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# **Soybean Yield Responses to Micronutrient Fertilizers**

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## **Abstract**

The availability of commercial products containing micronutrients for the management of crops has increased in recent years, but there are experimental results showing great variability in response to their application. A literature review was made in 28 scientific articles about the answers in the soybean yield in Brazilian agriculture due to the application of fertilizer containing micronutrients. Then, the aim of this chapter is to approach the efficiency of sources, doses, application methods, time, and yield results achieved in recent years by Brazilian research with the application of micronutrients in soybean. Adequate doses and sources of micronutrient increase Brazilian soybean yield, especially in that soil with low micronutrient content. High yields can be obtained in soils that have micronutrient levels considered adequate or high without their application. To right choice of micronutrients fertilizers, the farmer must know about solubility and other characteristics, including easiness to handling and applying and price. In general, the application method does not result in differences in soybean productivity. Thus, when applying micronutrients in the soil, topdressing or seed furrow, and leaf, and seed treatment, the most important aspects seem to be the time and dose to provide the nutrients in adequate amounts the plant requires.

**Keywords:** manganese, molybdenum, boron, zinc, copper

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## 1. Introduction

The increase in production capacity of Brazilian soybeans farmers is allied to scientific advances and the availability of technologies in the productive sector [1]. The use of mineral fertilizers for soil and foliar application and other technologies has greatly contributed to the production progress. In this context, the most efficient use of micronutrients is essential to achieve high yield.

The availability of commercial products containing micronutrients for the management of crops has increased in recent years, but there are experimental results showing great variability in response to its application [2]. The main sources of micronutrients used in soybean crops vary in their physical form, chemical reactivity, cost, and agronomic efficiency.

Some sources are water soluble, such as chelates, nitrates, sulfates, and chlorides, while others are water insoluble but provide micronutrients to plants when applied to the soil, which are carbonates, phosphates, oxides, and silicates, among others [3]. The main advantage of chelates is the low dissociation in solution, i.e., the binder tends to remain bound to the metal even under conditions in which the metal precipitate or become insoluble (in concentrated solutions with neutral or alkaline reaction). This feature allows Cu, Fe, Mn, and Zn to remain in solution and maintain its availability to plants. Thus, the efficiency of chelates applied to the soil may be two to five times per unit of micronutrient, as compared to the inorganic sources [4].

Micronutrient oxide sources have the lower solubility, therefore generally less costing than the more soluble sources. However, some research work has shown improved efficiency of oxide use in relation to other sources [5,6]. Another group of micronutrient sources has been widely used is oxide nanoparticles in concentrated suspension, in which due to the small particle size, the elements are absorbed by the leaves and, depending on the pH of the cell, the cations ( $\text{Zn}^{2+}$ ,  $\text{Cu}^{2+}$  and  $\text{Mn}^{2+}$ ) can be released [7].

Despite the recognized importance of fertilizer with micronutrients, there is a need for a literature review that demonstrates more broadly the breakthroughs achieved by scientific research in the fertilizer with micronutrients, particularly for soybean, which is an important agricultural commodity and large consumers of micronutrients in the world.

A literature review was made in 28 scientific articles about the answers in the soybean yield in Brazilian agriculture due to the application of fertilizer containing micronutrients. Detailed descriptions of the treatments and their discussion can be found in the original articles. In this chapter, we seek for the objectivity in the main information related to the application of fertilizers, that is, the yield responses. The data shown in the graphs were compiled from research papers, and their claims should be given to the cited authors.

The hypothesis of this review is that the adequate supply of micronutrient fertilizer can increase soybean yield in Brazilian agriculture. Then, the aim of this review is to approach the efficiency of sources, doses, application methods, time, and yield results achieved in recent years by Brazilian research with the application of micronutrients in soybean.

## 2. Bases for soybean fertilization with micronutrients in Brazil

The use of the history of the area for soybean cultivation is fundamental to the proper micronutrient fertilization management. Plants cultivated on those areas that receive frequent spray applications with fungicides containing micronutrient rarely develop nutrient deficiency symptoms. However, other factors affect the micronutrient availability to plants, such as soil pH, soil organic matter content, and soil redox potential. The pH increase implies decreases of the Cu, Fe, Mn, and Zn micronutrients in the soil solution and the cation exchange sites. Thus, excessive limestone application can reduce the availability of these micronutrients in the soil and induce deficiency. In addition, the organic matter can decrease the solubility of some micronutrients by the formation of organic complexes constituted by humic acids and Fe, Mn, Cu, and Zn. On the other hand, organic matter may also increase the availability of micronutrients by complexation with fulvic acids and can be a source of micronutrients to soil in conditions favorable to their decomposition, such as heat, moisture, aeration, and high microbial activity. These factors have mainly been related to the increase in B (boron) availability. Oxidation reactions influence in particular Fe and Mn availability. When soybean is grown in regions of high rainfall, if the soil is not well drained, Fe toxicity may occur due to the reduction of the redox potential, which causes reduction of  $\text{Fe}^{3+}$  to  $\text{Fe}^{2+}$  and can increase Fe availability in the soil [8].

To interpret micronutrient contents in the soil, it is necessary to perform the soil test. However, each region of Brazil follows its own methodology, because there is no standardization of the methods to be used throughout the territory, especially because the soil and climate characteristics are distinct between the regions. Thus, the interpretation of the micronutrient contents in the soil must be performed according to tables of each state. Soybeans are grown in all regions of the country, with emphasis on the central-west and south regions, where the largest grain quantities are produced. In Rio Grande do Sul and Santa Catarina states, the average soil contents for B (hot water), Cu, Zn (HCl), Mn (Mehlich-1), and Fe (ammonium oxalate) should be between 0.1–0.3, 0.2–0.4, 0.2–0.5, 2.5–5.0, and  $<5.0 \text{ mg dm}^{-3}$ , respectively. Values below or above those mentioned are interpreted as low or high [9]. In Paraná state, B (hot water), Cu, Zn, Mn, and Fe (Mehlich-1) must be between 0.5–0.6, 1.6–2.0, 1.6–2.0, 9.0–12.0, and  $40\text{--}60 \text{ mg dm}^{-3}$ , respectively. And, for biome Cerrado areas, the reference values for average contents are 0.3–0.5, 0.5–0.8, 1.1–1.6, and  $2.0\text{--}5.0 \text{ mg dm}^{-3}$ , respectively, for B (hot water), Cu, Zn, and Mn [10]. It is important to mention that soils with micronutrient contents above critical levels present a low likelihood of response to fertilization.

The evaluation of micronutrient availability can also be done by analysis of soybean leaves. The use of foliar diagnosis is based on the premises that there are direct relations between the dose of the nutrient and the production, dose of nutrient and content in soil and foliar, and foliar content and production. The procedure for sampling soybean leaves for leaf analysis is to collect the third leaf (third trifoliate leaves) from the apex on the main stem with petiole at the time of full bloom (R2). The sample should adequately represent nutritional status of the portion one wishes to evaluate. For soybean, it is suggested to sample 30 plants in each homogeneous field. Dirty soil samples and dry, diseased, or insect-attacked tissues should not be collected. Avoid taking samples before evaporation of dew or when, on previous days, the use of soil or

foliar fertilization or applied defensive. Samples should be sent to the laboratory as soon as possible. The interpretation of the results of the tissue analysis is done by comparing the levels observed in the sample with ranges of concentrations considered adequate, that is, the ranges of sufficiency. The reference values for the micronutrient contents in the soybean crop for B, Cu, Zn, Mn, Fe, and Mo are 21–55, 10–30, 20–50, 20–100, 50–350, and 1.0–5.0 mg kg<sup>-1</sup> [8, 11].

Amounts of micronutrients recommended vary depending on the region of Brazil. In Rio Grande do Sul and Santa Catarina states, the application of 12–25 g ha<sup>-1</sup> of molybdenum, via seed, or between 25 and 50 g ha<sup>-1</sup> of molybdenum, via foliar fertilization, is suggested for soybean cultivation. The Brazilian Agricultural Research Corporation recommends the following doses for the first soybean cultivation in micronutrient-deficient soils, 4–6 kg ha<sup>-1</sup> of Zn, 0.5–1.0 kg ha<sup>-1</sup> of B, 0.5–2.0 kg ha<sup>-1</sup> of Cu, 2.5–6.0 kg ha<sup>-1</sup> of Mn, 50–250 g ha<sup>-1</sup> of Mo, and 50–250 g ha<sup>-1</sup> of Co, all applied in haul and with residual effect for at least 5 years. For application to the groove, ¼ of the doses described is recommended, but the application should be repeated for 4 consecutive years. Mo and Co should be applied by the seed treatment with 12–25 g ha<sup>-1</sup> of Mo and 1–5 g ha<sup>-1</sup> of Co, and it requires high solubility products. In the Cerrado region, when soil fertilization is not possible, fertilization via seed applying 3 kg of Cu oxide with 80 kg of moist seeds and then bacteria inoculation with *Rhizobium* is suggested. In addition, Mo and Co should be provided via seed: 50–130 g Na molybdate or 40–90 g ammonium molybdate and 8–20 g cobalt chloride or 9–23 g of cobalt sulfate per 80 kg of seeds. Cobalt is not an essential element in plants. However, it is suggested to be applied in soybean cultivation, because Co is part of the structure of vitamin B12 required for the synthesis of leghemoglobin, a protein that has the function of transporting oxygen for the oxidative metabolism of the enzyme nitrogenase, responsible for the biological fixation of atmospheric nitrogen. The use of inoculation with nitrogen-fixing bacteria completely replaces the application of nitrogen in soybean cultivated in Brazil [8].

Micronutrients can be applied by different methods in soybean cultivation: soil fertilization, foliar fertilization, and seed treatment. The application via soil provides greater use efficiency by plants, because it increases the concentration of the element in the soil solution. The application via soil can be done to the haul with fertilizer incorporation during soil preparation, as occurs in conventional agriculture, and can also be applied to the haul without incorporation, as does not occur in no-till areas. And in both ways, the micronutrient can be separated or mixed with NPK. The most common is the application in the sowing lines, beside and below the seeds, usually mixed with NPK and applied with seeder-fertilizer machines.

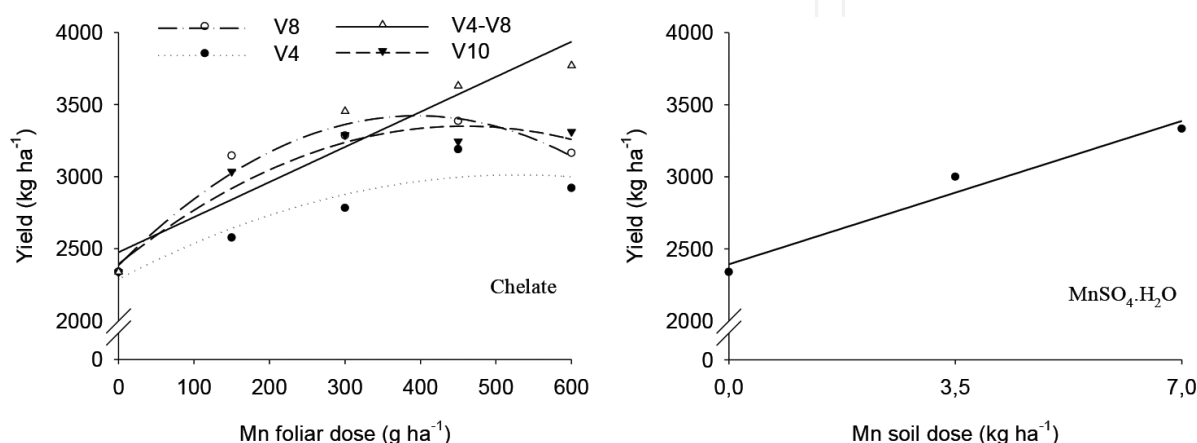
### 3. Soybean yield responses to fertilizer containing manganese

In soil, Mn occurs in three valences, Mn<sup>2+</sup>, Mn<sup>3+</sup> (Mn<sub>2</sub>O<sub>3</sub>·nH<sub>2</sub>O), and Mn<sup>4+</sup> (MnO<sub>2</sub>·nH<sub>2</sub>O), but is actively absorbed by the plant root system as Mn<sup>2+</sup> [12, 13]. For foliar applications, the most traditional source of manganese is sulfate. Some other sources present retention in the cuticle, MnSO<sub>4</sub> > MnCl<sub>2</sub> > Mn-EDTA [14].

The effect of manganese fertilization in the soil and leaf in different soybean crop seasons (*Glycine max* L. Merrill) was studied in Ijaci municipality, Minas Gerais state [15]. The authors



evaluated two cultivars (Conquista and Garimpo), leaf-applied four manganese dosages (150, 300, 450, and 600 g ha<sup>-1</sup>) and three application times (V4, V8, and V10, respectively, with 4, 8, and 10 trifoliate leaves with unfolded leaflets). Additional treatments consisted of control which had not received foliar application of Mn and Mn application on soil at sowing. For the application on the leaves, commercial product Mangan 10® chelate was used, while for Mn at sowing MnSO<sub>4</sub>·H<sub>2</sub>O (manganese sulfate) containing 30% Mn, mixed planting fertilizers was used. Mn foliar applications parceled in V4 and V8 stage at a dose of 450 g or 600 g ha<sup>-1</sup>, with chelated product containing 10% Mn, were responsible for the higher yields obtained, and it was considered more efficient than applications to the soil (Figure 1).



**Figure 1.** Doses, source, time, and local to apply Mn in soybean plants in Ijaci municipality, Minas Gerais state, Brazil. Note: Adapted from Ref. [14]. Other details are shown in the text.

Relations between limestone and manganese doses in mineral nutrition of soybean (*Glycine max* L. Merrill) were evaluated in Rio Verde, southwest of Goiás [16]. The soils (Dystrophic Red-Yellow Latosol (LVd) and Dystrophic Quartz Sand-AQd) were evaluated in natural conditions and showed low fertility and pronounced acidity problems, with calcium and magnesium below the critical level for soybean and manganese contents in toxic levels. The authors concluded that the use of manganese in these soils was unnecessary and harmful to soybean. On the other hand, other researchers have observed manganese deficiency cases in soybean in no-till system, because lime is applied on surface [17].

The hypothesis that tolerant soybean to glyphosate requires further addition of leaf manganese due to changes in absorption, and metabolism of the element was evaluated in Taquaraçu municipality do Sul, in Rio Grande do Sul state (RS) [18]. The Mn source used was a commercial product Profol® with 14% (w/v) manganese soluble in the formulation as chelate form. On the plots that received foliar application of Mn, the dose used was 2.0 L ha<sup>-1</sup> of commercial product. The conclusion was that although manganese supplementation increases foliar content, there was no increase in soybean productivity. This result showed that in soils with Mn levels considered adequate or high, transgenic soybeans do not require foliar manganese supplementation. Similar results were also obtained by other researchers [19] in the experimental area of São Paulo State University-UNESP Jaboticabal-São Paulo.

The application of Mn and glyphosate at different growth stages of soybean variety BRS 245 RR and its effects on foliar nutrient content and grain yield were assessed in Rio Brilhante municipality, Mato Grosso do Sul state (MS) [20]. The authors evaluated crops without foliar application with Mn, Mn application on V4 soybean growth stage, with Mn application at V4 + V8, with Mn application at V4 + R2, with Mn application at V4 + V8 + R2, with Mn application at V8; with Mn application at V8 + R2, and Mn application on growth stage R2. Each application was sprayed 332 g ha<sup>-1</sup> Mn on the leaves. The product used was Basfoliar Manganês® (10% Mn), containing Mn sulfate chelated with EDTA. No differences in yield were observed (3000 kg ha<sup>-1</sup>) as a function of Mn applications.

Chemical forms and manganese availability in soybean yield in soil under no-tillage system were evaluated in Tibagi and Castro municipalities, in Paraná state (PR) [21]. The authors used the MnSO<sub>4</sub> and varied the Mn doses from 0 to 48 kg ha<sup>-1</sup> applying manually to the soil. They did not observe variations in soybean yield (3000 kg ha<sup>-1</sup>). According to the authors, the lack of effect of Mn on soybean yield in no-tillage system may be due to the complexation of the nutrient by organic matter stable forms, non-available to plants.

The Mn availability to plants depends on many factors relating to the soil, particularly the pH and the organic matter. On the other side, even no-tillage system promotes increased soil pH in the surface layer, which implies less Mn availability in the soil; the research results have not shown soybean response to Mn leaf application.

#### 4. Soybean yield responses to fertilizer containing molybdenum

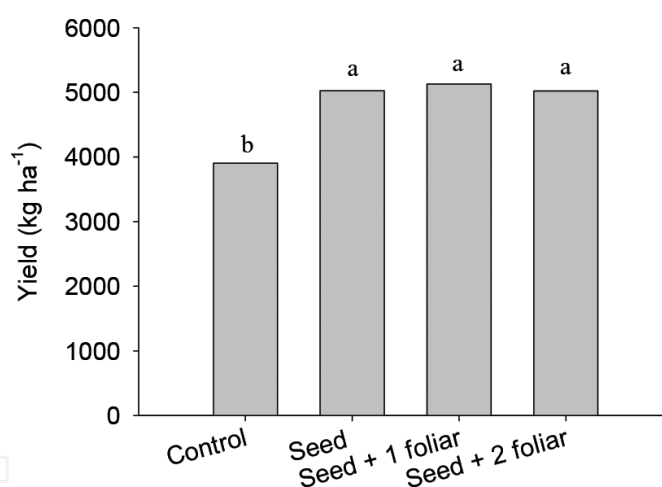
Mo is a micronutrient less abundant in the soil than other and the least required by crops. In the soil, Mo appears in the anionic form as HMoO<sub>4</sub><sup>-</sup> and MoO<sub>4</sub><sup>2-</sup>. In those soils with pH > 5.0, Mo is absorbed predominantly as MoO<sub>4</sub><sup>2-</sup> [11], while at pH < 4.3 the predominant forms are protonated species as HMoO<sub>4</sub><sup>-</sup>, MoO<sub>3</sub>(H<sub>2</sub>O)<sub>3</sub> [13]. Although Mo is considered as a low mobility nutrient in the plant, Mo can be applied to the leaves with good results, since redistribution is good [14].

The effect of foliar application of Mo dose in soybean and beans (*Phaseolus vulgaris* L. — Carioca Perola) at greenhouse was evaluated in Rio Verde municipality, Goiás state [22]. The authors varied the Mo doses between 0 and 160 g ha<sup>-1</sup> and observed no differences in any of the variables in the two species. The authors explained the results by stating that the Mo needed by the plant was supplied with the initial soil reserve. The pH of the soil was around 7.0, which is the pH to the greatest availability of Mo.

Foliar application of Mo and cobalt to soybean crop, CD 214 RR variety, was evaluated in São João (PR) [23]. Foliar application was carried out with cobalt and Mo micronutrients (12.0% sodium molybdate and cobalt sulfate 2.0% commercial product—Basfoliar CoMol HC). Dose which was 0–200% of the dose recommended by the manufacturer is 309 mL ha<sup>-1</sup>, and the application was carried out 25 days later after crop emergence. The authors found that the application of Mo and cobalt (Co) to the leaves did not affect the soybean development. Application of Mo concentrations at soybean seed treatment and foliar was evaluated in Palotina municipality, Paraná state (PR) [24]. The leaf application was made 25 days after

emergence at doses ranging from 0 to 160 g ha<sup>-1</sup>, while to seed treatment was used 0.6 g of Mo per seed kg. The authors found no significant differences in yields between treatments. The yield average was 2104 kg ha<sup>-1</sup>. The authors justified that the absence of response to the addition of Mo may be related to adequate levels of Mo availability in the soil or with concentrations of Mo in the seed sufficient to meet the needs of the plants.

Seed and foliar treatments with zinc (Zn) and Mo to soybean crop were evaluated in Cascavel (PR) [25]. For seed treatment and foliar application, the source of Mo + Zn was the commercial product Booster®: 3.5% Zn and 2.3% Mo. The treatments were distributed as follows: Treatment 01—control (only cultivation with application of insecticides, fungicides, and herbicides), Treatment 02—seed treatment (3 mL kg<sup>-1</sup> seed), Treatment 03—seed treatment (3 mL kg<sup>-1</sup> seed) + a foliar application (400 mL ha<sup>-1</sup>, which were applied when the soybean was at 4–5 trefoil), and Treatment 04—seed treatment (3 mL kg<sup>-1</sup> seed) + two foliar applications (400 mL ha<sup>-1</sup>, which was applied when soy was 4–5 trefoil + 400 mL ha<sup>-1</sup> when the soybean was at the beginning its flowering). The variety used in the experiment was a cultivar of BMX Apollo RR presenting with an early maturity of 5.5 group cycle with unlimited growth, with 340,000 plants per hectare. There was increase in 1100 kg ha<sup>-1</sup> in yield in the seed treatment (Treatment 02), as compared to the control. There was no difference between Treatment 02, Treatment 03, and Treatment 04 yield, with a mean of 5050 kg ha<sup>-1</sup> (Figure 2).

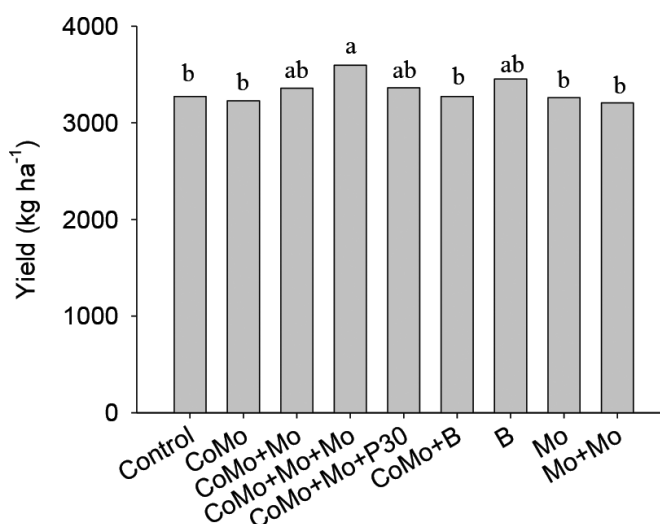


**Figure 2.** Soybean yield, due to the use of zinc and molybdenum. Note: Adapted from Ref. [25]. Other details are shown in the text.

The effectiveness of different molybdenum sources using the products, Nectar (225 g L<sup>-1</sup> Mo + 22,5 g L<sup>-1</sup> Co), Molybdate (254 g L<sup>-1</sup> Mo + 262 g L<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>), and MIQL-Mo (250 g L<sup>-1</sup> Mo) in the development and productivity of soybean cultivar BR-16, was evaluated in Santa Maria (RS) [26]. Before sowing, the molybdenum sources applied to soybean seeds using the following doses, Nectar, 0.15 g Mo kg<sup>-1</sup> seed; Molybdate, 0.15 g Mo kg<sup>-1</sup> seed; and MIQL, 0.15 g Mo kg<sup>-1</sup> seed. Seed inoculation with *Bradyrhizobium japonicum* inoculum through supplying 6 g kg<sup>-1</sup> of seed was also performed using the product with trade name “Emerge®.” The difference in yield between treatments with Mo and those without Mo was approximately 1600 kg ha<sup>-1</sup>. However, the authors found no significant differences in productivity (3570 kg ha<sup>-1</sup>) between different sources of Mo.



Technical and economic feasibility of the application of Mo, Co (cobalt), and B (boron) to increase soybeans yield (cultivar RS-10) was determined in Coronel Bicaco (RS) [2]. The treatments were the following combinations: CoMo, CoMo + Mo, CoMo + Mo + Mo, CoMo + Mo + P30 (30%  $P_2O_5$ , 5% N and 1.2% Mg), CoMo + B, B, Mo, Mo + Mo, and control treat. Product used to CoMo combinations was the commercial product CoMo Plus 250® (1.7% Co and 17% Mo) at a dose of  $0.09 \text{ L ha}^{-1}$  applied via seed. In treatments in which Mo was used separately, the source used was sodium molybdate (39.5% Mo) at a dose of  $0.12 \text{ kg ha}^{-1}$ , applied to the leaves together with herbicides at 30 days after emergence (DAE). When Mo was applied two times, it was performed at 30 and 60 DAE; P, N, and Mg were applied with the commercial product Nutijá P30 at a dose of  $2.0 \text{ L ha}^{-1}$  applied at 60 DAE. B was applied with the commercial product Solubor (20.5% B) at a dose of  $1.0 \text{ kg ha}^{-1}$ , applied to the leaves at 60 DAE of soybean plants. The highest yield ( $3596 \text{ kg ha}^{-1}$ ) and economic viability (net return  $\text{US\$ ha}^{-1}$  49.19) were obtained with the application of CoMo + Mo + Mo (Figure 3).



**Figure 3.** Soybean grain yield, under the application of micronutrients in crop year 2001/02. Note: Adapted from Ref. [2]. Other details are shown in the text.

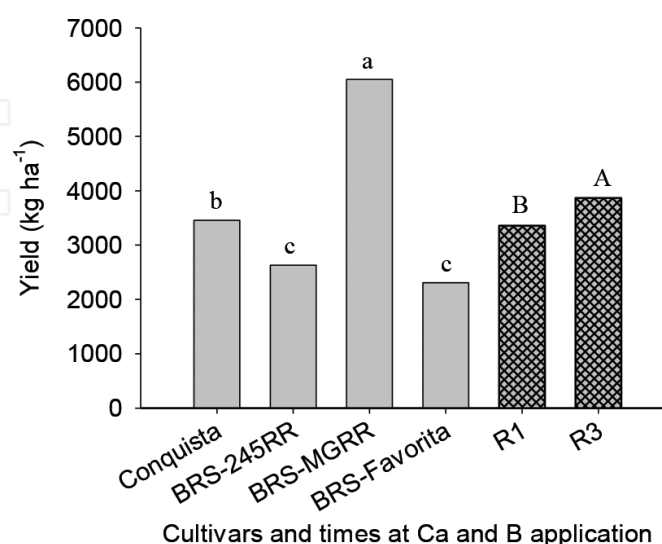
Molybdenum and cobalt applications on soybean nodulation, cultivar COODETEC 201, and their effects on grain yield were evaluated in Ponta Grossa (PR) [27]. Mo was applied at two doses (0 and  $48 \text{ g ha}^{-1}$ ), and Co was applied at four doses (0, 2, 4, and  $8 \text{ g ha}^{-1}$ ) to seeds. The sources of molybdenum and cobalt were sodium molybdate ( $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$ ) and cobalt sulfate ( $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$ ), respectively. Molybdenum treatment decreased the iron content in the leaves, but did not affect soybean yield ( $3000 \text{ kg ha}^{-1}$ ). There was a linear decrease in plant height, leaf zinc concentration, and yield with increasing dose of cobalt applied. The authors concluded that the molybdenum application to soybean is not required in soil pH 5.2 ( $\text{CaCl}_2$   $0.01 \text{ mol L}^{-1}$ ) and that cobalt applied to the seed at doses greater than  $3.4 \text{ g ha}^{-1}$  is toxic to soybean.

Due to the small quantities required by the soybean crop and partial mobility in the plant, the application of molybdenum to leaf or seed treatment has shown satisfactory results in increasing the productivity. Regarding Co, the provision should be made with caution, because Co excess in the soil can cause toxicity to plants and reduces Fe and Mn absorption, leading to deficiency of these micronutrients [12].

## 5. Soybean yield responses to fertilizer containing boron

Boron (B) is probably absorbed by the roots of the plants in the undissociated form as boric acid ( $H_3BO_3$ ), which is the main soluble form in the soil. In the same way as calcium, boron undergoes a unidirectional transport in the xylem, via transpiration stream from roots to shoots; in phloem, B is practically immobile. Thus, boron is not redistributed in plants, and causes the appearance of withdrawal symptoms primarily in younger organs and in growth regions [12]. However, there is a statement in the literature that plants containing appreciable amounts of polyols (with cis-hydroxyls) that bind to the boron present the mobility of B in the phloem. Soy, for example, contains large amounts of the cis-diol pintol molecule, which may result in the phloem mobility of B [14].

After zinc, boron is the micronutrient whose deficiency occurs more widely in the areas of Cerrado, Brazil. Applying it at soil is the most efficient way to provide B. However, Ca and B foliar spraying is very widespread at the time of flowering. Supposedly, this procedure favors better fertilization of the flowers and grain formation by the B effect and reduces the abortion of the newly formed pods due to the presence of Ca [28]. The productivity of four soybean cultivars was evaluated as a function of foliar mineral fertilizer application containing 8% calcium and 2% boron in R1 stage (early flowering 50% of flowering plants) and R3 (final flowering, pod up to 1.5 cm in length) [1]. The productivity was significantly higher when the solution based on Ca and B was applied in R3. The BRS MG 705S RR showed the best performance among cultivars, reaching an average yield of 6506 kg ha<sup>-1</sup> with the fertilizer of 1.0 kg ha<sup>-1</sup> of fertilizer in Selvíria (MS) (**Figure 4**). However, the response of soybeans to leaf-borated fertilizer at different stages and application rates was not observed in Borrazópolis (PR) [29]. The borated foliar fertilization did not affect the productivity of soybeans. However, the application of 1 kg ha<sup>-1</sup> of B in soybean development V4 stadium reduced the leaf N content compared to the control treatment. Application of 2 kg ha<sup>-1</sup> of B in R2 stadium resulted in an increase in the fertilization efficiency for potassium.



**Figure 4.** Effect of foliar application of Ca and B on productivity of soybean cultivars and application time of Ca and B to the leaves in Selvíria municipality, Mato Grosso do Sul state, Brazil, 2007. Note: Adapted from Ref. [1]. Other details are shown in the text.

The effect of B applied in different doses and stages by foliar spray on the morphological characteristics, production and physiological quality of soybean seeds of M-SOY 8411 variety, was evaluated in Santa Carmem (MT) [30]. The seeds were treated with fungicide Fludioxonil + metalaxyl-M + and molybdenum and cobalt using liquid inoculants of 100 mL, 150 mL, and 300 mL, respectively, per 100 kg of seed. Boron doses ranged from 0 to 400 g ha<sup>-1</sup> (0–4 L ha<sup>-1</sup> of the commercial product Basfoliar Boron 10%). There were no yield differences between different B doses or application at soybean growth stage (V5, V9, and R3).

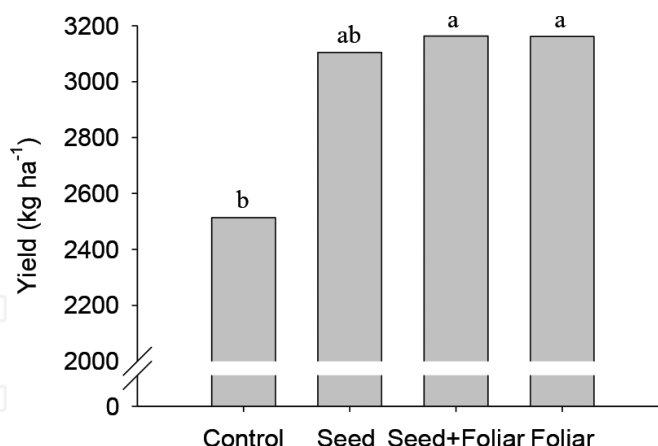
Overall, the research work of foliar application of B in soybean showed no yield responses due to the nutrient application. It may be related to the nutrient content in the soil. The nutrient might be sufficient to the crop need in places where the studies were carried out.

## 6. Soybean yield responses to fertilizer containing zinc and copper

Zinc deficiencies have occurred in a wide variety of soils around the world and in Brazil. Zn deficiencies are the most common among the micronutrients, especially in sandy soils and savannah. Zinc is absorbed predominantly as a divalent cation (Zn<sup>2+</sup>); at high pH, it may be absorbed as monovalent cation (ZnOH<sup>+</sup>) [13]. The zinc sulfate application has been considered the standard for the nutrient. However, zinc nitrate, zinc chloride, or sulfate mixed with zinc chloride has shown good results. The zinc chelated with EDTA has shown better absorption than zinc sulfate form [14], while zinc oxides are materials which have a lower solubility.

Productivity and yield of soybean cultivar “Spring” fertilized with different zinc doses in field conditions were evaluated in Palotina (PR) [31]. The Zn doses tested were 0, 2, and 4 kg ha<sup>-1</sup>, applied at sowing as zinc sulfate (ZnSO<sub>4</sub>). Zn doses applied did not influence significantly the yield. The authors attributed the result to the Zn content in the soil prior to application. The Zn content in the layer 0–20 cm was presented as medium (1.4–2.0 mg dm<sup>-3</sup>) and therefore considered somewhat responsive to fertilizer. In the same municipality, differences in yield when NPK (02-20-18) + 0.3% Zn was applied in the sowing using different commercial products as source of Zn were not observed [32]. On the other hand, there was response to Zn doses applied. The soil Zn content at the beginning of the experiment was 3.65 mg kg<sup>-1</sup>, even so the authors observed yield increase of 679 kg ha<sup>-1</sup> when they applied twice the dose suggested for that soil.

Copper and zinc fertilizer doses on the soybean yield were evaluated in Assis Chateaubriand municipality, Paraná state (PR) [33]. The authors cultivated soybeans without application of micronutrients, with application of copper and zinc oxide to seed, with application of copper and zinc oxide via seed and leaf, and applying copper and zinc oxide only to leaf. The copper and zinc oxide doses applied in seed treatment were 1.88 mL kg<sup>-1</sup> and 4.24 mL<sup>-1</sup>, respectively, and foliar sprays at 35 days after emergence were 109 mL ha<sup>-1</sup> of copper oxide and 245 mL ha<sup>-1</sup> of zinc oxide. Regardless of the application mode, copper and zinc micronutrient supply provided an increase in 600 kg ha<sup>-1</sup> in soybean yield compared with control treatment. On the other hand, there was no significant difference in soybean yield (3100 kg ha<sup>-1</sup>) when Cu and Zn were applied to seed, seed and leaf, and leaf (Figure 5).



**Figure 5.** Soybean yield as a function of using zinc and copper. Note: Adapted from Ref. [33]. Other details are shown in the text.

Copper doses and application methods in soybean cultivation were evaluated in Planaltina municipality, Federal District (DF\_ [34]. The authors tested Cu applications via soil, topdressing ( $0 - 4.8 \text{ kg ha}^{-1}$ ), and drilling ( $1.2$  and  $2.4 \text{ kg ha}^{-1}$ ) using copper sulfate pentahydrate. They cultivated soybean three times after applications and did not reapply copper in the second and third crops to assess the residual effect. All plots received  $3880 \text{ kg ha}^{-1}$  of limestone ( $229 \text{ g kg}^{-1}$  of Ca  $72 \text{ g kg}^{-1}$  of Mg) to raise base saturation to 50%,  $1031 \text{ kg ha}^{-1}$  of agricultural gypsum,  $240 \text{ kg ha}^{-1}$  of  $\text{P}_2\text{O}_5$  in the form of superphosphate triple,  $100 \text{ kg ha}^{-1}$  of  $\text{K}_2\text{O}$  using potassium chloride and a mixture with  $2 \text{ kg ha}^{-1}$  of B (borax),  $6 \text{ kg ha}^{-1}$  Zn (sulfate),  $3 \text{ kg ha}^{-1}$  of Mn (sulfate),  $0.25 \text{ kg ha}^{-1}$  of Mo (ammonium molybdate), and  $0.3 \text{ kg ha}^{-1}$  of Co (chloride). In the first crop after Cu applications, the average yield was  $2320 \text{ kg ha}^{-1}$  of grains, and they did not observe difference between treatments. In the second crop after application, there was increase of soybean yield at  $600 \text{ kg ha}^{-1}$  in the treatments without Cu fertilizer or received only  $0.4 \text{ kg ha}^{-1}$  at topdressing and  $1082 \text{ kg ha}^{-1}$  in soybean yield to the other treatments. In the third crop after Cu applications, the control plot (without Cu) and the plot that just received  $0.4 \text{ kg ha}^{-1}$  produced  $548 \text{ kg ha}^{-1}$  less soybean grains compared to those that received from  $1.2$  to  $4.8 \text{ kg ha}^{-1}$  a haul and  $1.2$  to  $2.4 \text{ kg ha}^{-1}$  in the planting furrow. For these last treatments mentioned, the yield average was  $3168 \text{ kg ha}^{-1}$ , without significant difference between them.

The scientific papers generally have not shown differences in soybean yield due to application method when Zn and Cu are applied in the soil to the furrow, to the haul, to the leaves, or in seed treatment, but the right doses are important to obtain high yield, especially when contents of Cu and Zn in soil are below critical levels.

## 7. Conclusions

Adequate doses and sources of micronutrient increase soybean yield especially in that soil with low micronutrients content. However, high yields can be obtained in soils that have micronutrient levels considered adequate or high without their application.

To right choice of micronutrients fertilizers, the farmer must know about solubility and other characteristics as easiness to handling and applying and price.

In general, the application method does not result in differences in soybean productivity. Thus, when applying micronutrients in the soil, topdressing or seed furrow, and leaf or seed treatment, the most important aspects seem to be the time and dose to provide the nutrients in adequate amounts the plant requires.

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