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Growth, yield and nutrients of sweet cassava fertilized with zinc

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ABSTRACT: The application of zinc fertilizers in the soil has been an agronomic practice to correct Zn deficiency in plants, aiming to increase productivity and/or nutritional quality. This study evaluated how zinc sulfate fertilization affects plant growth, yield performance and nutrient accumulation in the cassava 'IAC 576-70'. The experimental design was in randomized blocks with eight replications. The treatments consisted of 0, 1.5, 3.0, 4.5 and 6.0 g pl^{-1} $ZnSO_4$. Results showed improvement in yield with soil fertilization with $ZnSO_4$, with the optimal dose of 2.5 g pl^{-1}. The uptake of nutrients in plant parts is favored with lower doses of zinc fertilizer, with maximum points ranging from 0.8 to 3.2 g pl^{-1} for macronutrients and 1.6 to 3.6 g pl^{-1} for micronutrients. The Zn content in tuberous roots increases by more than 40% with fertilization up to 2.8 g pl^{-1} of fertilizer, which contributes to the nutritional value of roots.
Key words: *Manihot esculenta*, fertilization, minerals, biofortification.

Crescimento, produtividade e nutrientes da mandioca adubada com zinco

RESUMO: A aplicação de fertilizantes com zinco no solo tem sido uma prática agronômica para corrigir a deficiência de Zn nas plantas, visando aumentar a produtividade e/ou a qualidade nutricional. O objetivo deste estudo foi avaliar como a fertilização com sulfato de zinco afeta o crescimento da planta, o desempenho produtivo e o acúmulo de nutrientes na mandioca 'IAC 576-70'. O delineamento experimental foi em blocos casualizados com oito repetições. Os tratamentos consistiram de 0, 1,5, 3,0, 4,5 e 6,0 g pl^{-1} $ZnSO_4$. Os resultados mostraram melhoria no rendimento com a fertilização via solo com $ZnSO_4$, com a dose ótima em 2,5 g pl^{-1}. A absorção de nutrientes nas partes da planta é favorecida com menores doses de fertilizante de zinco, com pontos de máximo variando de 0,8 a 3,2 g pl^{-1} para macro e 1,6 a 3,6 g pl^{-1} para micronutrientes. O conteúdo de Zn nas raízes tuberosas tem aumento superior a 40% com a fertilização até 2,8 g pl^{-1} de fertilizante, o que contribui para o valor nutricional da mandioca.
Palavras-chave: *Manihot esculenta*, adubação, minerais, biofortificação.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a vital source of energy for both global food security and the Brazilian people. Cassava is an energy-dense food and; therefore, rated high for its caloric value, based on its carbohydrate content, providing 250 Kcal/ha/day compared to 200 Kcal/ha/day for corn, 176 Kcal /ha/day for rice, 114 Kcal/ha/day for sorghum and 110 Kcal/ha/day for wheat (EL-SHARKAWY, 2012; LEONEL et al., 2015; FAOSTAT, 2018; BAYATA, 2019; BYJU & SUJA, 2020).

The cassava crop requires adequate nutrition to maintain high production, as it absorbs large amounts of nutrients and exports around 1.27; 0.52; 3.02; 0.76; 0.60 and 0.36 kg t^{-1} of roots produced from N, P, K, Ca, Mg and S and 16.0; 1.51; 0.68; 2.23 and 2.43 g t^{-1} of Fe, Mn, Cu, Zn and B, respectively. Thus; although, it is considered a low fertility crop, the plant's demands must be met by fertilizers at economically adequate levels (NGUYEN et al., 2002; LEONEL et al., 2015; EZUI et al., 2016).

Micronutrients play a central role in plant metabolism maintenance, growth and production, stress tolerance and disease resistance (SHAHZAD & AMTMANN, 2017). Zn is important for enzyme activation, regulation, and gene expression in plants, as well as protein synthesis, glucose metabolism, photosynthesis, phytohormones, fertility, growth regulation, seed development, and disease tolerance (TAIZ et al., 2017; REHMAN et al., 2018; RAI et al., 2021). LEKSUNGNOEN et al. (2022) highlighted

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that the interaction between the soil Zn concentration and the cassava Zn concentration is poorly understood and that the Zn input from weathering is insufficient for the production of cassava.

Increases in Zn content in plants when subjected to various treatments involving this nutrient supplementation depend on genotypes, application methods, element concentration, and interactions with other elements (WHITE & BROADLEY, 2011; KACHINSKI, 2019). Fertilizers such as $ZnSO_4$, soluble in water, are often more efficient as their rapid release rapidly increases the concentration of Zn in the soil solution and this can result in greater plant uptake (MATTIELLO et al., 2021).

Appropriate Zn fertilization can promote growth by improving photosynthetic performance and chlorophyll synthesis, in addition to decreasing oxidative damage to the cell membrane induced by adverse environmental conditions. However, excess doses of Zn interfere with the absorption of essential elements and result in heavy metal toxicity (NATASHA et al., 2022).

Zinc deficiency in soil has increased the number of studies on agronomic biofortification of world food staple crops (VALENÇA et al., 2017). JOY et al. (2015) modelled the potential of Zn-enriched fertilizers to alleviate dietary Zn deficiency, focusing on ten African countries with zinc deficiency. Their results showed that agronomic biofortification can increase the amount of absorbable Zn in the diet by 5%.

Micronutrient deficiencies (hidden hunger) have become a silent epidemic and inadequate Zn intake is quite substantial, affecting approximately two billion people worldwide, most of them pregnant women and children. Zn deficiency can cause anemia, dermatitis, growth retardation, affect reproductive capacity and mental function, with results showing that zinc supplementation reduced the incidence of diarrhea and respiratory infections in children (WESSELLS & BROWN, 2012; LIVINGSTONE, 2015; OKWUONU et al., 2021).

Given the importance of cassava as a staple food crop and the need for a balanced approach to Zn fertilization to achieve increased food production in a sustainable and responsible manner, this study verified how $ZnSO_4$ doses affect plant growth, yield performance and nutrient absorption in the sweet cassava 'IAC 576-70'.

MATERIALS AND METHODS

The experimental study was done in Botucatu, in the state of São Paulo, Brazil. The geographic coordinates are 22º59' S; 48º30' W, with an altitude of 778 meters above sea level.

The soil used in the study was a dystrophic Red Latosol with a sandy texture sampled at a depth of 20 cm. Soil chemical characteristics before experiment planting were: pH ($CaCl_2$): 5.1; M.O (g dm^{-3}): 10.0; P_{resin} (mg dm^{-3}): 6.0; H+AL ($mmol_c$ dm^{-3}): 14.0; K ($mmol_c$ dm^{-3}): 1.1; Ca ($mmol_c$ dm^{-3}): 11.0; Mg ($mmol_c$ dm^{-3}): 5.0; CTC ($mmol_c$ dm^{-3}): 31.0; base saturation (%): 55.0; Fe (mg dm^{-3}): 5.0; Cu (mg dm^{-3}): 0.4; Mn (mg dm^{-3}): 2.2; B (mg dm^{-3}): 0.1 and Zn (mg dm^{-3}): 0.4. Soil Zn contents are considered low for cassava (Zn < 0.6 mg dm^{-3}) (LORENZI et al., 1997).

The experiment was conducted in a randomized block design with eight replications. Zinc sulfate ($ZnSO_4$ $7H_2O$ with 20% of zinc) was employed as the zinc source, and five doses of $ZnSO_4$ were applied: 0, 1.5, 3.0, 4.5, and 6.0 g pl^{-1}. A 310 L plastic box containing a cassava plant was used to represent each plot. The plants were spaced at a distance of 1.00 × 1.5 m (Figure 1).

For cassava planting, the soil was first poured into 310 L boxes with a height of 0.54 m and a diameter of 1.04 m. In the planting fertilization was used 100 g pl^{-1} P_2O_5, 25 g pl^{-1} K_2O, and 0.88 g pl^{-1} boron. As sources of P, K and B were used simple superphosphate (18% P_2O_5), potassium chloride (60% K_2O) and boric acid (17% B) fertilizers.

Pits were opened for fertilizing, and fertilizers were poured into the pits' soil. After that, one cassava stem cutting was planted horizontally in each pit and manually filled with dirt. Cassava stem cutting with 15 cm in length were obtained from the middle third of 12-month-old plants. The planting was completed on April 25, 2019. Nitrogen was applied using urea (45% N) at 35 days after planting (DAP) at a rate of 13.64 g pl^{-1} (equivalent to 40 kg ha^{-1}).

The crop was irrigated using a drip irrigation system, which met the crop's water need. The pests and disease control was carried out in accordance with the requirements and technical guidelines. The plants were harvested at 368 DAP.

The number of stems and leaves per plant was determined by counting. The diameter of the stems was measured at a height of 10 cm from the soil surface. Plant height was determined from the soil surface to the highest point of the plant. The length of the roots was measured from one end to the other and the diameter was determined in the region of the middle third with a caliper.

Plant parts were weighed to obtain fresh matter values. Then, samples of fresh material were dehydrated in an oven with forced air circulation at 65 °C until


Figure 1- Image of the installation of the experiment and cassava plants.

reaching constant weight. After drying, the material was weighed and the dry matter accumulated in each part of the plant was calculated.

The N concentration in the plant tissues was determined by sulfuric acid (H_2SO_4) digestion and quantified using the semi-micro-Kjeldahl method. P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn concentrations were determined by atomic absorption spectrophotometry after nitric acid (HNO_3) – perchloric acid ($HClO_4$) digestion (MALAVOLTA et al., 1997).

The amounts of accumulated nutrients in each plant organ were calculated by multiplying the concentrations of nutrients by the accumulated amount of dry matter in each plant organ.

The data were submitted to analysis of variance in order to perform the statistical analysis. Regression analysis was used to assess the effect of $ZnSO_4$ doses ($P \leq 0.05$). The highest value of the coefficient of determination was used as the criterion for selecting the linear or quadratic model (R^2) ($P \leq 0.05$). Sisvar software was used for statistical analysis, while Excel was used to create graphics.

RESULTS AND DISCUSSION

The growth parameters were influenced by the doses of $ZnSO_4$ tested in the cultivation of cassava ‘IAC 576-70’ (Figure 2). Cassava plants had an increase in the height of the main stem with zinc fertilization. Stem diameter and number of leaves increased with maximum points at doses of 2.7 and 2.8 g pl^{-1}, respectively. The number of roots per plant was positively affected by $ZnSO_4$ fertilization, but shorter roots were produced.

The effects of zinc fertilization on growth parameters are due to the fundamental roles of this nutrient in numerous biochemical pathways of plants, such as auxin, which is a growth regulator (AIRES, 2009).

Fertilization with $ZnSO_4$ interfered with the accumulation of dry matter (DM) in parts of the cassava plant, with the exception of the seed stem. The total amount of dry matter accumulated in the plant increased up to the dose of 2.8 g pl^{-1}, with a decrease at higher doses (Figure 3).

CAMPOS (2000) discovered that a dose of 2.04 g pl^{-1} $ZnSO_4$ enhanced the DM of tuberous roots and MALAVOLTA et al. (1997) explained that the reduction in the production of DM in plants subjected to high levels of zinc is due to the accumulation of plugs containing Zn in the xylem of plants, which hinder the rise of crude sap.

Yield was positively affected by fertilization with $ZnSO_4$, with a maximum point at 2.8 g pl^{-1}.

Zinc is a cation that interacts with almost all plant nutrients present in the soil, especially anions. REHMAN et al. (2018) reported that Zn interacts positively with N, K, Mg, and negatively with P, Mn and B.

The fertilization of sweet cassava with $ZnSO_4$ pronouncedly affected the accumulation of macronutrients in the plant shoot (leaves and stems), but with an effect on the accumulation of N, P, K, Ca and Mg in the tuberous roots. In general, the use of high doses of $ZnSO_4$ in the fertilization of cassava ‘IAC 576-70’ decreased the accumulation of macronutrients in the plant parts, with variations in the maximum accumulation points among the nutrients (Figures 4 to 6).

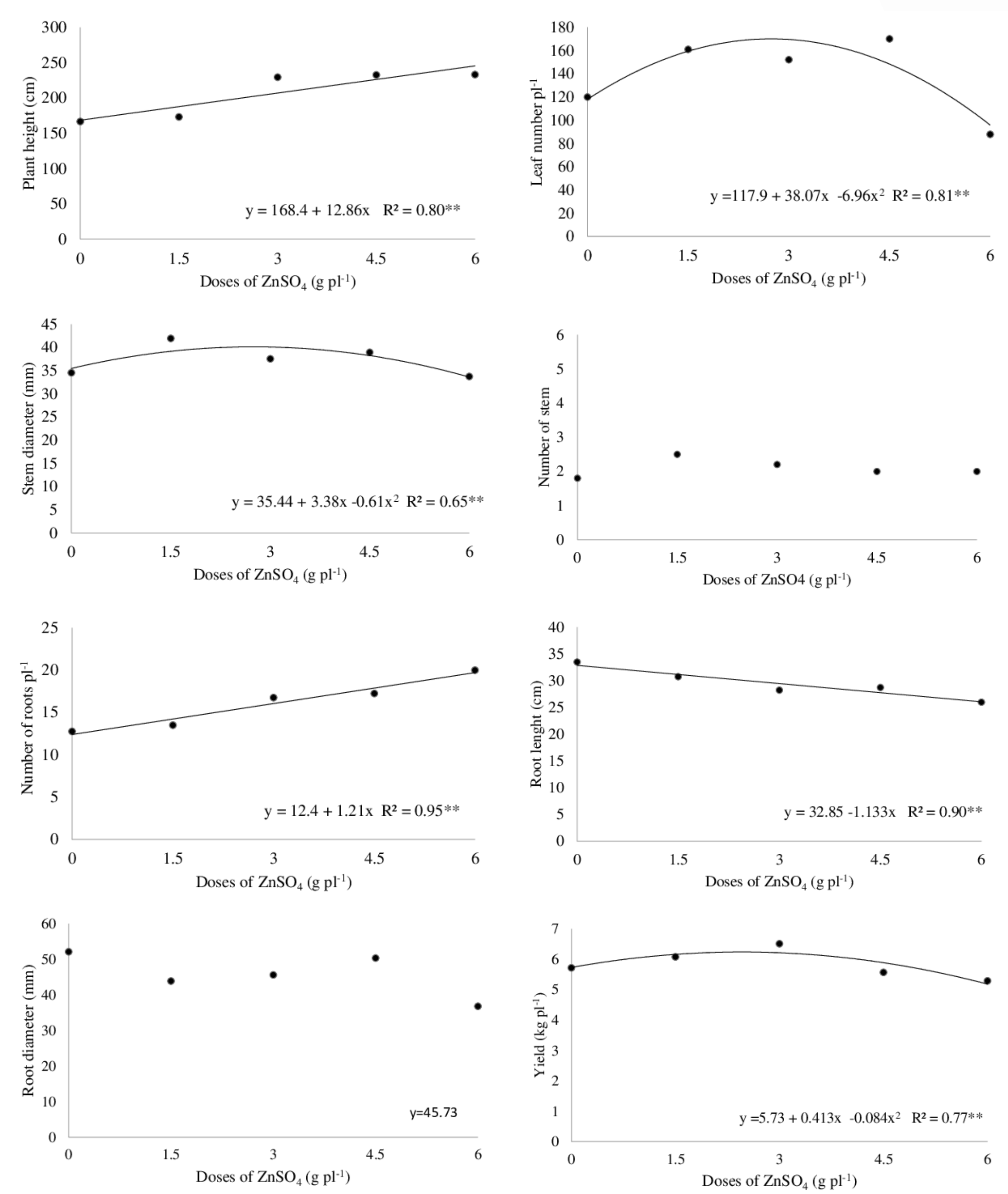

Figure 2 - Plant height, leaf number, stem diameter, stem number, number of roots, root length, root diameter and yield of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^*P < 0.05$, $^{**} P < 0.01$).

The accumulation of N in the leaf was higher up to the estimated dose of 2.6 g pl^{-1} $ZnSO_4$, it was greater in the stem until 0.8 g pl^{-1} $ZnSO_4$, with a decline beyond these doses, and it had a linear decline in seed stem (Figure 4). Plant productivity is largely determined by the interaction between carbon and N metabolism, with N assimilation resulting directly or indirectly from photosynthesis. The role of zinc in these processes can be seen in the effect of doses on N accumulation in leaves and stems, when higher doses had a negative effect on this

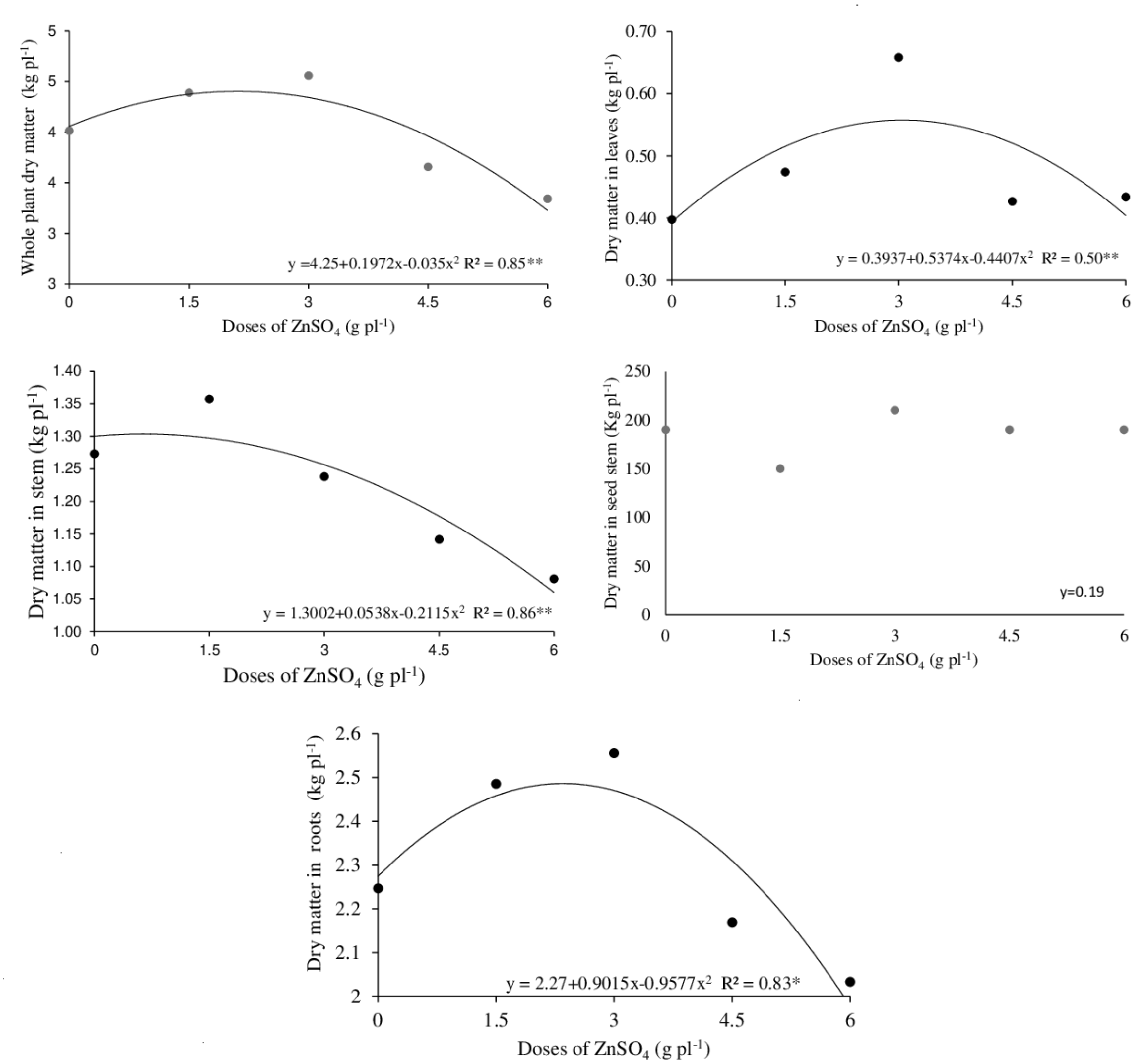

Figure 3 - Dry matter accumulation in parts of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^*P < 0.05$, $^{**} P < 0.01$).

nutrient. In addition, the toxic effect of zinc on chlorophyll can be observed indirectly by N, since 50% of the total N in leaves is part of the chloroplast and leaf chlorophyll compounds (CHAPMAN & BARRETO, 1997).

KUTMAN et al. (2011) reported a positive relationship between N and Zn in plants, with N increasing the uptake of Zn by the roots, as well as its translocation to the shoot.

The accumulation of P in the leaf, stem, and tuberous root was usually larger than the control, with the maximum accumulation at 2.5, 1.4, and 3.2 g pl^{-1} $ZnSO_4$ dose, respectively (Figure 4).

The accumulation of K in the leaf, stem and tuberous root followed a similar pattern, being higher than the control and decreasing after $ZnSO_4$ doses of 2.9, 2.1, and 2.5 g pl^{-1}, respectively (Figure 5).

Regardless of the levels of zinc sulphate fertilization, the aerial part of cassava (stem and leaves) showed the highest calcium accumulations, with effect of fertilization levels on the accumulation of this nutrient in leaves, seed stems and tuberous roots (Figure 5). Increasing levels of zinc fertilization increased Ca accumulation in leaves with decrease at the highest dose. The accumulation of Ca decreased in the seed stem with increasing fertilization. Increased accumulation in roots was observed only at the lowest dose. These results showed the reduction of Ca availability under high doses of $ZnSO_4$, as reported by PRASAD et al. (2014).

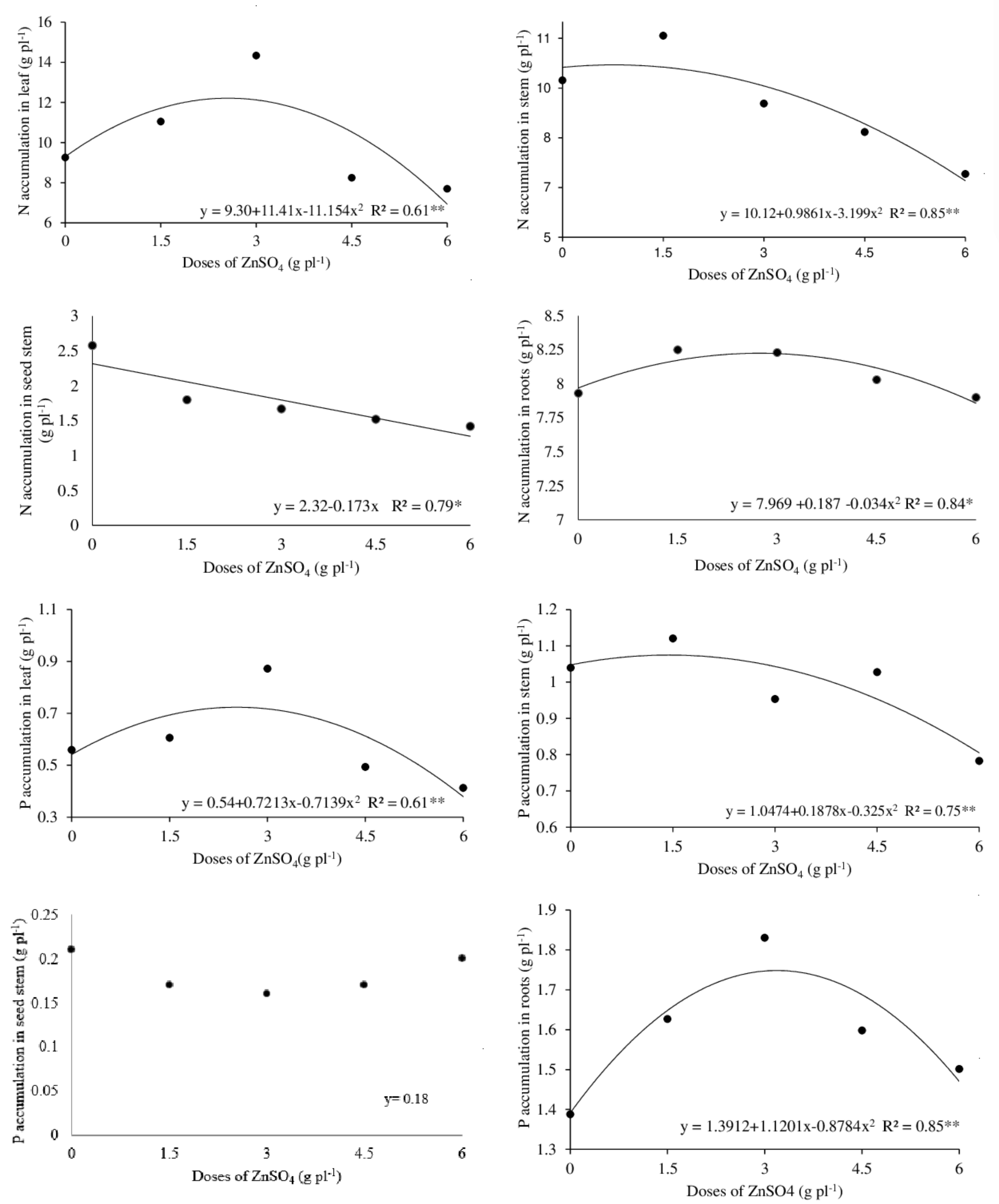

Figure 4 - Nitrogen (N) and phosphorus (P) accumulation in parts of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^{*}P < 0.05$, $^{**}P < 0.01$).

Mg in the leaf, stem, root, and S in stem and root all behaved the same way, being greater than control and decreasing with doses of 2.7, 2.6, 2.1, and 2.6 g pl^{-1} $ZnSO_4$, respectively (Figure 6). The lower concentration of Mg might be due to the physiological response of the plant to the highest Zn concentration in solution, which may have affected the uptake system and thus lowered the apparent concentration.

The effects of zinc fertilization on micronutrients were variable among nutrients and for each nutrient among plant parts. Data analysis revealed that $ZnSO_4$ doses had no effect on Cu in cassava

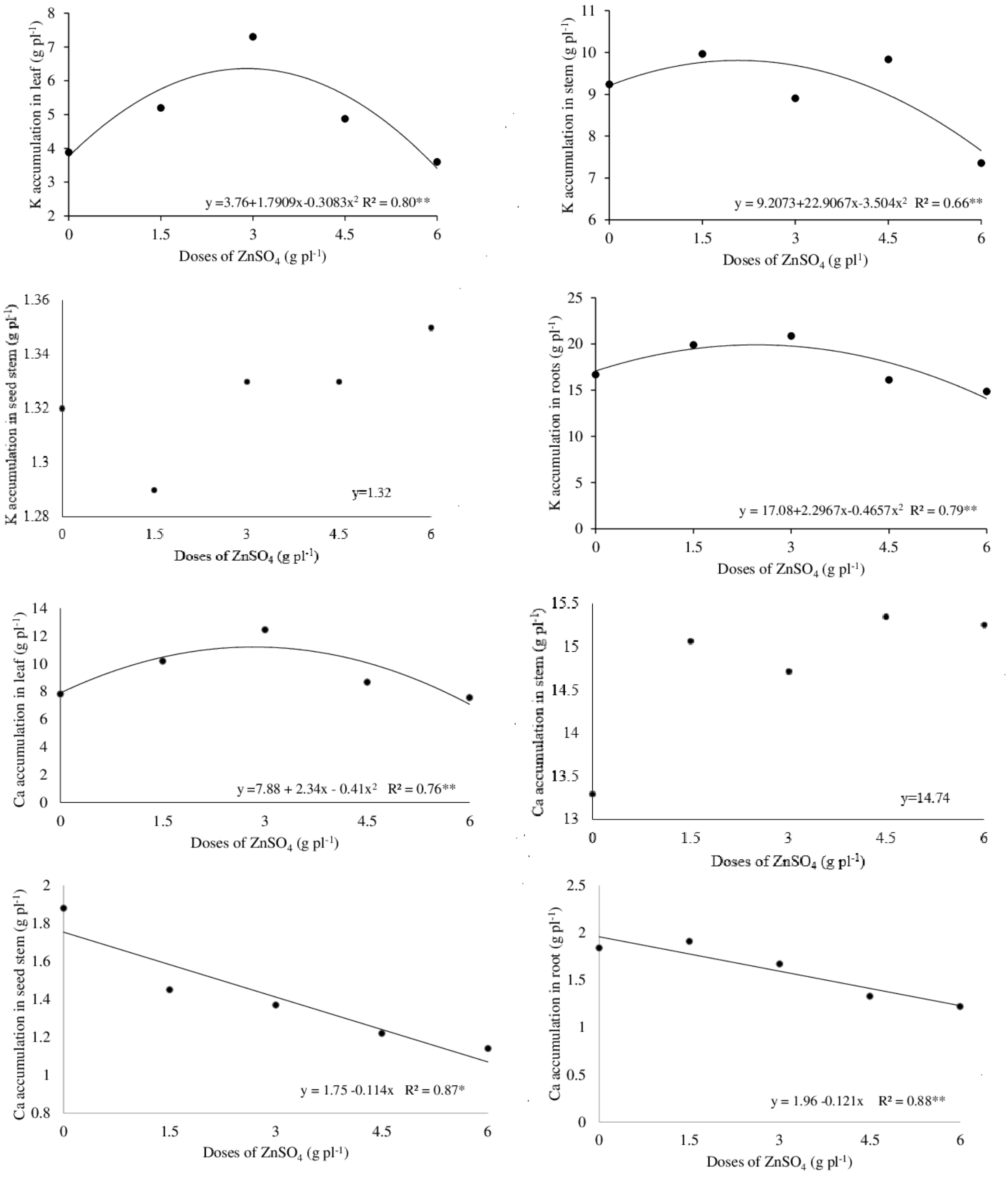

Figure 5 - Potassium (K) and calcium (Ca) accumulation in parts of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^{*}P < 0.05$, $^{**}P < 0.01$).

leaves. Doses had no influence on the accumulation of Zn and Mn in the seed stem (Figure 7).

In the aerial part of cassava plants, the increase in the levels of zinc fertilization increased the accumulation of iron (Fe); however, with decreases in the highest doses. For the seed stem and tuberous roots, decreases in iron accumulation were observed with fertilization (Figure 7). The decrease of Fe may be due to competitive interactions with Zn, which probably occur at the absorption sites of plant roots.

Mn had the greatest accumulation in leaves and stems (Figure 6), as Mn is preferentially

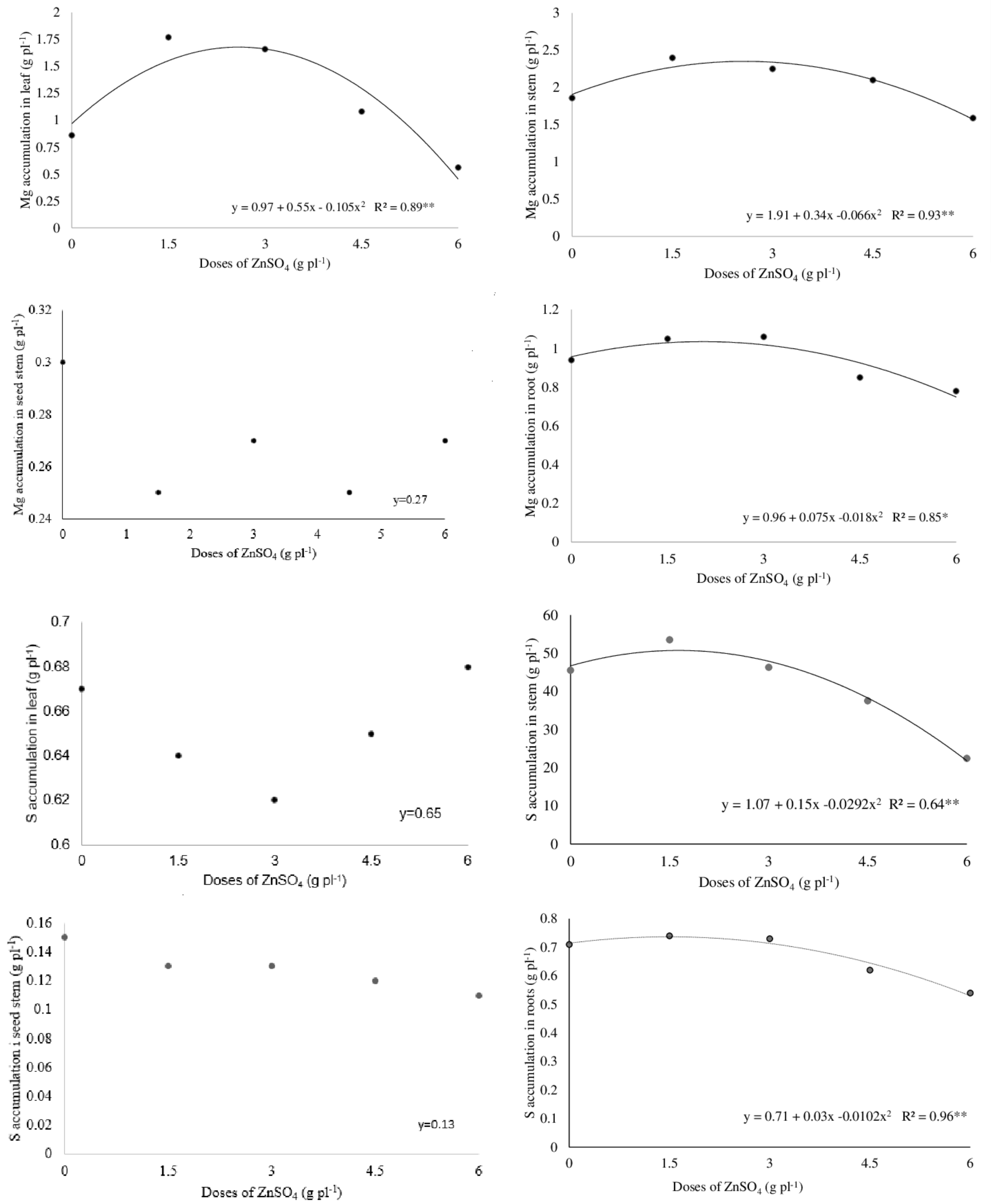

Figure 6 - Magnesium (Mg) and sulphur (S) accumulation in parts of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^{*}P < 0.05$, $^{**}P < 0.01$).

reported to the plant shoot, to act in the photosynthetic processes of the plant (TAIZ et al., 2017).

Fertilization with $MnSO_4$ negatively affected the accumulation of manganese in tuberous roots (Figure 7). The adverse relationship between Zn and Mn was also described by BARBEN et al. (2010) who observed that Mn concentrations in potato plant tissues decreased with increasing Zn concentration in the nutrient solution.

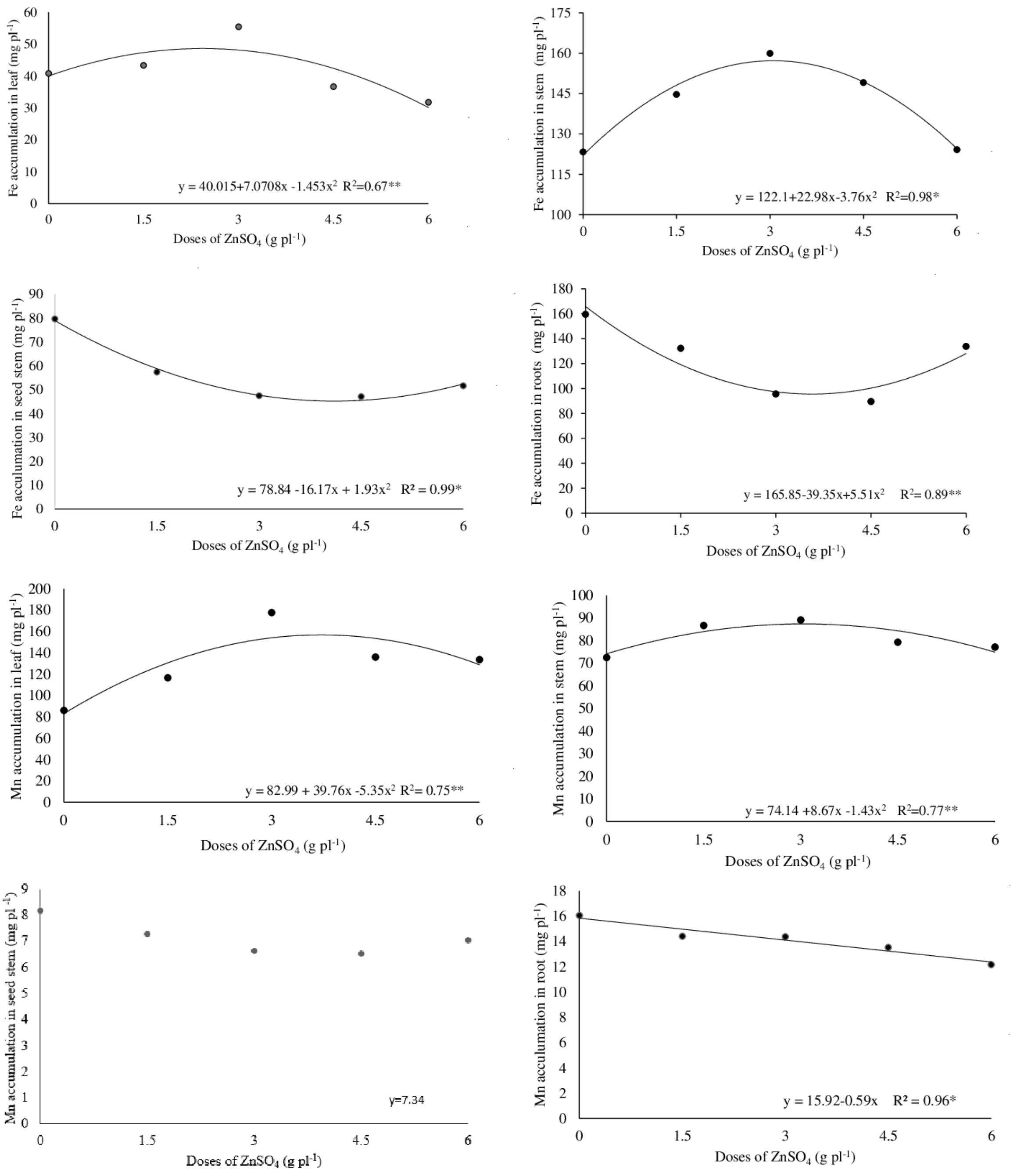

Figure 7 - Iron (Fe) and manganese (Mn) accumulation in parts of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^{*}P < 0.05$, $^{**}P < 0.01$).

VADLAMUDI et al. (2020) discussed that excess zinc usually affects the absorption of P, Fe and Mn, causing structural deficiencies in the plant.

In the absence of $ZnSO_4$, copper (Cu) accumulation was higher in the seed stems; although, the maximal accumulation in the stem was higher up to the estimated dose of 2.1 g pl^{-1} of $ZnSO_4$ (Figure 8). Cu is a key micronutrient for crops because it regulates enzymatic activity in shoot tissues' photosynthetic and respiratory functions (KIRKBY & RÖMHELD, 2007). SAMREEN et al. (2017) suggested that both Cu and Zn are absorbed through same mechanism and might suppress the other if one is present in excess.

Zinc uptake depends on the different types of plant species as mainly depends upon the concentration and composition of media. Zinc translocation happens through the symplast and apoplast from roots to plant tissue (TAIZ et al., 2017).

Zn is absorbed predominantly as Zn^{2+}, and soil texture, pH, organic matter, microbial activity and concentrations of P and cationic elements affect the availability of Zn for plant absorption (ALLOWAY,

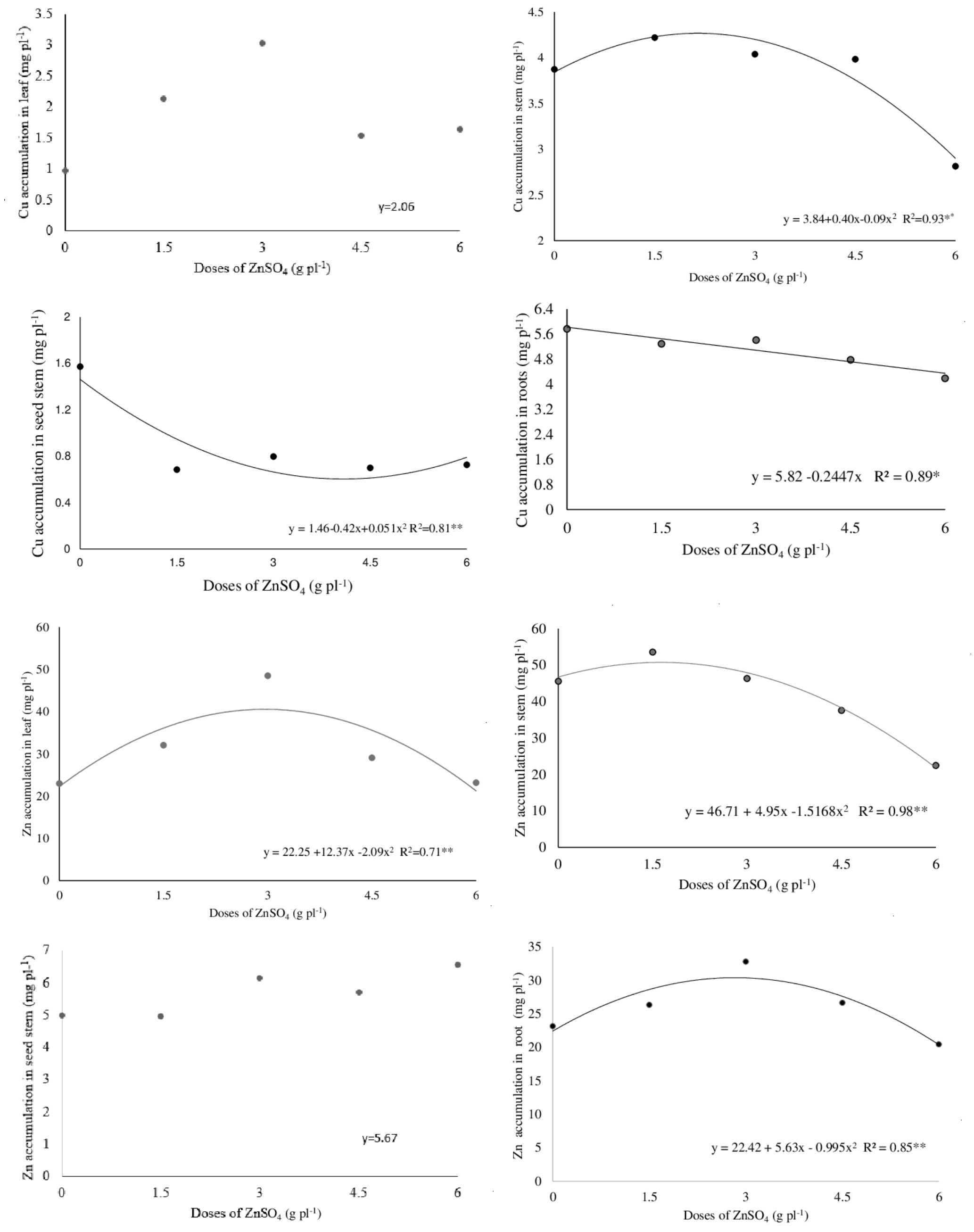

Figure 8 - Cooper (Cu) and zinc (Zn) accumulation in parts of sweet cassava plants in response to $ZnSO_4$ fertilizer ($^{*}P < 0.05$, $^{**}P < 0.01$).

2009; BROADLEY et al., 2012). The accumulation of Zn in the parts of the plant was influenced by fertilization, with the exception of the accumulation in the seed stem (Figure 8).

Zinc contents were higher in the shoot cassava parts. According to LEKSUNGNOEN et al. (2022), Zn concentrations vary between cassava cultivars and plant parts, with shoot biomass being more abundant in Zn than below ground biomass. In their study, the results showed that 88% of the total Zn absorption was accumulated in the shoot of the cassava plant.

The amount of Zn in the tuberous roots increased until the estimated dose of 2.8 g pl^{-1} $ZnSO_4$, after which the amount of Zn accumulated in the tuberous roots reduced (Figure 8). It is important to note that the 41.62% increase in zinc accumulated in cassava tuberous roots indicates possibilities for agronomic biofortification.

GARCIA-BANUELOS et al. (2014) discussed that; although, food fortification and supplementation are the most commonly used strategies to alleviate micronutrient deficiencies, agronomic biofortification is potentially easy, cost-effective, efficient and applicable to most crops.

Zinc deficiency in humans is largely due to inadequate intake or absorption of zinc from the diet. This mineral deficiency affects about a third of the world population and leads to physiological disorders that affect the immune, gastrointestinal, epidermal, central nervous, skeletal and reproductive systems (ROOHANI et al., 2013).

CONCLUSION

Soil fertilization with zinc sulphate increased the number of tuberous roots per plant, with an increase in dry matter accumulation and yield; however, excess Zn impaired cassava growth. The best dose to maximize root production is 2.5 g pl^{-1}, with estimated doses ranging from 0.8 to 3.2 g pl^{-1} of $ZnSO_4$ for greater macronutrient accumulation and 1.6 to 3.6 g pl^{-1} of $ZnSO_4$ for the highest accumulations of micronutrients in the whole plant. The positive response of Zn accumulation in sweet cassava leaves and roots can be better explored in studies aiming at agronomic biofortification.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analysis, or interpretation of the data; in the writing of the manuscript, and in the decision to publish the results.

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AUTHORS' CONTRIBUTIONS

All authors contributed equally for the manuscript.

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