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Zinc foliar spray enhances growth, yield and economic return of cassava variety Kasetsart 50 production

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Abstract

Cassava is extensively cultivated in low fertility sandy soils in the Northeast Thailand. Low yield and economic return of cassava grown in this area is partly due to deficiency of micronutrients especially zinc (Zn). The objective of this study was to investigate the effects of foliar spray of Zn on growth, yield, quality and economic return of the cassava variety Kasetsart 50. Five treatments consisted of unfertilized control (T1), recommended fertilizer (formula (formula 15-15-15 at the rate of 313 kg ha^{-1}) (T2), recommended fertilizer plus foliar spray of Zn at the rate of 6.25 kg ha^{-1} (2% Zn) (T3), recommended fertilizer plus foliar spray of Zn at the rate of 12.50 kg ha^{-1} (4% Zn) (T4) and recommended fertilizer plus foliar spray of Zn at the rate of 18.75 kg ha^{-1} (6% Zn) (T5). The treatments were assigned in a randomized complete block design with three replications. The crop was planted in a Korat soil series (loamy sand soil) under rainfed conditions. Data were recorded for soil chemical properties and plant growth parameters at 11 months after planting. The recommended fertilizer plus foliar spray of 2% Zn (T3) resulted in the highest fresh root yield (26.0 t ha^{-1}), starch content (27.83%), and economic return over the fertilizer cost (960.0 USD ha^{-1}), and the increases in fresh root yield, starch content and economic return over the fertilizer cost compared to T1 were 100, 54 and 69%, respectively. The results suggested that foliar spray of 2% Zn together with chemical fertilizer was effective in overcoming Zn deficiency in the loamy sand soils for cassava variety Kasetsart 50 production.

Keywords: Northeast Thailand; chemical fertilizer; economic return; loamy sand soil; zinc foliar spray.
Abbreviations: ANOVA _Analysis of variance; B_Boron; Ca_Calcium; Cu_Copper; CV_ Coefficient of variation; EC_Electrical conductivity; Fe_Iron; K_Potassium, LSD_Least significant difference; MAP_Months after planting; Mg_Magnesium; Mn_Manganese; N_Nitrogen; OM_Organic matter; P_Phosphorus; S_Sulfur; SOM_Soil organic matter; Zn_Zinc; ZnO_Zinc oxide; $ZnSO_4.7H_2O$_Zinc sulfate heptahydrate.

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the leading crops of the world as it feeds more than half a billion of the world population. Cassava is also used as a raw material for several products such as animal feed, starch, flour and bio-ethanol (Zhou and Thomson, 2009). Cassava yield in small plots with irrigation in Thailand was recorded at 52.0 t ha^{-1} (Polthanee and Srisutham, 2018), and an average yield of the country was recorded at of 21.1 t ha^{-1} (Office of Agricultural Economics, 2022) yield gap of cassava production in Thailand is still wide. According to Office of Agricultural Economics (2022), total harvest area in Thailand in 2021 was 1.67 million hectares, and harvest area in the Northeast, which is the main growing area of cassava in Thailand, was 0.92 million hectares. Average cassava yield in the Northeast was 21.7 t ha^{-1}. The cassava yield has steadily increased, while cassava production area has steadily reduced. Low cassava yield in Thailand is caused mainly by poor soil fertility and unpredictable rainfall. Long-term continuous cultivation of cassava without appropriate soil management has led to a reduction in both soil nutrients and cassava yields (Buasong et al., 2014; Panitnok et al., 2013).

The insufficient use of external nutrients leads to soil nutrients depletion (Howeler, 2002). Howeler (2012) continuous long-term production of cassava reduces soil fertility and leads to great reduction in cassava yield. Soil nutrient loss during cassava harvesting by removal of adhering soil with root tuber was 1.15 kg of N, 1.99 kg of P and 2.91 kg of K ha^{-1} harvest^{-1} (Sumithra et al., 2013). Other studies reported that nutrient removal resulting from root harvest occurred in the following order; N, K, Ca, P, Mg, sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B) (Fergeria et al., 2010). The optimum soil pH range for most crops including cassava is between 5.5 and 7.5 (Nanganoa et al., 2020). Although the pH values are within this range, the low availability of micronutrients is a factor limiting crop yields (Moosavi et al., 2015).

Micronutrients such as Zn, Mn, Fe, Cu and B are generally deficient in most cassava growing soils as these elements decrease rapidly through water runoff or soil adsorption especially in high pH soils (Howeler, 2001; Achakzai et al., 2010; Fergeria et al., 2010). In calcareous soil, Cu, Fe, Mn and Zn are reduced and lower available as these elements precipitate in soil to form carbonates or bicarbonates, and they are also lower available in high soil organic matter (SOM) (Lee and Saunders, 2003).

Cassava can also encounter Zn deficiencies in both acid and alkaline soils (Howeler, 2001) and Zn deficiency has been reported in several countries including Colombia, Indonesia, Malaysia, Australia, Mexico, Brazil and Nigeria (Howeler, 2002). Severe Cu deficiency, resulting in yield reductions of up to 30%, has been reported in peat soil in southern Malaysia (Howeler, 2002). Manganese deficiency has been reported in northeast Brazil, Colombia and Vietnam (Howeler, 2001). Zinc deficiency, however, can be controlled by the band application of 5-10 kg Zn ha^{-1} as $ZnSO_4.7H_2O$ or by the broadcast application of 10-20 kg Zn ha^{-1} as zinc oxide (ZnO).

In Thailand, Kasetsart 50 is the most popular cassava variety grown over an area of 606,577 hectares, accounting for 61% of the country's total cassava cultivation with an average tuber yield of approximately 17.5 t ha^{-1} (Thai Tapioca Development Institute, 2022).

Kasetsart 50 can be more productive than other cassava varieties in low-fertility soil such as in the Northeast region of Thailand. During the growing season, plants require a balanced and sufficient supply of nutrients for maximum growth and yield. According to Kunlanit et al. (2022), soil application of Zn to Kasetsart 50 at the rate of 18.75 kg $ZnSO_4.7H_2O$ ha^{-1} gave the highest root yield and starch content compared to other rates. However, in alkalize soil (high pH >7.0) with Zn deficiently, application of Zn in to the soil is not appropriate, and foliar spray of Zn might be more effective. The effects of foliar spray of Zn on the growth and yield of Kasetsart 50 grown in loamy sand soil have not been clearly investigated. Thus, this study aimed to determine the effects of foliar spray of Zn on growth, yield and quality of cassava variety Kasetsart 50. The information obtained in this study can be used as a guideline for recommendations of Zn application in Zn deficient soils.

Results and discussion

Soil properties before and after cassava planting

The soil at the experimental site was neutral (pH=7.06) and not saline (electrical conductivity, EC=0.04 dS m^{-1}) (Table 1) (Kunlanit et al., 2022). Soil pH and EC are important soil properties affecting cassava growth. However, the soil had low OM (0.30%), low available P (6.85 mg kg^{-1}), low exchangeable K (40.29 mg kg^{-1}) and low Zn (2.15 mg kg^{-1}). Based on the chemical properties described by Sanchez et al. (2003), the soil in this study was considered to be infertile as it did not provide sufficient essential chemical elements for crop growth. Therefore, application of chemical fertilizers and micro nutrients is necessary in order to enhance growth and yield of cassava.

Fertilizer treatments did not have significant (P>0.05) effects on soil pH, EC, OM content, available P and exchangeable K after cassava planting, whereas the treatments significantly (P<0.01) affected exchangeable Zn (Table 2).

Plant height and shoot fresh weight

The treatments were significantly different (P<0.05) for plant height at 6, 8 and 10 months after planting (MAP) (Figure 1). However, all fertilizer treatments (T2 to T5) showed greater plant height than unfertilized control (T1) evaluated at 2, 4, 6, 8 and 10 MAP. Fertilizer plus 6% Zn tended to have taller plants at all growth stages especially at 6-8 MAP (p<0.05). Micronutrients play a vital role in growth and yield of cassava, which is widely grown under poor soil fertility and micronutrient deficient conditions (Howeler, 2001). The results of this study were similar to those reported in Kasetsart 50. Janket and Jogloy (2018) showed that the application of chemical fertilizer (15-7-18) + Mg + Zn resulted in taller plants at 3 MAP than the same chemical fertilizer application formula without the inclusion of Zn. Panitnok et al. (2013) reported that soil- and foliar-applied fertilizer treatments had little effect on the height of cassava. In potatoes, Rahman et al. (Rahman et al., 2018) reported that the foliar application of Zn at the rate of 560 ppm produced larger potatoes than the comparative treatments without Zn. Application of N-P-K (180-65-6 kg ha^{-1}) together with the foliar application of Zn and Mn at the concentration of 10 ppm resulted in bigger potatoes than that of the control (no Zn application) (Kaur et al., 2018).

Shoot fresh weight

All fertilizer treatments (T2-T5) had higher shoot fresh weight (100-171%) than unfertilized control (T1) (Figure 2). Recommended fertilizer alone (T2) had the highest shoot fresh weight, which was 171% higher than unfertilized control (T1), but it was not significantly different from recommended fertilizer +6% Zn (T5). However, foliar spray at the rates of 2 and 4% Zn solution did not increase shoot fresh weight. The results of this study were similar to those in a previous study. Panitnok et al. (2013) revealed that application of chemical fertilizer with foliar spray of Zn did not significantly increase stem fresh weight and leaf fresh weight of cassava compared to application of chemical fertilizer without foliar spray of Zn.

Root number, root fresh weight and starch content

The treatments were significantly different (P<0.05) for root number and root fresh weight, but they were not significantly different for starch content (Table 3). All fertilizer treatments (T2-T5) had higher root number than unfertilized control although significant differences were found in recommended fertilizer +2% Zn (T2) and recommended fertilizer +6% Zn (T5). Differences between fertilizer treatments and untreated control were clearer for fresh root weight as al fertilizer treatment were significantly higher than untreated control. Recommended fertilizer + 2% Zn (T2) had the highest root number and fresh root weight. Similarly, Janket and Jogloy (2018) reported that the application of the chemical fertilizer 15-7-18 + Mg + Zn produced 9.7 root $plant^{-1}$ (76% increase compared to 5.5 root $plant^{-1}$ of the same chemical fertilizer application without Zn.

For fresh root weight, the current findings agreed with those previously reported in the Northeast Thailand. Kunlanit et al. (2022) found that soil application of $ZnSO_4.7H_2O$ at the rate of 18.75 kg ha^{-1} gave the highest fresh root weight (45.8 t ha^{-1}). The small difference was that Kunlanit et al. (2022) incorporated Zn into the soil, while this study used foliar spray method. The methods of application yielded different results although the rate of application was the same.

Table 1. Soil properties before cassava planting.

Soil property	Value
Soil texture	Loamy sand
Soil pH	7.06
Electrical conductivity (dS m^{-1})	0.04
Organic matter (%)	0.30
Available P (mg kg^{-1})	8.65
Exchangeable K (mg kg^{-1})	40.29
Exchangeable Zn (mg kg^{-1})	2.15

Source: Kunlanit et al. (2022).

Table 2. Means for pH, electrical conductivity (EC), organic matter (OM), available phosphorus (P), exchangeable potassium (K) and exchangeable zinc (Zn) in the soil after cassava variety Kasetsart 50 harvest.

Treatment	pH	EC (dS m^{-1})	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})	Zn (mg kg^{-1})
Unfertilized control (T1)	7.03	0.036	0.30	4.98	41.60	2.22b
Recommended fertilizer (T2)	6.96	0.028	0.33	5.31	40.06	2.49b
Recommended fertilizer + 2% Zn (T3)	7.10	0.024	0.32	4.83	36.26	2.47b
Recommended fertilizer + 4% Zn (T4)	7.10	0.023	0.32	5.61	41.13	2.65ab
Recommended fertilizer + 6% Zn (T5)	7.03	0.021	0.29	5.00	35.76	3.19a
F-test	ns	ns	ns	ns	ns	**
CV (%)	2.25	23.82	10.35	23.73	21.73	8.35

Means in the same column followed by different lowercase letters are significantly different by LSD (*P*<0.01), ns represents not significantly different (*P*>0.05).

Table 3. Means for root number, fresh root weight and starch content of Kasetsart 50 cassava as affected by different fertilizer management methods.

Treatment	Root number (root number ha^{-1})	Fresh root weight (t ha^{-1})	Starch content (%)
Unfertilized control (T1)	42,200c	13.0c	18.03
Recommended fertilizer (T2)	60,000abc (42%)	23.0ab (77%)	22.47 (25%)
Recommended fertilizer + 2% Zn (T3)	75,567a (79%)	26.0a (100%)	27.83 (54%)
Recommended fertilizer + 4% Zn (T4)	51,100bc (21%)	20.0b (54%)	26.80 (49%)
Recommended fertilizer + 6% Zn (T5)	66,667ab (58%)	24.0ab (85%)	24.17 (34%)
F-test	*	*	ns
CV (%)	19.96	25.45	18.76

Number in parenthesis is % increase in root number, fresh root weight, and starch content compared to unfertilized control (T1). Means in the same column followed by different lowercase letters are significantly different by LSD (*P*<0.05). ns represents not significantly different (*P*>0.05).

Recommended fertilizer (15-7-18) + Mg + Zn significantly increased root dry weight in Kasetsart 50 (2.4 t ha^{-1}) and Rayong 9 (1.1 t ha^{-1}) compared to 1.1 and 0.8 t ha^{-1} of the same varieties, respectively, treated with chemical fertilizer formula 15-7-18 + Mg without Zn (Janket and Jogloy, 2018). In a similar study on a highly acidic soil in Thailand, the foliar fertilization of Zn + Mg at the rate of 10 ml per 20 L of water, and 30 ml per 20 L of water at 2 and 3 months after planting (twice a month) produced higher root fresh yields of cassava than that without the addition of Zn (Panitnok et al., 2013).

In tuber crops, Bari et al. (2001) found that potato treated with micronutrient combination including Zn, B, S and Mg produced the highest tuber yield (30.90 t ha^{-1}) compared with the no micronutrient control, which produced the lowest yield of 25.40 t ha^{-1}. The foliar application of Zn at the concentration of 560 ppm provided the highest potato yield ranging from 36.7-37.2 t ha^{-1} (Rahman et al., 2018).

In loamy sand soil in India, foliar application of Zn at the concentration of 15 ppm produced higher potato yield than did a no Zn control (Parmar et al., 2016). Kailash et al. (2017) found that the application of zinc sulfate to soil at the rate of 25 kg ha^{-1} at the time of potato planting resulted in higher tuber number and tuber weight of 10.42 tuber $plant^{-1}$ and 516.67 g $plant^{-1}$, respectively, whereas the no Zn control had tuber number and tuber weight of 8.92 tubers $plant^{-1}$ and 454.17 g $plant^{-1}$, respectively.

Recommended fertilizer plus foliar spray of 2% Zn (T3) also showed a trend to have the highest starch content (27.83%) compared with all other treatments although they were not significantly different. Panitnok et al. (2013) reported that the foliar application of Zn + Mg + S in the cassava variety Huai Bong 80 had the highest starch contents by 29.33%, which was slightly higher than in this study (27.83%).

Table 4. Means for fertilizer cost, fresh root weight, yield value and economic return over fertilizer cost of cassava variety Kasetsart 50 as affected by zinc foliar sprays.

Treatment	Fertilizer cost (USD ha^{-1})	Fresh root weight (t ha^{-1})	Yield value (USD ha^{-1})	Economic return over fertilizer cost (USD ha^{-1})
Unfertilized control (T1)	0	13.0c	567.9c	567.9c
Recommended fertilizer (T2)	170.8	23.0ab (77%)	1,004.7ab	833.9ab (47%)
Recommended fertilizer + 2% Zn (T3)	175.7	26.0a (100%)	1,135.7a	960.0a (69%)
Recommended fertilizer + 4% Zn (T4)	180.6	20.0b (54%)	873.6b	693.0b (22%)
Recommended fertilizer + 6% Zn (T5)	185.5	24.0ab (85%)	1,048.4ab	862.9ab (52%)
F-test	-	*	*	*
CV (%)	-	35.00	35.00	35.00

Means in the same column followed by different lowercase letters are significantly different by LSD (P<0.05).
The cost of the chemical fertilizer formula 15-15-15 at the time of application was 0.5 USD kg^{-1} applied at the rate of 313 kg ha^{-1} in treatments T2-T5. The cost of the $ZnSO_4.7H_2O$ at the time of application was 1.6 USD kg^{-1} in treatments T3-T5. The cost of cassava root in 2018 was 0.044 USD kg^{-1}. Number in parenthesis is % increase of root yield and economic return over fertilizer costs compared to the unfertilized control (T1).

Economic return

The treatments were significantly different (P<0.05) for fresh root weight, yield value and economic return (Table 4). All fertilizer treatments were significantly higher than unfertilized control for fresh root weight, yield value and economic return. Unfertilized control had the lowest fresh root weight (13.0 t ha^{-1}), the lowest yield value (567.9 USD ha^{-1}) and the lowest economic return (567.9 USD ha^{-1}), whereas recommended fertilizer + 2% Zn had the highest fresh root weight (26.0 t ha^{-1}), the lowest yield value (1,135.7 USD ha^{-1}) and the lowest economic return (960.0 USD ha^{-1}). Yield increases ranged between 54% in recommended fertilizer + 4% Zn and 100% in recommended fertilizer + 2% Zn, whereas economic return increases ranged between 22% in recommended fertilizer + 4% Zn and 6% in recommended fertilizer + 2% zinc. It is highly recommended to apply Zn by foliar spray for rapid remedy Zn deficiency in cassava to achieve the highest yield and the highest return per unit of fertilizer application (kg of fertilizer used). However, other application methods such as stake immersion and soil incorporation should be considered when the situation is not urgent because the crop take up most nutrients by root.

Based on the law of diminishing return of fertilizer application, which has been applied in agriculture since 1923, yield of the crop is limited by the deficiency of one element although the other elements are sufficient (Spillman, 1923). Micronutrient deficiency for other elements such as S, B and others should be investigated to maximize yield of cassava and maximize return. Further investigations are also required to vary Zn rates to find the most appropriate rate.

Materials and methods

Treatments and experimental design

Field experiment was conducted in a farm located in Phochai district, Roi-Et province in the Northeast Thailand (16°17'41"N, 103°48'2" E). Five treatments were arranged in a randomized complete block design with three replications.The treatments consisted of unfertilized control (T1), recommended fertilizer (15-15-15 of N-P-K at the rate of 313 kg ha^{-1}) (T2), recommended fertilizer plus $ZnSO_4.7H_2O$ at the rate of 6.25 kg ha^{-1} (2% Zn) (T3), recommended fertilizer plus $ZnSO_4.7H_2O$.

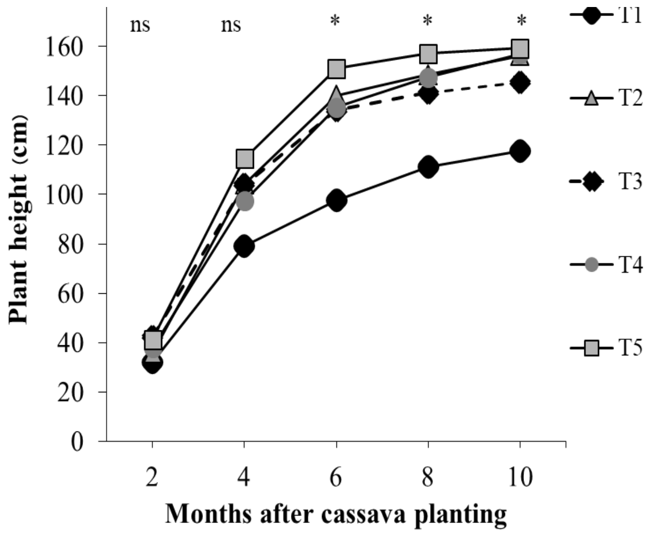

Figure 1. Effects of zinc management on plant height of cassava (Kasetsart 50). ns: not significant differences (P>0.05).
*: significant differences (P<0.05) T1= unfertilized control, T2 = recommended fertilizer, T3 =recommended fertilizer +2% Zn, T4 =recommended fertilizer +4% Zn and T5 = recommended fertilizer +6% Zn.

The chemical fertilizer formula 15-15-15 at the rate of 313 kg ha^{-1} was applied to the crop uniformly from T2 to T5 at two splits at one month (156.5 kg ha^{-1}) and three months (156.5 kg ha^{-1}) after planting.

Zinc in the form of $ZnSO_4.7H_2O$ was diluted, and Zn solution was applied to T3, T4 and T5 at the rates of 6.25, 12.50 and 18.75 kg ha^{-1}, which were equivalent to 2, 4 and 6% of Zn weight by water volume, respectively. Zinc solution was applied to the crop by foliar spray at two splits at the first month (first half) and three months after planting (second half).

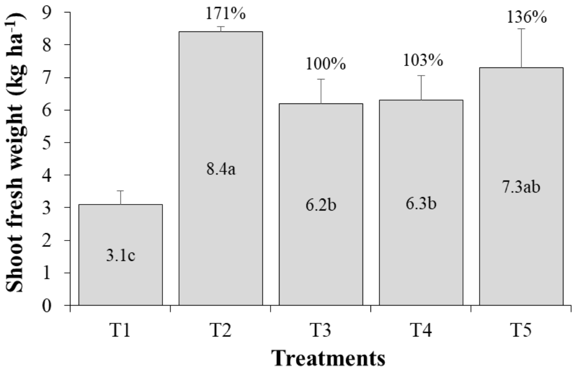

Figure 2. Effects of zinc management on shoot fresh weight of cassava Kasetsart 50. % indicates the increase in shoot fresh weights compared to unfertilized control. Error bars represent standard error of the mean. Different lowercase letters denote significantly different shoot fresh weight ($p<0.05$) among treatments. T1= unfertilized control, T2 = recommended fertilizer, T3 = recommended fertilizer +2% Zn, T4 = recommended fertilizer +4% Zn and T5 = recommended fertilizer +6% Zn.

Crop management

The soil was ploughed twice, and soil ridges at the distance of 0.8 m apart from each other were constructed after tillage. The experimental area was divided into 20 experimental plots each of which had two soil ridges with 7 m long. Each plot accommodated 15 plants. Two soil ridges between plots were used as an alley, and the alley between replications was 3 m wide.

The stems of Kasetsart 50 with 12-month-old were used for seed stakes. The stems were cut into stem cuttings of approximately 25 cm in length. The stakes were inserted vertically into the soil on the ridges to the depth of 2/3 of its length at the spacing of 0.8 m × 0.8 m. The cassava was grown in May 2017 and harvested in April 2018.

Chemical fertilizer was applied according to the specified treatments. Chemical fertilizer, formula 15-15-15, was applied twice at the first month (first half) and at three months after planting (second half). Zinc solution was applied to the crop by foliar spray at two splits at the first month (first half) and three months after planting (second half). Weed control was conducted manually at 1, 2 and 3 months after planting.

Data collection and data analysis

The crop was grown under rainfed conditions and harvested at 11 months after planting. Data were recorded for plant height at 2, 4, 6, 8 and 10 months after planting. At harvest, the data were recorded for shoot fresh weight, root number, root fresh yield and starch content. Fresh root samples of 5 kg $plot^{-1}$ were randomly chosen and used for determination of starch content via the Riemann Scale.

Topsoil samples (0-20 cm) of the experimental site was collected before planting, and topsoil samples of experimental plots were collected after harvest. The soil samples were analyzed for physical and chemical properties including soil texture (hydrometer method), pH (1: 2.5; soil: H_2O), electrical conductivity (EC, 1: 2.5; soil: H_2O), organic matter (OM) (Walkley and Black method), available P (Bray II extractant), exchangeable K (1 *N* NH_4OAc extractant) and exchangeable Zn (1 *N* HCl DTPA extractant) (Jones, 2001).

Data for each parameter were analyzed statistically using analysis of variance (ANOVA) with Statistix 8 software according to the experimental design (Analytical Software, 2003). Means were separated by least significant difference (LSD) at 0.05 probability level.

Conclusions

This study investigated the effects of rates of zinc (Zn) on growth, yield and economic return of cassava variety Kasetsart 50 grown in a loamy sand soil. The Zn rates of 2, 4 and 6% were used by a by foliar spray. The highest yield, starch content and economic return were obtained by chemical fertilizer plus foliar spray of 2% Zn. The information obtained in this study is important for cassava growers and agriculture personnel to give recommendations to cassava growers to increase cassava yield in loamy sand soils. The results may be extrapolated to other cassava varieties with similar response to Zn.

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References

Achakzai AKK, Kayani SA, Hanif A (2010) Effect of salinity on uptake of micronutrients in sunflower at early vegetative stage. Pak J Bot. 42: 129-139.

Analytical Software (2003) Statistix 8 Users Manual. Analytical Software, Tallahassee.

Bari MS, Rabbani Z, Rahman MS, Islam MI (2001) Effect of zinc, boron, sulfur, and magnesium on the growth and yield of potato. Pak J Biol Sci. 4: 1090-1093.

Buasong A, Narangajavana L, Thitamadee J, Punyasuk N (2014) Correlation of fertilizer application, growth and nutrient transporter gene expressions in Thai cassava. The 26th annual meeting of the Thai society for biotechnology and international conference. Mae Fah Luang University, Chiang Rai, Thailand. pp. 203-209.

Fageria NK, Baligar VC, Li YC (2008) The role of nutrient efficient plants in improving crop yields in the twenty first century. J Plant Nutr. 31: 1121-1157.

Fergeria NK, Baliger VC, Jones CA (2010) Growth and Mineral Nutrition of Field Crops. CRC Press, Florida. 590 p.

Howeler RH (2002) Cassava mineral nutrition and fertilization. In Hillocks RJ, Thresh MJ, and Bellotti AC. (Eds.) Cassava: Biology, Production and Utilization. CAB International, Wallingford. 115-147.

Howeler RH (2012) Effect of cassava production on soil fertility and the long-term fertilizer requirements to maintain high yields. In: Howeler RH (ed.). The Cassava Handbook: A Reference Manual Based on the Asian Regional Cassava Training Course, held in Thailand. Centro Internacional de Agricultura Tropical (CIAT), Bangkok, TH. p. 411-428.

Janket A, Jogloy S (2018) Influence of zinc, copper, and manganese on dry matter yield and physiological traits of three cassava genotypes grown on soil micronutrient deficiencies. Pak J Bot. 50: 1719-1725.

Jones JB (2001) Laboratory Guide for Conducting Soil Tests and Plant Analysis. CRC Press. 384 p.

Kailash S, Raghav M, Singh CP, Singh VK, Shukla A (2017) Effect of zinc sulfate application on growth and yield of potato (*Solanum tuberosum* L.). Res Environ Life Sci. 10: 685-68.Kaur M, Singh S, Dishri M, Singh G, Singh SK (2018) Foliar application of zinc and manganese and their effect on yield and quality characters of potato (*Solanum tuberosum* L.) cv. Kufri Pukhraj. Plant Arch. 18: 1628-1630.

Kunlanit B, Siritrakulsak T, Vityakon P (2022) Zinc promotes growth, yield and economic return of cassava variety Kasetsart 50 production**.** Asia Pac J Sci Technol. 27 (25): 1-9.

Lee MK, Saunders JA (2003) Effects of pH on metals precipitation and sorption: Field bioremediation and geochemical modeling approaches. Vadose Zone J. 2: 177-185.

Moosavi AA, Dehghani S, Sameni A (2015) Spatial variability of plant-available micronutrients in the surface and subsurface layers of a calcareous soil. Thai J Agric Sci. 48(3): 165-178.

Nanganoa LT, Ngome FA, Suh C, Basga SD (2020) Assessing soil nutrients variability and adequacy for the cultivation of maize, cassava, and sorghum in selected agroecological zones of Cameroon. Int J Agron. 2020: 8887318. https://doi.org/10.1155/2020/8887318

Office of Agricultural Economics. (2022) Agricultural economics of Thailand in 2021. Available at: https://www.oae.go.th/assets/portals/1/files/มันสำปะหลังปี%2064.pdf. Verified September 2, 2022.

Panitnok K, Chaisri S, Sarobol ED, Ngamprasitthi S, Chaisri P, Changleke P, Thongluang P (2013) The combination effects of zinc, magnesium, sulfur foliar fertilizer management on cassava growth and yield and yields grown on Map Bon, coarse-loamy variant soil. Procedia Soc Behav Sci. 91: 288-293.

Parmar M, Nandre BM, Pawar Y (2016) Influence of foliar supplementation of zinc and manganese on yield and quality of potato, *Solanum tuberosum* L. Int J Farm Sci. 6: 69-73.

Polthanee A and Srisutham M (2018) Growth, yield and water use of drip irrigated cassava planted in the late rainy season of Northeastern Thailand. Indian J Agric Res. 52(5) 2018: 554-559.

Rahman W, Islam M, Sheikh M, Hossain I, Kawochar A, Alam S (2018) Effect of foliar application of zinc on the yield, quality and storability of potato in Tista Meander floodplain soil. Pertanika J Trop Agric Sci. 41: 1779-1793.

Sanchez PA, Palm CA, Buol SW (2003) Fertility capability soil classification: a tool to help assess soil quality in the tropics. Geoderma. 114: 157-185.

Spillman WJ (1923) Application of the law of diminishing returns to some fertilizer and feed data. Am J Agric Econ. 5: 36-52.

Sumithra R, Thushyanthy M, Srivaratharasan T (2013) Assessment of soil loss and nutrient depletion due to cassava harvesting: A case study from low input traditional agriculture. Int Soil Water Conserv Res. 1(2): 72 -79.

Thai Tapioca Development Institute (2022) Kasetsart 50. Available at: https://tapiocathai.org-/English/K2_-e.html. Verified September 3, 2022.

Zhou A, Thomson E, (2009) The development of biofuels in Asia. Appl Energy. 86: S11-S20.