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Foliar copper uptake by maize plants: effects on growth and yield

Absorção foliar de cobre por plantas de milho: efeitos no crescimento e rendimento

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ABSTRACT

A slight increase in the levels of a certain nutrient can cause a significant increase in crop yield or can cause phytotoxicity symptoms. Thus, the aim of this study was to evaluate the effect of foliar application of copper (Cu) on the growth and yield of DG-501 maize. The experiment was carried out between December 2009 and April 2010 in conventional tillage. When plants were with six to eight leaves, Cu (0, 100, 200, 300, 400, 500 and 600g ha^{-1}) was applied to the leaves. Treatments were arranged in randomized complete block with five replications. When 50% of the plants were in flowering, it was evaluated the plant height, culm diameter, height of the first ear insertion, leaf area, and chlorophyll content. At harvest, it was evaluated diameter and length of the ear, yield and thousand grain weight. There was a linear reduction in the plant height and in the height of the first ear insertion with increasing Cu doses. On the other hand, chlorophyll content, leaf area, diameter and length of ear, thousand grain weight and yield increased at doses up to 100g ha^{-1} Cu, however, decreased at higher doses. Therefore, foliar Cu application at doses higher than 100g ha^{-1} has toxic effect in maize plants with losses in growth and yield.

Key words: *fertilization, micronutrient, toxicity,* ***Zea mays****.*

RESUMO

Um leve aumento nos níveis de certos nutrientes pode causar um significante aumento no rendimento das culturas ou causar sintomas de fitotoxicidade. Assim, o objetivo deste trabalho foi avaliar o efeito da fertilização foliar com cobre (Cu) sobre o crescimento e rendimento do milho híbrido triplo DG-501. O experimento foi desenvolvido no período entre dezembro de 2009 e abril de 2010, em sistema de plantio convencional. Quando as plantas encontravam-se com 6-8 folhas totalmente desenvolvidas, o Cu (0; 100; 200; 300; 400; 500 e 600g ha^{-1}) foi aplicado via foliar. Os tratamentos foram arranjados em delineamento experimental de blocos casualizados, com cinco repetições. Quando 50% das plantas apresentavam-se no período de florescimento, avaliaram-se a altura de plantas, diâmetro de colmo, altura da inserção da primeira espiga, área foliar e teor de clorofila. Na colheita, avaliaram-se o diâmetro e o comprimento da espiga, o rendimento e o peso de mil grãos. Houve redução linear na altura de plantas de milho e na altura de inserção da primeira espiga com o aumento das doses de Cu. Por outro lado, os dados de índice relativo de clorofila, área foliar, diâmetro e comprimento da espiga, peso de mil grãos e rendimento aumentaram quando foram utilizadas doses de Cu de até 100g ha^{-1} e diminuíram nas doses maiores. Portanto, o Cu aplicado via foliar em doses maiores que 100g ha^{-1} exerceu efeito tóxico às plantas de milho, com prejuízos no crescimento e no rendimento.

Palavras-chave: *adubação, micronutriente, toxicidade,* ***Zea mays****.*

INTRODUCTION

Maize (***Zea mays*** L.) is one of the main products of Brazilian agriculture not only in quantitative parameter but also regarding its strategic significance, since it is the basis for animal feed. Maize crop presents a high yield potential (GONÇALVES et al., 2008). However, deficiencies in soil fertility may be listed as one of the main factors responsible for the inability of maize cultivars to manifest their full potential genetic production (FERREIRA et al., 2001;

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CARVALHO et al., 2004). It is important that studies show the nutritional real needs of the maize crop for each region as well as its responses to fertilization levels and the way in which nutrients are available in order to obtain an increase in its yield.

Cerrado soils are weathered, highly acidic, and contain small amounts of nutrients essential for the cultivation of plants (VENDRAME et al., 2010). In agreement with previous studies, micronutrient deficiencies in Brazil have been observed more frequently in Cerrado soils (LUCHESE et al., 2004). Accordingly, several studies have been directed to the use of micronutrients as a way of increasing the efficiency of plant production and of improving the economic returns to producers (ALAM & RAZA, 2001). Although copper (Cu) is required in small quantities by maize plants (LEITE et al., 2003), it is essential to make their life cycle complete. When Cu is provided in quantities below the requirements, a decrease in the crop yield may occur (LUCHESE et al., 2004). Copper occurs in enzymatic compositions of vital importance in plant metabolism and participates in the photosynthesis, respiration, carbohydrate metabolism, nitrogen reduction and fixation, protein metabolism and cell wall (DEMIREVSKA-KEPOVA et al., 2004; GUO et al., 2010). Copper is also important for the plant resistance to diseases (TOMAZELA et al., 2006). On the other hand, the excess of Cu is cytotoxic due to its role in the catalysis of reactions which generates reactive oxygen species (ROS) ultimately leading to increased oxidative stress in plants (ANDRE et al., 2010). Free Cu ions readily oxidize thiol bonds within proteins, causing a disruption of their secondary structure (DUCIC & POLLE, 2005). Furthermore, excessive quantities of Cu may lead to leaf chlorosis and growth inhibition (BOUAZIZI et al., 2010).

The providing of Cu to crops can be made directly into the soil in the form of fertilizer, in the plant via foliar fertilizer or in the seed treatment (LUCHESE et al., 2004). Copper application in maize seeds at doses of 1 to 6g kg^{-1} of seeds decreased the ability of seed emergency without affecting the dry weight of plants that emerged (LUCHESE et al., 2004). In soil, more than 98% of the Cu of the solution is complexed as chelated with organic compounds of low molecular weight (FAQUIN, 1997). Moreover, Cu greater availability is in the range of pH 5.0 to 6.5. In view of these factors, soil applications may not be effective under particular conditions of soil and climate, such as high organic matter content or hot and humid summer. In these cases, the foliar instead of soil application of Cu could avoid these problems.

The toxic effect of root-up taken Cu on growth and development of plants has been largely studied in several plant species (GUO et al., 2010; CHOUDHARY et al., 2012). On the other hand, little is known about Cu uptake by plant leaves and its effects on growth and yield of crops. The knowledge of the relationships between foliar uptake of metal cations plays a substantial role for foliar fertilization technologies and also for risk assessment of toxic metal penetration into the food chain from plants exposed to rain and toxic fallout (SOLECKI & KRUK, 2011) as well as to swine wastes (SEGANFREDO, 1999). Thus, the aim of this study was to evaluate the effect of foliar application of different doses of Cu on the growth and yield of maize plants.

MATERIAL AND METHODS

The experiment was carried out at the Farm School of Faculdade Anhanguera de Dourados, in Dourados, MS, Brazil, located at 22º13'15"S of latitude, 54º48'21"W of longitude and 430m of altitude, from December 2009 to April 2010. The climate of Dourados according to KÖPPEN (1948) is mesothermal humid, Cwa type, with temperature and annual rainfall averages ranging from 20º to 24ºC and 1250-1500mm, respectively.

The soil from the cultivated area is classified as dystrophic red oxisol of clayey texture, with the following chemical characteristics: pH (H_2O) 5.0; organic matter 25.09g dm^{-3}; P 36.0mg dm^{-3}; Al^{+3} 0.05$mmol_c$ dm^{-3}; K 24.05$mmol_c$ dm^{-3}; Ca 46.05$mmol_c$ dm^{-3}; Mg 22.05$mmol_c$ dm^{-3}; H+Al 53.05$mmol_c$ dm^{-3}; SB 92.15$mmol_c$ dm^{-3} and CTC (pH 7.0) 145.2$mmol_c$ dm^{-3}; Fe 16.0mg dm^{-3}; Cu 2.1mg dm^{-3}; Zn 13.50mg dm^{-3} and Mn 22.20mg dm^{-3}, and 63.46% of saturation. Accumulation of rainfall during the experiment was 603mm and the average temperature was of 25.3ºC (Max. 31.1ºC and Min. 18.7°C).

Seeds of triple hybrid maize DG-501 of early maturity with characteristics of grain semihard, yellow-orange and medium-sized plants were used. Seeds were sown in rows in conventional tillage system after soil preparation. Seeds were treated with the imidacloprid (52.5g ha^{-1}) + thiodicarb (157.5g ha^{-1}) insecticides and sown at a depth of 5 to 7cm, spaced 0.90m between rows and five plants per linear meter, corresponding to approximately 55,000 plants per hectare. Fertilization was applied at planting with 500kg per hectare of N-P-K with the formulation 08-10-10, respectively.

The control of weeds and defoliating caterpillars was carried out 20 days after sowing (DAS) with a backpack pump of 20L, adjusted to 150L ha^{-1}, using the tembotrione herbicide (100.8g ha^{-1}) and the thiodicarb insecticide (120g ha^{-1}).

Treatments consisted of foliar applications of seven increasing doses of Cu (0, 100, 200, 300, 400, 500 and 600g ha^{-1}) distributed in a randomized complete block design with five replications of 4x5m each (20m^2). Pentahydrate sulfate copper ($CuSO_4.5H_2O$) (25% Cu) was used as Cu source.

The spraying was done when the maize plants were with six to eight leaves fully developed, using backpack sprayer with steady flow equipped with 1m bar and with two nozzles spaced at 0.40m. The spray tip of flat fan TeeJet XR11002 (Dourados/MS, Brazil) was used to apply 150L ha^{-1} of spray. The application was made by keeping the tips at 0.30m height, approximately, above the top of the plant canopy.

When 50% of the plants were in the flowering stage, four plants were evaluated per plot. The plant height (using a tape line from the soil until insertion of the last leaf); the stem diameter (measured with a digital caliper at 15cm soil); the height of the first ear insertion (using a tape line, measured of the base from the soil to insertion of the first ear); and chlorophyll content (with Falker Clorofilog) were analyzed. After physiological maturity, at the time of harvest, it was evaluated the diameter and length of the ear (with a caliper on four ears per plot), the yield and thousand grain weight (using ears harvested at three meters central to the plot, with the exclusion of the one external row from each side). At harvest, grains had moisture between 13-15%. Data were subjected to analysis of variance and when significance was found by F test, data were subjected to regression analysis at 5% probability.

RESULTS AND DISCUSSION

With increasing doses of Cu there was a linear reduction in the height of the maize plants and in the height of the first ear insertion (Figure 1a and 1b). Genetic studies have shown that these two characteristics have a high correlation between each other (YAN et al., 2010). Plant height is a parameter for assessing crop performance (TITTONELL et al., 2005). Thus, height reduction is a factor that may contribute to the availability of assimilates for grain filling and may, when significant, affect yield. On the other hand, studies have shown that smaller plants do not necessarily affect yield, especially in the absence of water stress (FORTIN & PIERCE, 1990).

It has been suggested that the primary sites of growth inhibition by excess of Cu are molecules of chlorophyll of the antenna pigment of photosystem II (LIDON et al., 1993). Even without the significant effect of Cu on the culm diameter (data not shown), the shortening of internodes in maize plants exposed to Cu may compromise the potential of this extra source of photoassimilates fixed in the culms of the maize plant. These data contradict those reported by LEITE et al. (2003) who found that fertilization with Cu ranging from 0 to 16mg kg^{-1} soil increased significantly the dry weight of shoots of maize plants grown in pots. According to MALAVOLTA (2006), Cu concentrations in the experimental area were relatively high (2.1mg dm^{-3}), which may explain the lack of more significant effects of Cu in maize plants.

On the other hand, both the relative chlorophyll content and leaf area increased at lower doses and decreased at higher doses of Cu (Figure 1c and 1d). Relative chlorophyll content and leaf area showed maximum points at doses of 257.7 and 112.8g ha^{-1} of Cu, respectively (Figure 1c and 1d). This increase in leaf area and chlorophyll content at lower doses of Cu can maximize the photosynthetic efficiency of maize plants, which improves the interception of PAR and promotes a more efficient conversion of intercepted radiation into dry matter and photoassimilate partition in the reproductive organs, resulting in higher yield and seed weight. On the other hand, as the leaf is the main source of assimilates to plant maize (MAGALHÃES et al., 1995), the reduction in leaf area and chlorophyll content at higher doses of Cu may be related

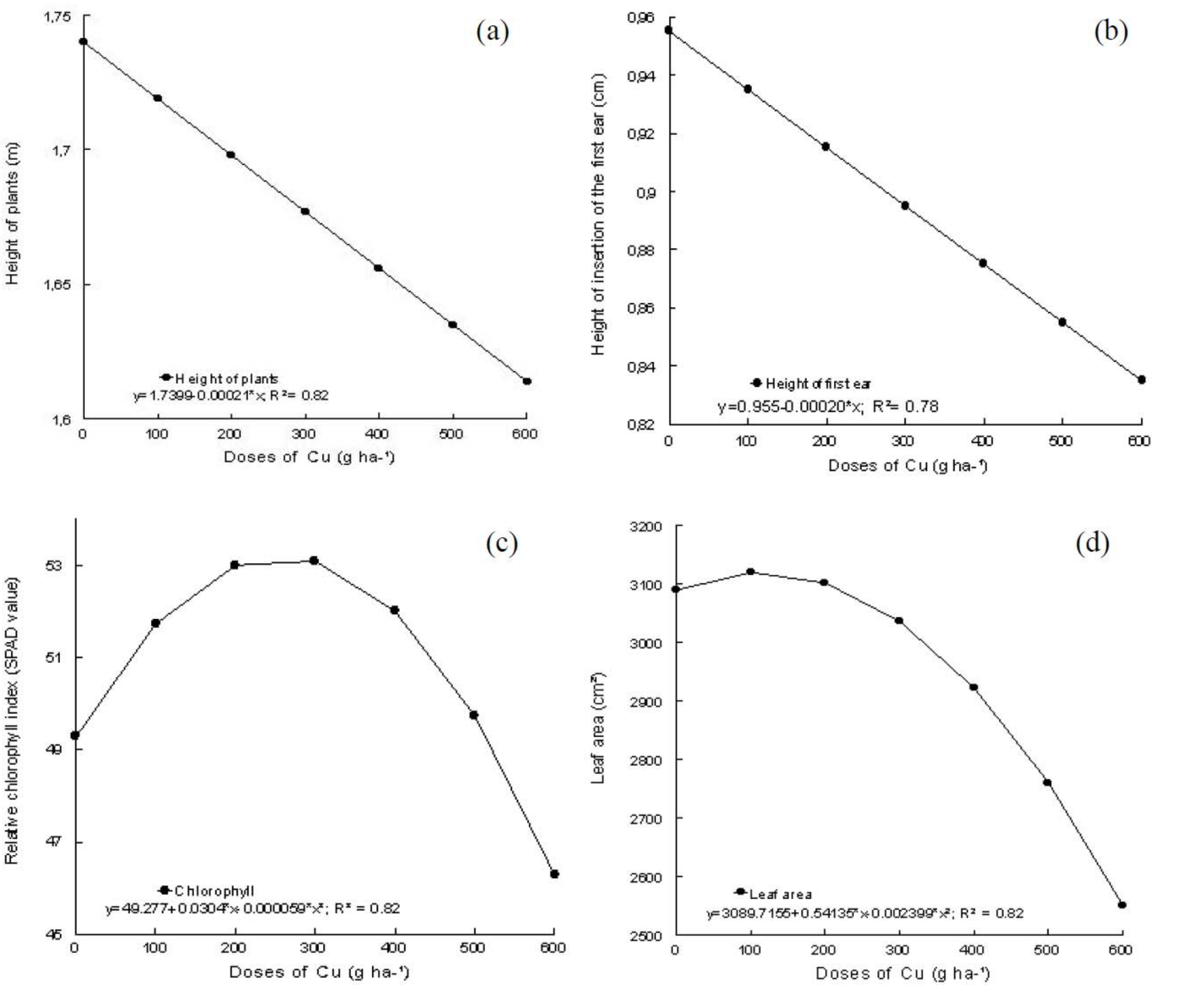

Figure 1 - Plant height (a), height of insertion of the first ear (b), relative content of chlorophyll (c) and leaf area (d) of maize plants submitted to increasing rates of foliar-applied copper. Dourados-MS, 2010.

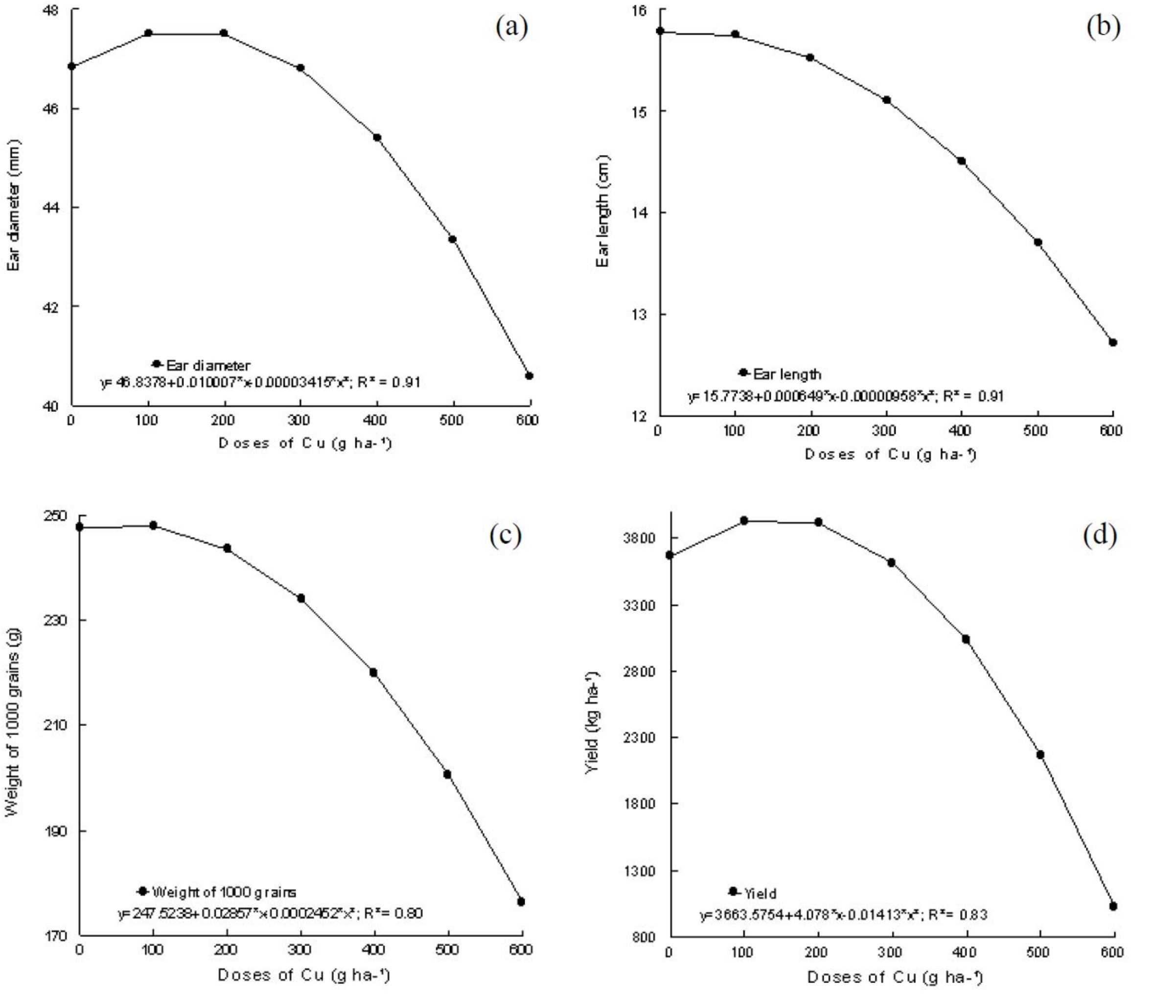

Figure 2 - Ear diameter (a), ear length (b), weight of 1000 grains (c) and yield (d) of maize plants submitted to increasing rates of foliar-applied copper. Dourados-MS, 2010.

to the adverse effects of Cu on the chlorophyll molecule or interference with enzymes such as ALA deshydratase, an enzyme implicated in the porphyric pathway (SCARPONIL & PERUCCI, 1984). As a consequence, a reduction in the photosynthetic activity and growth is observed (UPADHYAY & PANDA, 2009).

As for leaf area and chlorophyll content, data of ear diameter (Figure 2a) and length (Figure 2b), thousand grain weight (Figure 2c), and yield (Figure 2d) showed quadratic response in function of Cu doses presenting an increase at lower doses and a reduction at higher doses. Ear diameter (Figure 2a) and length (Figure 2b) had maximum points at the doses of 33.87 and 147.44g ha^{-1} Cu, respectively. Moreover, the maximum points for thousand grain weight (Figure 2c) and yield (Figure 2d) were at the doses of 58.26 and 144.29g ha^{-1} Cu, respectively. At the dose of 144.29g ha^{-1}, Cu provided an increase of 8% in maize yield (Figure 2d). These results are related to the data of leaf area and chlorophyll content, indicating that at lower doses Cu promotes an increase in growth and consequently in the yield of maize, whereas at higher doses Cu becomes toxic to the culture. LUCHESE et al. (2004) observed symptoms of toxicity in treatments with application of Cu equal or greater than 4g kg^{-1} seed. These data show that the toxic effects of Cu at high concentrations affect the growth and grain production.

These data suggest that the reduction in plant height of maize (Figure 1a) at lower doses of Cu did not significantly affect the final yield of these plants. The same did not happen at higher doses of Cu, where a decrease in parameters related to yield was observed. This reduction may be related to the fact that the excess of Cu inhibits cell elongation, a complex process dependent on cell turgor pressure, synthesis of wall components, and growth regulators (ALAOUI-SOSSÉ et al., 2004). According to LU et al. (2012), yield in maize plants is affected by height reduction since the plant needs to reach a sufficient stature to have adequate photosynthate. Thus, the fine control of cellular concentrations of this metal needs to be strongly adjusted.

CONCLUSION

Under the conditions that the experiment was carried out, it is concluded that foliar Cu application at doses higher than 100g ha^{-1} has toxic effect in maize plants with losses in growth and yield.

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