects and means were compared by Tukey's test at 5% probability level. Micronutrient use efficiencies in the tops of 14 cover crop species were calculated by using the following equation:

$$Nutrient\ use\ efficiency\ (g\ mg^{-1}) = \frac{Shoot\ dry\ weight\ in\ g}{Nutrient\ uptake\ in\ mg}$$

RESULTS AND DISCUSSION

The P X cover crops interactions for micronutrient use efficiency (Cu, Fe, Mn, and Zn) were significant (Tables 2, 3, 4 and 5), indicating that cover crops responded differently to changing P levels and their nutrient use efficiency also varied accordingly.

Copper Use Efficiency

Copper use efficiency varied from 68.96 g mg^{-1} produced by smooth crotalaria to 276.31 g mg^{-1} produced by lablab bean, with an average value of 128.65 g mg^{-1} at low P level (Table 2). At medium P level, the Cu use efficiency varied from 61.50 g mg^{-1} produced by pigeon pea (black) to 178.50 g mg^{-1} produced by lablab bean, with an average value of 108.70 g mg^{-1}. Similarly, at high P level, Cu use efficiency varied from 74.53 g mg^{-1} produced by pigeon pea (black) to 188.28 g mg^{-1} produced by jack bean, with an average value of 110.98 g mg^{-1}. Across three P levels, Cu use efficiency varied from 69.05 g mg^{-1} produced by pigeon pea (black) to 199.41 g mg^{-1} produced by jack bean, with an average value of 116.11 g mg^{-1}. Cover crops which produced higher Cu use efficiency at the lower as well as higher P levels can be considered most useful. These cover crops are lablab bean, jack bean, black velvet bean and gray velvet bean.

Table 2. Copper use efficiency (g mg^{-1}) in 14 tropical legume cover crops under three P levels. Santo Antônio de Goiás, 2012.

Cover crops	P levels (mg kg^{-1})			Across three P levels
	Low(0)	Medium (100)	High (200)	
Shortflower rattlebox	75.22c	97.76ab	83.57c	85.51defg
Sunn hemp	120.79c	123.67ab	137.75ab	127.40bc
Smooth crotalaria	68.96c	86.85ab	102.06bc	85.96defg
Showy rattlebox	103.11c	110.81ab	110.83bc	108.25cde
Slender leaf rattlebox	113.91c	109.77ab	104.40bc	109.36cde
Calopo	114.13c	96.45ab	119.55bc	110.04cde
Tropical kudzu	88.86c	106.51ab	122.56bc	105.97cdef
Pigeon pea (black)	71.11c	61.50b	74.53c	69.05g
Pigeon pea (mixed color)	74.56c	61.85b	79.99c	72.13fg
Lablab bean	276.31a	178.50a	138.81ab	197.87a
Dwarf velvet bean	92.03c	69.07b	74.60c	78.57efg
Black velvet bean	220.83ab	130.11ab	123.70bc	158.22b
Gray velvet bean	148.51bc	111.78ab	93.08bc	117.79cd
Jack bean	232.81ab	177.15a	188.28a	199.41a
Average	128.65	108.70	110.98	116.11
Test-F				
P levels (P)	NS			
Cover crops (C)	**			**
P X C	**			
CV(%)	22.50			9.92

**, NS Significant at the 1% probability level and non-significant, respectively.
Means followed by the same letter in the same column are significantly not different by Tukey's test at the 5% probability level.

The variation in Cu use efficiency among cover crops was associated with their different responses in tops dry matter production and consequently different uptake of nutrients, including copper. Figure 1 shows that there was a significant variation in shoot dry weight among the cover crop species.

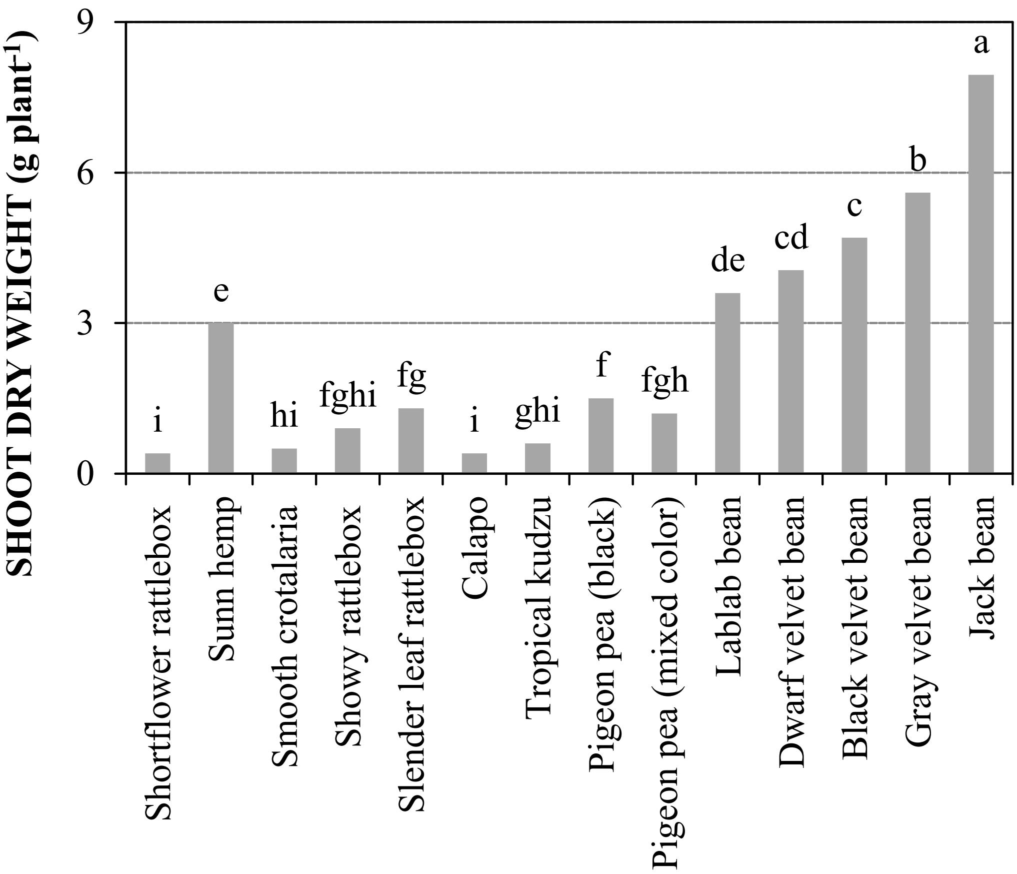

Figure 1. Shoot dry weight of 14 cover crops across three P levels. Santo Antônio de Goiás, 2012.

The cover crop species which produced highest dry matter also having highest Cu use efficiency. Baligar and Fageria (2007) and Fageria et al. (2008) reported significant variation in shoot dry weight of tropical cover crops. Copper use efficiency was also highest among four micronutrients (Cu, Fe, Mn and Zn). Higher Cu use efficiency was associated with lower concentration of this element in the tops of cover crops compared with other three micronutrients (Fe, Mn and Zn). The lower concentration of Cu in the shoots of cover crops gave lower values of Cu uptake and consequently higher Cu use efficiency. Fageria (2009) reported that copper is taken up by the plants in only very small quantities. The copper content of most plants is generally between 2 and 20 mg kg^{-1} in the dry plant material (MENGEL et al., 2001). About 5 to 8 mg Cu kg^{-1} dry plant tissue may be considered as the critical level for most crops (FAGERIA et al., 2010).

Overall, copper use efficiency decreased from 128.65 g mg^{-1} at low P level to 108.70 g mg^{-1} at medium P level. At high P level the average Cu use efficiency was 110.98 g mg^{-1}. The decrease in Cu use efficiency at medium and high P levels compared with low P level may be associated with high shoot dry weight at high P levels compared with low P level. Cover crops with high shoot dry weight accumulated higher Cu in their aerial parts compared to lower P level and consequently lower Cu use efficiency. Because copper use efficiency was a function of shoot dry weight divided by Cu uptake in the shoot. Figure 2 shows that shoot growth of two cover crops was much higher at medium and high P levels compared with low P level.

Iron Use Efficiency

Iron use efficiency at low P level varied from 0.82 g mg^{-1} produced by shortflower rattlebox to 7.32 g mg^{-1} produced by smooth crotalaria, with an average value of 4.75 g mg^{-1} (Table 3). At medium P level, the Fe use efficiency varied from 1.75 g mg^{-1} produced by tropical kudzu to 9.71 g mg^{-1} produced by showy rattlebox, with an average value of 5.80 g mg^{-1}. At high P level, the Fe use efficiency varied from 3.08 g mg^{-1} produced by calopo to 9.00 g mg^{-1} produced by slender leaf rattlebox, with an average value of 6.11 g mg^{-1}. Across three P levels, the Fe use efficiency in cover crops varied from 2.34 g mg^{-1}

produced by calopo to 8.01 g mg^{-1} produced by sunn hemp, with an average value of 5.56 g mg^{-1}. Phosphorus addition to cover crops improved Fe use efficiency. For example, average Fe use efficiency was 4.75 g mg^{-1} at low P level and at medium P level Fe use efficiency was 5.80 g mg^{-1}. Similarly, at high P level the Fe use efficiency was 6.11 g mg^{-1}. Data are limited in the literature on the influence of P on Fe use efficiency for tropical cover crops and hence we cannot compare our results with the published ones.

Figure 2. Growth of smooth crotalaria (A) and showy rattlebox (B) at three P levels. Left to right 0, 100 and 200 mg P kg^{-1} soil. Santo Antônio de Goiás, 2012.

Table 3. Iron use efficiency (g mg^{-1}) in 14 tropical legume cover crops under three P levels. Santo Antônio de Goiás, 2012.

Cover crops	P levels (mg kg^{-1})			Across three P levels
	Low(0)	Medium (100)	High (200)	
Shortflower rattlebox	0.82c	8.66ab	6.37abc	5.28bc
Sunn hemp	7.07ab	8.52abc	8.43ab	8.01a
Smooth crotalaria	7.32a	8.50abc	7.71ab	7.84a
Showy rattlebox	6.23abc	9.71a	4.42bc	6.79ab
Slender leaf rattlebox	4.11abc	7.19abcd	9.00a	6.77ab
Calopo	2.14abc	1.81f	3.08c	2.34e
Tropical kudzu	1.50bc	1.75f	4.18bc	2.48de
Pigeon pea (black)	5.64abc	4.68def	7.99ab	6.11abc
Pigeon pea (mixed color)	5.30abc	5.51cde	6.11abc	5.64bc
Lablab bean	3.95abc	4.92de	4.79abc	4.55cd
Dwarf velvet bean	5.86abc	4.06ef	6.65abc	5.52bc
Black velvet bean	5.21abc	6.05bcde	7.50abc	6.25abc
Gray velvet bean	5.52abc	5.07de	5.16abc	5.25bc
Jack bean	5.88abc	4.79def	4.17bc	4.95bc
Average	4.75	5.80	6.11	5.56
Test-F				
P levels (P)	NS			
Cover crops (C)	**			**
P X C	**			
CV(%)	26.84			12.82

**,NS Significant at the 1% probability level and nonsignificant, respectively.
Means followed by the same letter in the same column are significantly not different by Tukey's test at the 5% probability level.

Manganese Use Efficiency

Manganese use efficiency varied from 8.52 g mg^{-1} produced by dwarf velvet bean to 34.76 g mg^{-1} produced by jack bean, with an average value of 15.29 g mg^{-1} at low P level (Table 4).

At medium P level, the Mn use efficiency varied from 5.84 g mg-1 produced by dwarf velvet bean to 22.12 g mg-1 produced by shortflower rattlebox, with an average value of 11.78 g mg-1. At high P level, the Mn use efficiency varied from 6.45 g mg -1 produced by dwarf velvet bean to 21.97 g mg-1 produced by jack bean, with an average value of 12.34 g mg-1. Across three P levels, the Mn use efficiency varied from 6.94 g mg-1 produced by dwarf velvet bean to 26.05 g mg-1 produced by jack bean, with an average value of 13.14 g mg-1. Dwarf velvet bean produced lowest Mn use efficiency at three P levels and jack bean produced maximum Mn use efficiency at low and high P levels. The lowest value of Mn use efficiency in dwarf velvet bean may be related to highest uptake of Mn by this cover crop compared to other cover crop species. Variation in Mn use efficiency in crop plants is reported by Fageria (2009). Fageria et al. (2008) reported that variation in nutrient use efficiency in crop plants may be related to better root geometry (length, weight, density, root hairs, and surface area), high rate of nutrient absorption and utilization, ability of plant to solubilize nutrients in rhizosphere, better distribution of nutrients within plants, and balanced source and sink relationship. The Mn use efficiency decreased at high P level compared with low P level. This may be related to higher dry matter and consequently higher quantity of Mn accumulated in the cover crop tops. Figure 2 shows that growth of shoot of two cover crop species was significantly higher at higher P levels compared with low P level.

Table 4. Manganese use efficiency (g mg^{-1}) in 14 tropical legume cover crops under three P levels. Santo Antônio de Goiás, 2012.

Cover crops	P levels (mg kg^{-1})			Across three P levels
	Low(0)	Medium (100)	High (200)	
Shortflower rattlebox	17.37bc	22.12a	18.44ab	19.31b
Sunn hemp	12.71bc	11.97cd	9.25def	11.31ef
Smooth crotalaria	9.23bc	7.97cd	8.01ef	8.41ef
Showy rattlebox	14.29bc	12.07cd	11.21cdef	12.52de
Slender leaf rattlebox	18.18bc	15.05abc	15.12bc	16.12bcd
Calopo	19.52b	13.78bcd	18.59ab	17.29bc
Tropical kudzu	9.93bc	9.04cd	14.65bcd	11.21ef
Pigeon pea (black)	11.55bc	7.81cd	10.61cdef	9.99ef
Pigeon pea (mixed color)	11.57bc	7.97cd	12.21cde	10.58ef
Lablab bean	15.91bc	12.33cd	9.61cdef	12.62cde
Dwarf velvet bean	8.52c	5.84d	6.45f	6.94f
Black velvet bean	16.56bc	10.17cd	10.16cdef	12.30de
Gray velvet bean	13.89bc	7.42cd	6.46f	9.26ef
Jack bean	34.76a	21.42ab	21.97a	26.05a
Average	15.29	11.78	12.34	13.14
Test-F				
P levels (P)	**			
Cover crops (C)	**			**
P X C	**			
CV(%)	21.43			12.07

**Significant at the 1% probability level.
Means followed by the same letter in the same column are significantly not different by Tukey's test at the 5% probability level.

Zinc Use Efficiency

Zinc Use efficiency varied from 18.87 g mg-1 produced by pigeon pea (black) to 64.93 g mg-1 produced by jack bean, with an average value of 35.27 g mg-1 at low P level (Table 5).

Table 5. Zinc use efficiency (g mg^{-1}) in 14 tropical legume cover crops under three P levels. Santo Antônio de Goiás, 2012.

Cover crops	P levels (mg kg^{-1})			Across three P levels
	Low(0)	Medium (100)	High (200)	
Shortflower rattlebox	38.93bc	41.63ab	44.07abcd	41.54bcd
Sunn hemp	27.90cd	40.93ab	51.62ab	40.15bcde
Smooth crotalaria	23.76cd	26.93bcd	29.96def	26.88fgh
Showy rattlebox	28.17cd	32.23abcd	34.82cdef	31.73efg
Slender leaf rattlebox	28.16cd	33.71abcd	38.58bcdef	33.48def
Calopo	32.90cd	37.45abc	38.01bcdef	36.12cdef
Tropical kudzu	33.03cd	24.53bcd	41.21abcdef	32.92def
Pigeon pea (black)	18.87d	18.53d	25.30f	20.90h
Pigeon pea (mixed color)	22.27d	19.29cd	26.59ef	22.71gh
Lablab bean	35.38bcd	41.45ab	42.29abcde	39.70bcde
Dwarf velvet bean	39.50bc	30.59abcd	35.61bcdef	35.23cdef
Black velvet bean	50.12ab	45.99a	49.94abc	48.68ab
Gray velvet bean	49.88ab	39.45ab	40.45abcdef	43.26bc
Jack bean	64.93a	46.03a	55.90a	55.61a
Average	35.27	34.20	39.60	36.35
Test-F				
P levels (P)	**			
Cover crops (C)	**			**
P X C	**			
CV(%)	15.81			16.21

**Significant at the 1% probability level.
Means followed by the same letter in the same column are significantly not different by Tukey's test at the 5% probability level.

At medium P level, Zn use efficiency varied from 18.53 g mg-1 produced by pigeon pea (black) to 46.03 g mg-1 produced by jack bean, with an average value of 34.20 g mg-1. At high P level, Zn use efficiency varied from 25.30 g mg-1 produced by pigeon pea (black) to 55.90 g mg-1 produced by jack bean, with an average value of 39.60 g mg-1. Across the three P levels, the Zn use efficiency varied from 20.90 g mg-1 produced by pigeon pea (black) to 55.61 g mg-1 produced by jack bean, with an average value of 36.35 g mg-1. Pigeon pea (black) produced lowest Zn use efficiency at three P levels. The smallest variation range in Zn use efficiency was observed under medium and high P levels probably because Zn absorption capacity is reduced by high P utilization (MOUSAVI, 2011). Besides, variation in macronutrient use efficiency among crop species is reported by Fageria et al. (2002) and Fageria (2009).

CONCLUSIONS

The micronutrient (Cu, Fe, Mn and Zn) use efficiency varied from cover crop to cover crop as well as from nutrient to nutrient. The P X cover crop interactions were significant for Cu, Fe, Mn and Zn use efficiency, indicating change in nutrient use efficiency is affected by P levels. Overall, Cu, Mn and Zn use efficiency decreased with increasing P levels, whereas Fe efficiency increased with the addition of P in the growth medium. Tops growth were obtained at medium and high P levels, indicating the necessity of P fertilization for good growth of cover crops under Brazilian Oxisol.

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