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Zinc promotes growth, yield and economic return of cassava variety Kasetsart 50 production

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Abstract

Low yield and economic return of cassava, which is extensively cultivated in low fertility sandy soils in Northeast Thailand, are partly due to micronutrients, notably zinc (Zn), deficiency in these soils. The objective of this study was to investigate the effect of Zn on growth, yield, quality and economic return of the cassava variety Kasetsart 50. Eight fertilizer treatments including 1) no fertilizer, 2) chemical fertilizer formula 15-15-15 at the rate of 313 kg/ha (CF), 3), 4) and 5) soaking stake in 2, 4, and 6%, of $ZnSO_4.7H_2O$, respectively + CF, 6), 7) and 8) soil incorporation of $ZnSO_4.7H_2O$ at the rate of 6.25, 12.50, and 18.75 kg/ha, respectively + CF were assigned in a randomized complete block design with three replications. Cassava variety Kasetsart 50 was planted in a loamy sand soil of a farmer's field in Phochai district, Roi-Et province in Northeast Thailand. Soil incorporation of $ZnSO_4.7H_2O$ at the rate of 18.75 kg/ha plus chemical fertilizer resulted in the highest plant height (196.7 cm), root fresh yield (45.8 t/ha), starch content (28.6%), Zn use efficiency and economic return over the fertilizer cost (1,850.77 USD/ha). The results suggested that application of $ZnSO_4.7H_2O$ at the rate of 18.75 kg/ha together with chemical fertilizer was effective in overcoming Zn deficiency in the loamy sand soils, widely distributed in Northeast Thailand, and also provided the highest yield, quality and economic return for cassava variety Kasetsart 50 production.

Keywords: Cassava, Chemical fertilizer, Northeast Thailand, Loamy sand soil, Zinc

1. Introduction

Cassava (*Minihot 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 in many industries, such as animal feed, starch, flour and bio-ethanol production [1, 2]. Yield potential of cassava in Thailand has been recorded at 50 t/ha, whereas an average yield of 22.6 t/ha has been attainable [3-5]. Land area for cassava production in Thailand comprised 1.38 million hectares in 2018 and sandy soils, covering approximately 0.42 million hectares, are normally used for cassava production in Northeast Thailand [6]. Low attainable yield of cassava is mainly due to low fertility of sandy soils. Long-term continuous cultivation of cassava without appropriate soil management has led to a reduction in both soil nutrients and cassava yields [7, 8].

Howeler [9] reported that reductions in yields from 26-29 t/ha to 10-12 t/ha were due to the continuous, long-term production of cassava without the necessary fertilizer applications. Howeler [10] determined that nutrient losses from a ton of cassava root were 2.3, 0.5, 4.1, 0.6 and 0.3 kg/ha for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg), respectively. Other studies have 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) [11, 12]. The optimum soil pH range for cassava is 5.5-7.5, although, within this range, the low availability of micronutrients in some soils can limit yield [12].

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 [11-14]. In calcareous soil, Cu, Fe, Mn and Zn are rendered less available as these elements precipitate in soil to form carbonates or bicarbonates and are also less available in high organic matter (OM) soil [15].

Cassava can also encounter Zn deficiencies in both acid and alkaline soils [14, 16], and Zn deficiency has been reported in several countries including Colombia, Indonesia, Malaysia, Australia, Mexico, Brazil and Nigeria [14, 17]. Severe Cu deficiency, resulting in yield reductions of up to 30%, has been reported in peat soil in southern Malaysia [14, 18]. Manganese deficiency has been reported in northeast Brazil, Colombia and Vietnam [14]. Zinc deficiency, however, can be controlled by the band application of 5-10 kg Zn/ha as $ZnSO_4.7H_2O$ or by the broadcast application of 10-20 kg Zn/ha as ZnO.

In Thailand, Kasetsart 50 is the most popular cassava variety grown over an area of 606,577 ha, accounting for 61 % of the country's total cassava cultivation with an average tuber yield of approximately 17.5 t/ha [19]. 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. However, the effects of rates and application methods of Zn on the growth and yield of Kasetsart 50 grown in loamy sand soil have not been thoroughly investigated. Thus, this study aims to determine the effects of rates and application methods 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.

2. Materials and methods

2.1 Treatments and experimental design

The field experiment was conducted in a farm located in Phochai district, Roi-Et province in Northeast Thailand (16º17'41"N, 103º48'2" E). Eight treatments were arranged in a randomized complete block design (RCBD) with three replications. The treatments were divided into four categories that were 1) no fertilizer control, 2) fertilizer control, 3) fertilizer plus Zn with three rates applied by stake soaking and 4) fertilizer plus Zn with three rates applied by incorporation of Zn into the soil. No fertilizer control was assigned as T1, and fertilizer control was assigned as T2. Chemical fertilizer formula 15-15-15 at the rate of 313 kg/ha (CF) was applied to the crop uniformly from T2 to T8 at two splits one month (156.5 kg/ha) and three months (156.5 kg/ha) after planting.

Zinc solution in the form of $ZnSO_4.7H_2O$ was applied to T3, T4 and T5 at the rates of 2, 4 and 6% weight by volume, respectively, by soaking the cassava stakes. Zinc powder in the form of $ZnSO_4.7H_2O$ was applied to T6, T7 and T8 at the rates of 6.25, 12.50 and 18.75 kg/ha, respectively, by incorporating into the soil at two splits at the first month (first half) and at three months after planting (second half).

2.2 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 24 experimental plots, each of which had two 7 m long soil ridges. Each plot accommodated 15 plants. Two soil ridges between plots were used as an alley, and the alley between replications was 3 m wide.

Cassava stems of Kasetsart 50 from 12-month-old plants 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. In treatments T3-T5, the cassava stalks were soaked in solutions containing 2% (6.25 kg $ZnSO_4.7H_2O$/ha), 4% (12.50 kg $ZnSO_4.7H_2O$/ha) and 6% (18.75 kg $ZnSO_4.7H_2O$/ha) $ZnSO_4.7H_2O$, respectively for 15 minutes before planting. Chemical fertilizer, formula 15-15-15, was applied twice. $ZnSO_4.7H_2O$ at the rates of 6.25, 12.50 and 18.75 kg/ha for treatments T6, T7 and T8, respectively, was applied twice along with the chemical fertilizer (15-15-15). Weed control was conducted manually at 1, 2 and 3 months after planting.

2.3 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 were randomly chosen and used for determination of starch content via the Riemann Scale. Agronomic efficiency (AE) was calculated according to Fageria et al. [20]:

Agronomic efficiency (AE) = (T_f - T_u / Zn_a) kg cassava root kg / Zn fertilizer applied

Where T_f is the root yield of the fertilized Zn plot (kg), T_u is the root yield of the unfertilized Zn plot (kg), and Zn_a is the rate of applied Zn fertilizer (kg).

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) [21].

Data for each parameter were analyzed statistically using analysis of variance (ANOVA) with Statistix 8 software for a RCBD [22]. Means comparisons were done through the least significant difference (LSD). Pearson's linear correlation analysis was measured to study relationships between zinc management and root fresh weight.

3. Results and discussion

3.1 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) (Table 1). 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), low exchangeable K (40.29 mg/kg) and low Zn (2.15 mg/kg). Based on the chemical properties, the soil in this study was considered to be infertile [23]. Therefore, a better, plant nutrient management is necessary in order to enhance growth and yield of cassava.

Table 1 Soil properties before cassava planting.

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

Fertilizer treatments did not have significant effects on soil pH, EC, OM content, exchangeable K and exchangeable Zn after cassava planting, whereas the treatments significantly ($p<0.01$) affected available P (Table 2). Application of chemical fertilizer plus Zn at the rate of 18.75 kg/ha resulted in the highest available P (17.16 mg/kg), and it was significantly higher than the others, which were similar to each other, ranging from 4.98 to 6.46 mg/P kg.

Most fertilizer treatments did not significantly change soil chemical properties except chemical fertilizer plus Zn at the rate of 18.75 kg/ha (T8), which increased available P in soil two-fold (17.16 mg/kg) compared to that of the soil before cassava planting (8.65 mg/kg). High available soil P in the treatment with fertilizer plus Zn at the rate of 18.75 kg/ha should promote growth and yield of cassava as P plays a key role in the distribution and development of plant roots [10].

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)	OM (%)	P (mg/kg)	K (mg/kg)	Zn (mg/kg)
T1	7.03	0.036	0.30	4.98^{b}	41.60	2.22
T2	6.96	0.028	0.33	5.31^{b}	40.06	2.49
T3	7.03	0.037	0.31	4.98^{b}	43.03	2.21
T4	6.93	0.031	0.30	5.06^{b}	40.36	2.47
T5	7.08	0.032	0.35	4.95^{b}	54.26	2.74
T6	7.11	0.043	0.33	5.28^{b}	45.10	3.08
T7	7.15	0.027	0.34	6.46^{b}	37.30	4.08
T8	7.43	0.037	0.31	17.16^{a}	40.66	2.49
F-test	ns	ns	ns	**	ns	ns
CV (%)	2.25	23.82	10.35	23.73	21.73	22.07

Means in the same column followed by different lowercase letters are significantly different by LSD ($p<0.01$), ns represents not significantly different ($p>0.05$). T1 = unfertilized control, T2 = fertilized control, T3, T4 and T5 = fertilizer plus Zn at the rates of 2, 4 and 6%, respectively, by stake soaking and T6, T7 and T8-fertilizer plus Zn at the rates of 6.25, 12.50 and 18.75 kg/ha, respectively, by incorporation into the soil.

3.2 Effects of the zinc applications on growth, yield, and quality of cassava variety Kasetsart 50

3.2.1 Cassava height

All fertilizer treatments (T2 to T8) showed greater plant height than the no fertilizer control (T1) evaluated at 2, 4, 6, 8 and 10 months after planting (Figure 1). T8 had taller plants at all growth stages, especially at 6-8 months after planting ($p<0.05$) which was due to the fact that it had the highest rate of Zn. Micronutrients play a vital role in growth and yield of cassava, which is widely grown under poor soil fertility and micronutrient deficient conditions [14]. The results of this study were similar to those reported in Kasetsart 50. Janket and Jogloy [24] showed that the application of chemical fertilizer (15-7-18) + Mg + Zn resulted in taller plants at 3 months after planting than the same chemical fertilizer application formula without the inclusion of Zn. Panitnok et al. [8] reported that soil- and foliar-applied fertilizer treatments had little effect on the height of cassava. In potatoes, Rahman et al. [25] 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) 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) [26].

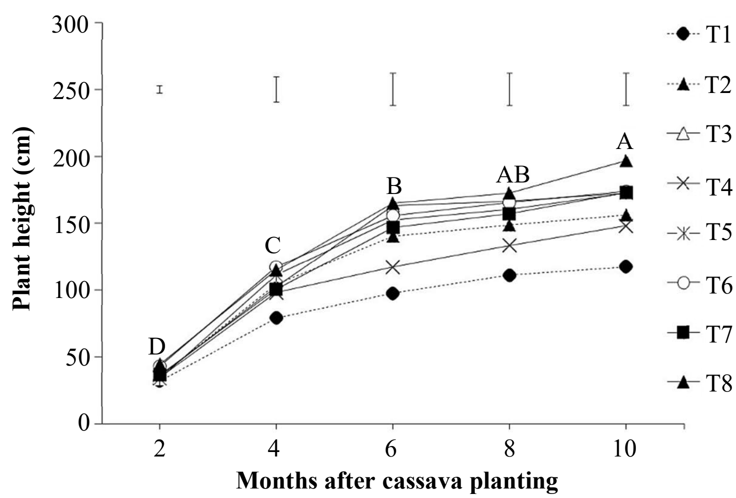

Figure 1 Effects of zinc management on plant height of cassava (Kasetsart 50). T1 = unfertilized control, T2 = fertilized control, T3, T4 and T5 = fertilizer plus Zn at the rates of 2, 4 and 6% $ZnSO_4.7H_2O$ solution, respectively, by stake soaking and T6, T7 and T8 = fertilizer plus Zn at the rates of 6.25, 12.50 and 18.75 kg $ZnSO_4.7H_2O$/ha, respectively, by incorporation into the soil. Uppercase letters denote different plant heights (means of all treatments) among the months after cassava planting ($p<0.05$). Vertical bars represent standard error of difference comparing plant heights among the treatments in each interval month.

3.2.2 Shoot fresh weight

All fertilizer treatments (T2-T8) had higher shoot fresh weight (143-464%) than with the no fertilizer control (T1) (Figure 2). T8 had the highest shoot fresh weight, which was 464% higher than the no fertilizer control (T1) and 110% higher than the no Zn control (T2). The soil in the current study had low primary nutrients (NPK) and low Zn (Table 1), and the application of chemical fertilizer together with a sufficient amount of Zn, therefore, was expected to enhance the growth of the cassava. The results of this study were similar to those in a previous study by Janket and Jogloy [24] showing that the application of chemical fertilizer (15-7-18) + Mg + Zn produced higher shoot dry weight in Kasetsart 50 at 3 months after planting compared to the similar treatments without Zn. Panitnok et al. [8] reported 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.

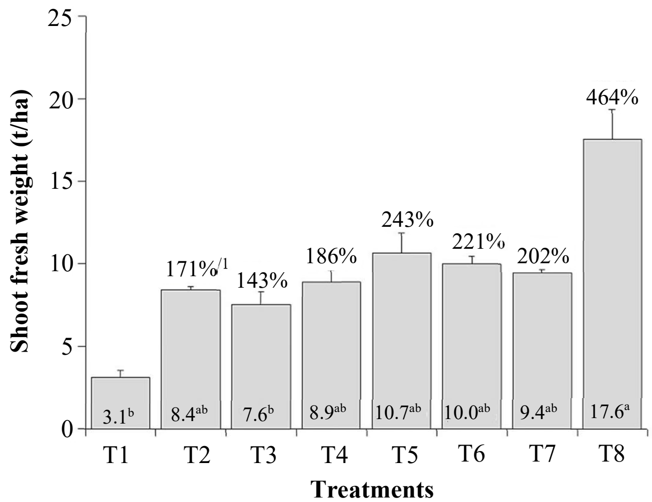

Figure 2 Effects of zinc management on shoot fresh weight of cassava Kasetsart 50. /1 % increase in shoot fresh weights compared to unfertilized control (T1). T1 = unfertilized control, T2 = fertilized control, T3, T4 and T5 = fertilizer plus zinc at the rates of 2, 4 and 6% $ZnSO_4.7H_2O$ solution, respectively, by stake soaking and T6, T7 and T8 = fertilizer plus zinc at the rates of 6.25, 12.50 and 18.75 kg $ZnSO_4.7H_2O$/ha, respectively, by incorporation into the soil. Error bars represent standard error of the mean. Different lowercase letters denote significantly different shoot fresh weight (p<0.05) among treatments.

3.2.3 Yield and quality

The chemical fertilizer plus Zn treatments (T3-T8) resulted in higher root numbers (34-79%) than in the control (T1) (Table 3). Similarly, Janket and Jogloy [24] reported that the application of the chemical fertilizer 15-7-18 + Mg + Zn produced 9.7 root/plant (increasing 76%), compared to 5.5 root/plant of the same chemical fertilizer application without Zn.

In the current study, chemical fertilizer treatments (T2-T8) resulted in significantly higher ($p < 0.05$) root fresh weight and starch content than in the no fertilizer control (T1), and the highest root fresh weight of 45.8 t/ha was obtained in chemical fertilizer plus Zn at the rate of 18.75 kg/ha (T8) (Table 3). The current findings agreed with those previously reported in Northeast Thailand. Chemical fertilizer (15-7-18) + Mg + Zn significantly increased root dry weight in Kasetsart 50 (2.4 t/ha) and Rayong 9 (1.1 t/ha) compared to 1.1 and 0.8 t/ha of the same varieties, respectively, treated with chemical fertilizer formula 15-7-18 + Mg without Zn [24]. In a similar study involving 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 [8].

In tuber crops, Bari et al. [27] found that potato treated with micronutrient combination including Zn, B, S and Mg produced the highest tuber yield (30.90 t/ha) compared with the no micronutrient control, which produced the lowest yield of 25.40 t/ha. The foliar applications of Zn at the concentration of 560 ppm provided the highest potato yield ranging from 36.7-37.2 t/ha [25].

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 [28]. Kailash et al. [29] found that the application of zinc sulfate to soil at the rate of 25 kg/ha at the time of potato planting resulted in higher tuber number and tuber weight of 10.42 tuber/plant and 516.67 g/plant, respectively, whereas the no Zn control had tuber number and tuber weight of 8.92 tubers/plant and 454.17 g/plant, respectively.

Chemical fertilizer plus $ZnSO_4.7H_2O$ at the rate of 18.75 kg/ha (T8) also produced the highest starch content (28.63%) compared with all other treatments (Table 3). Starch content in T8 was significantly different from T1, T2 and T4-T7, however, it was not significantly different from T3. Panitnok et al. [8] reported that the foliar application of Zn + Mg + S in the cassava variety Huai Bong 80 had the highest starch contents by 29.33%.

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

Treatment	Root number (root number/ha)	Root fresh weight (t/ha)	Starch content (%)
T1	42,200	12.6^{c}	18.03^{c}
T2	60,000 (42%)[/1]	23.3^{bc} (85%)[/1]	22.47^{bc} (25%)[/1]
T3	56,662.5 (34%)	20.0^{bc} (58%)	27.13^{ab} (51%)
T4	64,025 (52%)	31.1^{ab} (147%)	26.13^{bc} (45%)
T5	56,662.5 (34%)	28.7^{b} (127%)	25.90^{bc} (44%)
T6	75,562.5 (79%)	30.2^{b} (139%)	26.43^{bc} (47%)
T7	57,762.5 (37%)	34.5^{ab} (173%)	27.20^{bc} (51%)
T8	73,331.3 (74%)	45.8^{a} (263%)	28.63^{a} (59%)
F-test	ns	*	*
CV (%)	21.79	32.00	12.64

[/1]% increase in root number, root fresh 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). T1 = unfertilized control, T2 = fertilized control, T3, T4 and T5 = fertilizer plus zinc at the rates of 2, 4 and 6% $ZnSO_4.7H_2O$ solution, respectively, by stake soaking and T6, T7 and T8 = fertilizer plus zinc at the rates of 6.25, 12.50 and 18.75 kg/$ZnSO_4.7H_2O$ ha, respectively, by incorporation into the soil.

3.2.4 Relationship between zinc management and cassava root fresh weight

The correlation between soil application rate of Zn and root fresh weight was positive and significant (r = 0.725**, Figure 3B), whereas the correlation between stake soaking rate of Zn and root fresh weight was not significant although it was positive (Figure 3A). The results indicated that incorporation of Zn fertilizer into the soil was more effective than stake soaking of Zn. More effective application of Zn by incorporating Zn into the soil would be due to the fact that the methods experienced less loss of Zn than did the soaking application.

Incorporation of Zn into the soil at two splits greatly reduced Zn loss from leaching especially in a coarse textured soil like the soil in this study. The soil in this study was deficient in Zn (Table 1), and therefore the crop had a good response to Zn application. Leaf chlorosis, especially in young leaves, is a typical symptom of Zn deficiency [23]. Consequently, growth and yield of cassava is greatly affected by the reduced photosynthesis. In this study, the crop did not show Zn deficiency symptom and it had normal growth. Howeler [10] reported that cassava is highly susceptible to Zn deficiency, particularly in the early stages of growth. Under severe Zn deficiency the plant may die and yield no root.

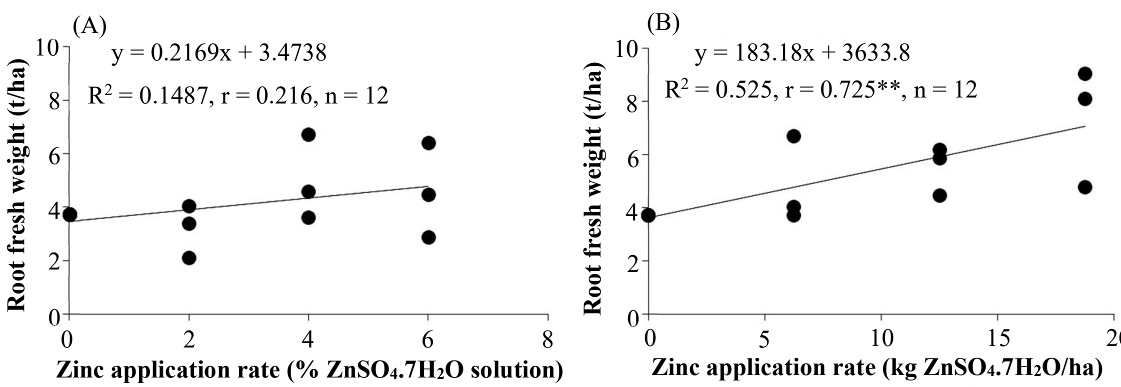

Figure 3 Correlation (Pearson correlation coefficients (r)) between zinc management and root fresh weight: (A) stake soaking of $ZnSO_4.7H_2O$ at the rates of 2% (6.25 kg/ha), 4% (12.50 kg/ha), and 6% (18.75 kg/ha) and (B) soil application of $ZnSO_4.7H_2O$ at the rates of 6.25, 12.50 and 18.75 kg/ha.

3.2.5 Agronomic zinc use efficiency

In comparing between the two methods of Zn application regarding agronomic efficiency (AE) for root fresh weight, both methods were efficient in increasing root fresh weight of cassava (Figure 4A, 4B). However, the efficiencies were different in magnitudes and patterns although these methods were applied at the same rates. Soaking application has the highest efficiency at the rate of 12.50 kg (122 kg/1 kg Zn), and then, the efficiency was reduced at the rate of 18.75 kg (91 kg/1 kg Zn). Soil incorporation increased efficiency at the rate of 12.50 kg (142 kg/1 kg Zn), and the efficiency was highest at the rate of 18.75 kg (259 kg/1 kg Zn).

The results revealed a higher efficiency of the soil incorporation method compared with the stake soaking method. The reduced efficiency at the rate of 18.75 kg in the stake soaking method was due to a high concentration of the solution that could be toxic to cassava plants at early growth stages. The rate recommended by CIAT was 4% for the soil with low Zn (1.0 ug/g), and the increases in root yield were recorded between 11.5 to 25.0 t/ha [30]. The rate of 6% in this study was higher than the recommended rate and it might have been toxic to the plants.

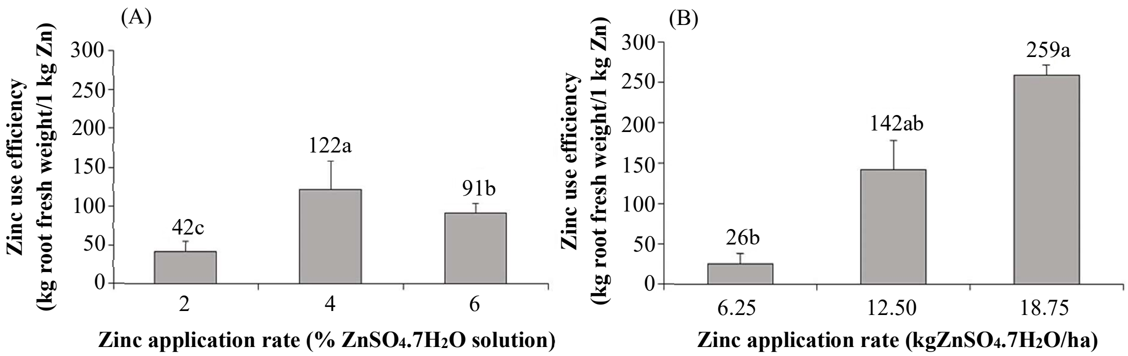

Figure 4 Effects of zinc rate on zinc use efficiency for cassava yield: (A) stake soaking of $ZnSO_4.7H_2O$ at the rates of 2% (6.25 kg/ha), 4% (12.50 kg/ha), and 6% (18.75 kg/ha) and (B) soil application of $ZnSO_4.7H_2O$ at the rates of 6.25, 12.50 and 18.75 kg/ha. Error bars represent standard error of the mean.

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

Treatment	Fertilizer cost (USD/ha)	Root fresh weight (t/ha)	Yield value (USD/ha)	Economic return over fertilizer cost (USD/ha)
T1	0	12.6^{c}	565.75	565.75^{c}
T2	5,475	23.3^{bc} (85%)$^{/1}$	1,046.18	870.59^{bc} (54%)$^{/1}$
T3	5,632	20.0^{bc} (58%)	898.01	717.38^{bc} (27%)
T4	5,788	31.1^{ab} (147%)	1,396.41	1,210.78^{ab} (114%)
T5	5,944	28.7^{b} (127%)	1,288.65	1,098.01^{b} (94%)
T6	5,788	30.2^{b} (139%)	1,356.00	1,170.37^{b} (107%)
T7	6,100	34.5^{ab} (173%)	1,549.07	1,353.43^{ab} (139%)
T8	6,413	45.8^{a} (263%)	2,056.45	1,850.77^{a} (227%)
F-test	-	*	-	*
CV (%)	-	32.00	-	32.00

The cost of the chemical fertilizer formula 15-15-15 at the time of application was 0.56 USD/kg; applied at the rate of 313 kg/ha in treatments T2-T8. The cost of the $ZnSO_4.7H_2O$ at the time of application was 1.60 USD/kg in treatments T3-T8. The cost of cassava root in 2018 was 0.04 USD/kg. $^{/1}$% increase of economic return over fertilizer costs compared to the control treatment (T1). T1= unfertilized control, T2 = fertilized control, T3, T4 and T5 = fertilizer plus zinc at the rates of 2, 4 and 6% $ZnSO_4.7H_2O$ solution, respectively, by stake soaking and T6, T7 and T8 = fertilizer plus zinc at the rates of 6.25, 12.50 and 18.75 kg $ZnSO_4.7H_2O$/ha, respectively, by incorporation into the soil.

3.3 Effects of the zinc applications on economic return over fertilizer costs in cassava production

All chemical treatments had significantly higher economic returns over fertilizer costs (717.38 to 1,850.77 USD/ha) than no fertilizer control (565.75 USD/ha) (Table 4). Chemical fertilizer plus Zn at the rate of 18.75 kg/ha (T8) provided the highest economic return over fertilizer cost of 1,850.77 USD/ha, and it also had the economic return over fertilizer cost of non-Zn control (T2) (27,145 USD/ha) by 173%. Therefore, application of Zn at the high rate 18. 75 kg/ha by soil incorporation in combination with chemical fertilizer is highly recommended to achieve the highest yield and the highest return per unit of fertilizer application (kg of fertilizer used).

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 [31]. 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.

4. Conclusion

This study investigated the effects of rates and application methods of zinc (Zn) on growth, yield and economic return of cassava variety Kasetsart 50 grown in a loamy sand soil. The $ZnSO_4.7H_2O$ rates of 2, 4 and 6% were used by a stake soaking method, and the Zn rates of and 6.25, 12.50 and 18.75 kg $ZnSO_4.7H_2O$/ha were used with a soil incorporation method. Growth and yield of cassava increased with the application of Zn from the lowest rate to the highest rate, and economic return was also increased accordingly. The highest growth, yield, Zn use efficiency and economic return were obtained by application of Zn to soil at the rate of 18.75 kg $ZnSO_4.7H_2O$/ha. 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. However, verification trials are also required.

5. Acknowledgements

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6. Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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