Australian Journal of Crop Science AJCS

AJCS 10(8):1092-1097 (2016) ISSN:1835-2707
DOI: 10.21475/ajcs.2016.10.08.p7367

Effects of micronutrients application on soybean yield

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Abstract

Soil fertilization with micronutrients increases micronutrient levels in cultivated areas providing yield gains of different cultures in different production systems. Therefore, the objective of this study was to estimate the agronomic efficiency of a powder fertilizer (a source of micronutrient; 6.8% Mn, 3.9% Zn, 2.1% Fe, 1.2% Cu and 1.1% B), applied to the soil in the agronomic performance of the soybean crop. The experiment was carried out under field conditions, in an Oxisol. The random block design was used, with five treatments and four replicates. The treatments consisted of five doses of the fertilizer: 0, 33.33 kg ha^{-1}, 66.66 kg ha^{-1}, 133.32 kg ha^{-1} and 66.66 kg ha^{-1} + 1.4 ton ha^{-1} of calcium oxide. The contents of Mn, Zn and Fe increased in the soil in all treatments, but no effect was observed in leaf contents with the application. The levels of Zn and Mn are adequate. The dose 133.32 kg ha^{-1} leads to an increase in the productivity of soybean plants in the Cerrado biome.

Keywords: Agronomic Efficiency; Mineral Nutrition; Fertilizer; *Glycine max*, Grains.
Abbreviations: Mn_manganese; Zn_zinc; Fe_iron; Cu_copper; B_boron.

Introduction

The Brazilian Cerrado region is prominent in grain production (Richards et al., 2015), holding about 50% of the entire corn and soybean yield in the country. Brazil is the second largest producer of soybeans, and the Midwest region currently accounts for 48.54% of the Brazilian production. Over 86 million tons of soybeans were harvested in 2013/2014, where the State of Goiás produced 8,995 million tons, ensuring to Goiás the fourth place in the national ranking in production (Conab, 2014). The soybean crop growth in the country has always been associated with scientific achievements and with the availability of technology to the productive sector. With a highly competitive market, the Brazilian farmers need to increase their productivity and to reduce costs. Therefore, some practices need to be adopted, and the use of micronutrients, is without doubt, essential (Nava et al., 2011; Karaman et al., 2013; Carvalho et al., 2014). The intensive land use, crop rotation and low organic matter (O.M.) contents provide lower availability of micronutrients and the plants consequently end up with deficiency symptoms (Mascarenhas et al., 2014). The chemical imbalance of the soil caused by unbalanced fertilization, either by nutrient surplus or deficit, is another factor able to generate micronutrient deficiency. The micronutrients most studied for soybean crops are Mn, B, Zn and Mo (Zahoor et al., 2013; Kobraee et al., 2014; Mascarenhas et al., 2014; Bender et al., 2015; Rechiatu et al., 2015). Studies carried out in several regions of Brazil report deficiency or acute toxicity of several elements in the soil, where Mo, Co, Zn, Cu, Mn and B have higher frequency of deficiency, especially in Cerrado soils (Sfredo and Oliveira, 2010). The addition of specific micronutrient fertilizers has been neglected, even facing such scenario (Carvalho et al., 2012). Thus, several studies have mentioned the difficulty in evaluating the effect of micronutrients in increasing yield. Other factors depend upon the micronutrient available in a solution and on the micronutrient sources applied. Nutrients applied via pesticides, soil adsorption and organic matter can affect response. Given the above, the objective of this study was to estimate the effect of soil fertilization with micronutrients in soybean yield.

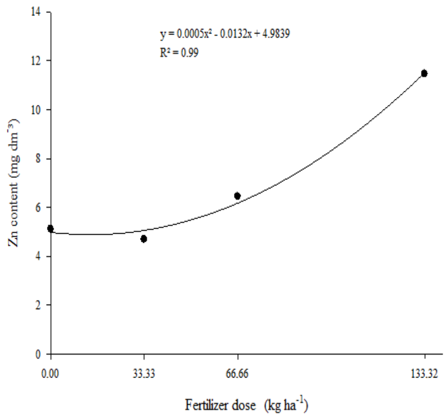
Results and Discussion

The highest dose of the fertilizer with micronutrients (133.32 kg ha^{-1}) provided the highest Mn and Zn levels in the soil (Table 1; Fig 1). The efficiency of applying Mn to the soil is overall low, and thus requires doses considered high when compared with the doses of micronutrient required. Doses up to 48 kg ha^{-1} of Mn also provided an increase in the levels of other micronutrients in soils (Moreira et al. 2006). It is noteworthy that Mondo et al. (2012) report a positive correlation between Mn contents in the soil and soybean yield.

Table 1. Chemical characteristics of the soil and analysis of variance according to the different doses of micronutrients applied in soil for the cultivation of soybeans. Goiânia, Goiás.

Dose of Fertilizer	Cu	Fe	Mn	Zn
(kg ha^{-1})	---------------------------------------mg dm^{-3}---------------------------------------			
0.0	0.60 b	24.30	14.17	5.12 b
33.33	0.58 b	23.70	14.42	4.70 b
66.66	0.70 b	29.45	15.70	6.45 b
132.32	2.67 a	18.48	22.95	11.47 a
66.66 + CaO [(1)]	0.75 b	20.45	15.68	5.70 b
Mean	1.06	23.35	16.58	6.69
Minimum	0.10	10.90	11.00	3.90
Maximum	5.80	40.00	43.50	20.50
F Test	2.83*	0.92 ns	1.38 ns	2.96*
VC%	19.57	36.89	37.28	47.86

[1]Calcium oxide. Means followed by different letters in the column, differ by the Tukey test ($P < 0.05$).
* - significant ($p<0.05$) ns – non significant ($p>0.05$)



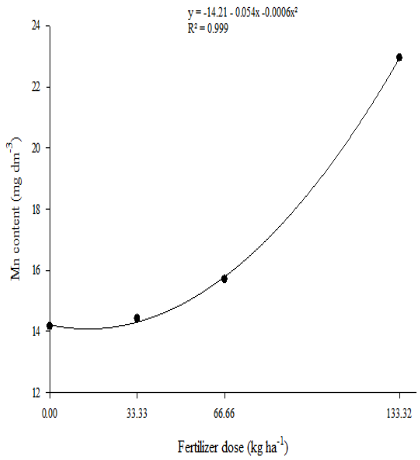


Fig 1. Average Zn and Mn (mg dm^{-3}) in the soil, according to the doses of micronutrient fertilizer, Goiânia (GO). (Average Zn levels at the dose of 66.66 kg ha^{-1} added to 1.4 t ha^{-1} CaO →15.68 mg dm^{-3} Mn and 5.70 mg dm^{-3} Zn).

The soybean yield responded to the highest doses of the micronutrient fertilizer, supporting Mondo et al. (2012). Galrão (2004) explains that one kg ha^{-1} of Zn applied on the first culture of an Argillaceous Oxisol was enough to increase grain yield and the Zn levels in soil and leaves of the third crop of culture. The micronutrients Cu and Fe (1.06 mg dm^{-3} and 23.35 mg dm^{-3}, respectively), had high levels according to the interpretation class proposed by Souza and Lobato (2004). According to Lopes and Abreu (2000), the critical Cu level is 1.0 mg dm^{-3}. Only the fertilizer dose of 133.32 kg ha^{-1} caused increases in Cu contents above this critical level.

The Cu content in the soil increased with increasing levels of the fertilizer applied (Fig 2). Calcium oxide did not affect the average amount of Cu (see Fig. 2 in regards to the calcium oxide application). Joris et al (2012) reported that inadequate liming, with excessive increase in pH, may entail a Cu deficiency. However, Cu availability was not affected even with the application of calcium oxide. The regression curve (Fig 2) indicated that Cu accumulation in the soil began from the dose 27.75 Kg ha $^{-1}$ of the micronutrient fertilizer This dose is therefore considered the starting point for nutrient accumulation in the soil. Only 0.33 kg ha^{-1} of Cu would be provided in this dose. This is an Cu level unsuitable for the development of soybean in the Cerrado area (Sousa and Lobato, 2004). The highest yield was obtained with the application of 1.54 kg ha^{-1} Cu, which increased Cu content in

Table 2. Average content of the chemical elements in the foliar analysis in soybean culture, Goiânia (GO).

Dose of Fertilizer	N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn
(kg ha^{-1})	--------------- ($g\ kg^{-1}$) ----------------						--------- ($mg\ kg^{-1}$) ----------			
0.0	42.5	3.65	16.0	10.0	3.5	0.9	3.0	435 ab	82 a	26 a
33.33	43.7	3.42	17.0	8.0	3.0	0.9	6.7	386 bc	82 a	24 ab
66.66	45.0	4.10	17.1	8.8	3.2	0.9	5.7	409 ab	74 ab	22 b
132.32	42.5	3.40	18.1	10.0	3.0	1.0	6.0	352 c	71 b	22 b
66.66 + CaO (1)	43.0	3.55	16.2	9.0	3.0	1.0	6.7	452 a	82 a	25 a
Mean	4.33	3.62	16.90	9.15	3.15	0.94	5.65	406.70	78.25	22.89
F Test	0.37 ns	2.62 ns	1.89 ns	2.72 ns	0.40 ns	0.69 ns	7.92 ns	11.33*	7.06*	11.35*
VC%	8.02	9.68	7.37	11.37	22.44	13.03	19.45	5.76	5.02	4.57

(1) Calcium oxide. Medium followed by different letters in the column, differ significantly by the Tukey test ($p < 0.05$).
ns – non significant ($p>0.05$); * significant ($p<0.05$)

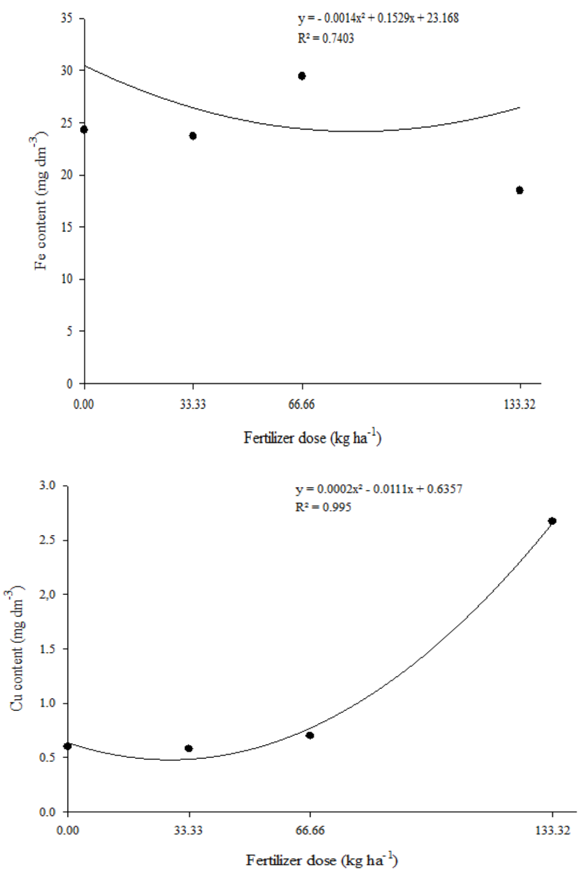


Fig 2. Average Fe and Cu (mg dm^{-3}) in the soil fertilized with different doses micronutrients in Goiânia (GO). (Average Fe and Cu levels at the dose of 66.66 kg ha^{-1} added to 1.4 t ha^{-1} CaO → 20.85 mg dm^{-3} Fe and 0.75 mg dm^{-3} Cu).

the soil. In addition, the regression curve (Fig 2) shows that a fertilizer dose of 54.60 kg ha^{-1} provides 1.15 kg ha^{-1} of Fe.

Micronutrient fertilizers provided higher accumulation of Fe, Mn and Zn in the leaves (Table 3). Fe was the only element recorded above adequate levels in the leaves, and may be associated with the large availability in the soil. N was recorded below the adequate levels based on the interpretation criteria proposed by Oliveira (2004), but adequate for the criteria proposed by Ambrosano et al. (1996). The inoculation of the seeds shows that biological fixation of N occurred. However, the biological fixation of N was not very expressive, once the nitrogen sufficiency ranges were very similar among all authors.

According to the interpretation classes of the nutrient content in leaves (Malavolta 2006), the average values of Mn (78.2 mg kg^{-1}) and Fe (406.7 mg kg^{-1}) were recorded above the adequate level, and Zn (22.8 mg kg^{-}1) and Cu (5.6 mg kg^{-1}) values below the adequate level. Fe content is associated to the capacity of reducing Fe^{+3} to Fe^{+2} in the roots. Therefore, these values may be associated with the absence of cobalt (Co), commonly conveyed through seeds (Sfredo and Oliveira, 2010).

Only the dose of 133.32 kg ha^{-1} of the fertilizer increased Mn contents in the soil. Still, this dose did not affect leaf contents. Similarly, applying Mn to the soil has caused increases in the soil without further accumulation in soybean plants (Moreira et al. 2006). In contrast, concomitant increases in the manganese levels of soil and leaves have been reported as a consequence of soil fertilization with manganese (Pinto 2012).

The dose of 133.32 Kg ha^{-1} of micronutrient fertilizer provided increases in Cu content in the soil without increasing Cu levels in the leaves (Table 2). The absorption of Cu is highly affected by soil pH, where Cu absorption decreases as pH increases (Joris et al. 2012). However, no reduction in Cu contents of the soil were recorded due to the

Table 3. Average grain yield in different doses of fertilizer in soybean culture. Goiânia, GO.

Dose of Fertilizer (kg ha^{-1})	Yield	Relative yield
0.0	1,869.4 b	100.00
33.33	2,513.9 ab	134.47
66.66	3,041.7 ab	162.70
132.32	3,359.7 a	179.72
66.66 + CaO [(1)]	2,590.3 ab	138.63
Mean	2,675.0	
F Test	4.69*	
CV (%)	19.57	

[1]Calcium oxide. Means followed by different letters in the column differ by the Tukey test ($p < 0.05$).
* - significant.

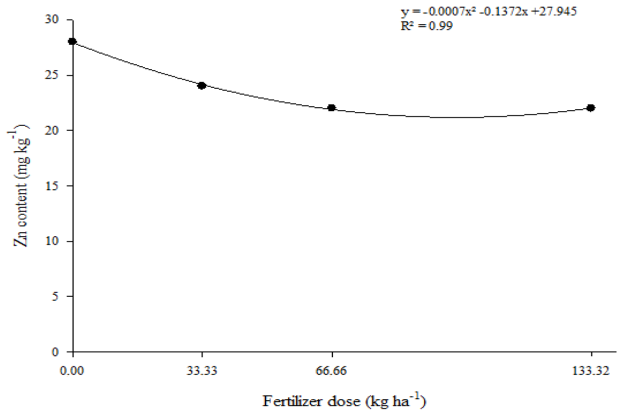


Fig 3. Average Zn (mg dm^{-3}) in leaves considering the different doses of micronutrient fertilizer, in Goiânia, Goiás (average Zn level at the dose of 66.66 kg ha^{-1} added to 1.4 t ha^{-1} CaO $\rightarrow$ 25.00 mg kg^{-1} Zn.

Table 4. Chemical characteristics of the soil in the 0-0.20 m layer before establishing the soybean experiment in Goiânia (GO).

O.M.	V	pH	P(Mel)	K	Ca	Mg	CEC	Cu	Fe	Mn	Zn
--------- % --------		$CaCl_2$	--- mg dm^{-3} ---		--- cmol$_c$ dm^{-3} ---				---------- mg dm^{-3} -----------		
2.3	55.8	5.3	8.3	205	3.2	0.7	7.9	0.8	12	19.4	1.6

O.M. = Organic Matter; V = base saturation; CEC (pH 7.0); P, K, Cu, Fe, Mn, Zn (Mehlich 1).

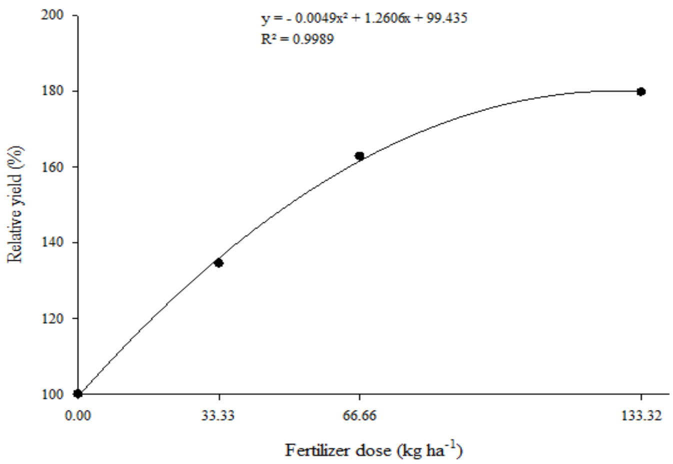


Fig 4. Relative yield (kg ha^{-1}) of soybeans subjected to different doses of micronutrient fertilizer applied to the soil, in Goiânia, Goiás (average productivity at the dose of 66.66 kg ha^{-1} added to 1.4 t ha^{-1} CaO $\rightarrow$ 2,590.3 kg ha^{-1}).

use of calcium oxide. Therefore, the micronutrients of the soybean plants were extracted in the following: Fe>Mn>Zn>Cu, and confirmed the results obtained by Battaglia & Mascarenhas (1977). The Zn contents in the leaves enabled adjusting a polynomial regression curve in regards to the different doses of the micronutrient fertilizer (Fig 3). The fertilizer dose of 98.0 kg ha^{-1} provided a lower absorption of Zn (considering mean values). The average Zn levels in dry leaves ranged from 22 to 28 mg kg^{-1} and is within the sufficiency range (Soy Production Technology, 2011). The plant suffers reduction in enzyme activity, chloroplast development, and in protein and nucleic acid contents in case of Zn deficiency. The interaction between Zn and P in the plant is negative, once the application of a soluble P source induces Zn deficiency (Carneiro et al. 2008).

The micronutrient fertilizer increased soybean yield (Table 3). The dose of 133.32 kg ha^{-1} increased soy yield in 79.72 % when compared with the treatment without fertilizer (1,869.40 kg ha^{-1}), and in 33,64 % when compared with the treatment that received 33.33 kg ha^{-1} of fertilizer. The average productivity of the state of Goiás in the harvest of 2013/2014 was 2,900 kg ha^{-1} (Conab 2014). Therefore, the treatments that received 66.66 and 132.32 kg ha $^{-1}$ of the fertilizer had satisfactory yields, above the state average.

The second degree polynomial fitting between the relative average productivity of soy and the dosages used (Fig. 4) showed maximum yield at the dose of 128.63 kg ha^{-1} of the micronutrient fertilizer applied in the soil. A relative productivity of 186.27% was obtained when using the maximum fertilizer dosage, which comprised 8.75 kg ha^{-1} Mn, 5.02 kg ha^{-1} Zn, 2.70 kg ha^{-1} Fe, 1.54 kg ha^{-1} Cu and 1.41 kg ha^{-1} B. The results show positive effects on productivity when applying the fertilizer via soil. Similar results have been reported by Mann et al. (2002), who recorded productivity increases resulting from foliar and soil applications of manganese. Positive effects of the application of Mn on the productivity of conventional and transgenic RR soybean have also been reported (Carvalho et al. 2014). An increase in Mn doses has provided a linear growth in soybean yield (Pinto 2012). However, genotype influences the plant response to Mn application (Loecker et al. 2010), i.e., not all cultivars will respond similarly.

Materials and Methods

Experimental site

The experiment was carried out under field conditions (16°35'59" S, 49°16'56" W, altitude of 704.35 m), from December to April, in an Oxisol (Embrapa, 2013). Physical and chemical characteristics of the soil are shown in Table 4. The experiment was conducted in an area occupied with pastures for ten years, which had never been subject to liming or fertilization.

Experimental procedure

The randomized block design was employed, with five treatments and four replications. The treatments consisted of five doses of the fertilizer (0 kg ha^{-1}, 33.33 kg ha^{-1}, 66.66 kg ha^{-1}, 133.32 kg ha^{-1} and 66.66 kg ha^{-1} in addition to 1.4 t ha^{-1} calcium oxide). Calcium oxide (CaO) was applied to assess whether it would increase the micronutrient availability for the plants, once it is a compound of high solubility.

The fertilizer was obtained by processing Mn ore into manganese monoxide to, subsequently, produce manganese sulphate and manganese solutions after attack with sulfuric acid. The inorganic source was mixed with other metal salts, sulfates and oxides (oxisulphates). Therefore, the product tested comprises 6.8% (Mn), 3.9% (Zn), 2.1% (Fe), 1.2% (Cu) and 1.1% (B).

The area was initially prepared by harrowing, using 12 harrow disks of 32 inches, and the leveling harrow was used to even out the land. Then, furrows were made in the 0.45 m spacing, to manually apply the micronutrient fertilizer. The experimental area amounted to 900m^2 and each experimental unit consisted of a 7 meters of width and 5 meters of length area.

Sowing was carried out using a seed-drill, in seven rows positioned 0.45 m apart from each other, in a population of 330,000 plants ha^{-1}. Soybean seeds of the cultivar ENG 313, previously treated with fungicide (fludioxonil and metalaxyl-M – one mL Kg^{-1} seed) and inoculated (6 g Kg^{-1} - concentration of 5 x 10^9 rhizobia g^{-1}) were used.

Planting fertilization consisted on the simple mixture of 450 kg ha^{-1} of super simple fertilizer (1 % N and 18 % P_2O_5) and 120 kg ha^{-1} potassium chloride (60 % of K_2O). Doses were determined according to the recommendations of Sousa and Lobato (2004).

The efficiency of the micronutrient fertilizer efficiency was evaluated through the chemical analysis of the soil and soybean leaves. A total of 14 soil samples were randomly collected per plot in the depth of 0-0.20m, using a Dutch auger. These simple samples were mixed homogeneously and formed the composite sample.

One sample was collected in the crop row for every 6 simple samples collected between the lines. The soil samples were collected during the crop flowering period. Chemical analyzes consisted of determining pH in $CaCl_2$, pH in SMP buffer (H+Al), micronutrients (Cu, Fe, Mn and Zn), available P and K (Mehlich 1 extractor), available Ca and Mg, Al content extracted with KCl, and O.M. contents in the soil measured using a potassium dichromate solution in sulfuric acid medium (Embrapa, 2011).

A total of thirty leaf samples were collected per plot during the full flowering of the third trefoil from the apex to evaluate leaf contents (Malavolta et al., 1997). The material was washed with distilled water and placed in paper bags to be dried in an oven with forced ventilation at 60 ºC. After reaching a constant weight, the leaves were crushed, and subjected to chemical analysis to determine the total foliar contents of N, P, K, Ca, Mg, S, Cu, Fe, Mn and Zn (Malavolta et al., 1997).

Soybean yield was determined after physiological maturity, in the center of each plot, considering five plantation rows of three meters and harvesting all the plants in the established area. Therefore, a 7.5 m^2 plot was used to determine productivity. The samples collected were identified, bagged and subsequently threshed. Humidity was corrected to 13 % after weighing and the productivity estimates were extrapolated into productivity ha^{-1}.

Data analysis

The significance of the effect of treatment was determined using an F-test, and the means were compared using a Tukey test ($p<0.05$). Polynomial regressions were adjusted for Mn, Zn, Fe and Cu levels in the soil, for the Zn contents of the leaf and for the soybean yield, in regards to the micronutrient fertilizer doses. The statistical software Statistical Analysis System - SAS (SAS, 2003), version 9.1. was used to perform the statistical analysis.

Conclusions

The dose of 133.32 kg ha^{-1} of a micronutrient fertilizer (6.8% Mn, 3.9% Zn, 2.1% Fe, 1.2% Cu, 1.1% B) leads to increases in productivity of soybean plants in Cerrado conditions.

Acknowledgments

We thank the research assistance provided by Stefani S/A and the financial support provided by CNPq.

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