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Original research article

The Effects of Sulfur, Calcium, Boron and Zinc on Leaf Characteristics and Fresh Fruit Bunch Yield of Oil Palm (Surat Thani 2 Var.) in Acid Sulfate Soil

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ABSTRACT

Oil palm, *Elaieis guineensis*, is one of the major crops of the world. Since most oil palms are planted in acidic soil, there are several nutrient deficiencies that occur in the oil palm. In this study, the levels of four trace elements were observed in oil palms, to understand their effects on leaf characteristics, fresh fruit bunch yield and flower sex. The trace elements tracked were calcium (Ca)13.29% in combination with boron (B) 0.95%, as well as zinc (Zn)19% in combination with sulphur (S)13%. Based on the results, there were no significant differences observed at the beginning of the data collection period, especially on leaf characteristics, fresh fruit bunch yield and flower sex. However, at 5 months after trace element application, leaf greenness showed a significant difference, at 8 months, leaf size (thickness, width and leaflet width) also was significantly different. The highest rates of trace element application (Ca 13.29% and B 0.95% at 4g per plant and Zn 19% and S 13% at 4g per plant) were the most effective at increasing growth, but these same rates were not the best for improving fresh fruit bunch yield and flower sex.

Keywords: Acidic soil; Flower sex; Leaf greenness; Oil palm; Trace elements

1. Introduction

Daily household products, like cooking oil, shortening, biofuel and roughage feed for ruminants [1], often contain at least one key ingredient sourced from a particular plant. This plant is widely known as oil palm, scientifically known as *Elaeis guineensis*. Oil palm is one of the major crops of the world; this crop is one of the largest contributors to the worldwide

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economy as well as to the development of Thailand. The reason oil palm is so popular throughout the world is its numerous uses. In response to massive global demand, oil palm has been grown at large scale on oil palm plantations, for at least the last forty years. According to [2], India and China are the world's largest importers of palm oil, taking in 10 million and 6 million tones palm oil respectively, while Indonesia and Malaysia produced more than 85% of the world's palm oil. Thailand is ranked third in the world for palm oil production, and is an important county for palm oil growing, processing and trading.

Oil palm can be classified as a monoecious plant because both male and female flowers grow from an individual tree. Due to differences in flowering times between male and female inflorescences, cross pollination is needed. However, in the early 1980s, weevil (*Elaedobius kamerunicus*) was introduced in South East Asia a natural pollinator able to be used at commercial scale. Oil palm is a unique crop as it does not have a perfect phase of flowering; this can be seen where abnormalities in flowering can occur on male and female flowers. It takes about two years between the sex differentiation and anthesis. The sex determination of a flower is affected by genetics, climate and environmental conditions present during what is known as floral determination [3]. The economic life span of an oil palm grown for commercial purposes is around 20 to 30 years. According to [4], boron (B) is needed for the normal growth of plants making it a fundamental micronutrient. Boron can be classified as a unique micronutrient, as the threshold between deficiency and toxicity is narrow. According to [5], due to said narrow range, boron level management in soils can be challenging. Boron plays an important role in plants, especially in pectin and the physical characteristics of cell walls. This function has been known for long time [5]. Excessive amounts of boron will affect the nitrogen and carbohydrate levels in plants [6]. A decline in leaf chlorophyll (Chl), the adjustment of metabolism and necrosis of mature tissues are the characteristics of B toxicity, while B deficiency may be similarly severe [7]. Deficiencies of B occur mainly in either coarse textured soils with low organic matter content, or acidic sandy soils [8].

Zinc (Zn) plays a major role in starch metabolism [8] and also in the growth of a plant [9] as it is one of the essential micronutrients. Zinc acts as a plant growth hormone, and is an important component of the enzyme system. Besides that, it's also involved in photosynthesis reactions, nucleic acid metabolism and protein biosynthesis [8]. Plants need zinc for chlorophyll production, carbohydrate formation, starch formation and seed formation [10]. According to [11], zinc deficiency is similar to B deficiency, as it happens mostly in either coarse textured soils with low organic matter content, or acidic sandy soils.

Calcium (Ca) is essential for plant growth and development and is also involved in activating enzymes, inducing water movement, maintaining salt balance in plant cells and stimulating K to manage the process of opening and closing stomata [12]. Ca is one of the main regulators of plant growth and development, and a deficiency of it will result in yellow coloration and black spots on leaves [12]. According to [13], sulphur can be found in the form of pure sulfide and sulphate minerals. Sulphur is an essential plant nutrient that aids in the synthesis of chlorophyll, proteins and seed oil content [14].

This study was conducted because most of the soil in the Southeast Asia region is acid sulphate soil, so the findings are particularly relevant to the region. Soil pH affects nutrient availability by changing the form of nutrients in the soil. Since most oil palms are grown on this type of soil, the application of fertilizer is crucial for the growth of oil palms, as it is an important source of nutrients. The objective of this study was to determine the application rates of sulphur, calcium, boron and zinc needed in oil palms, growing in acidic soil, that will result in increased plant growth, optimal flower sex determination and increased yield.

2. Materials and Methods

2.1 Study site and experimental design

This experiment was conducted on the oil palm plantation located in the Rangsit basin. This plantation is supervised by the Faculty of Agriculture, Kasetsart University. The oil palms grown were the Surathani 2 variety at the age of 8 years old.

According to the Köppen-Geiger climate classification, the area of our study site is considered as AW or wet tropical climate with an average temperature of 27.8^0 C. The average rainfall of this area is 1480 mm with a drier period during the month of January. The soil type for this location is acid sulphate soil with a pH of less than 4.

The experiment started in November, 2017 and the oil palms were 8 years old. The trials continued for 12 months, ending in October, 2018. The trace elements studied in this experiment were grouped as two mixtures, first of 13.29% Calcium (Ca) and 0.95% Boron (B), and second of 19% Zinc (Zn) and 13% Sulphur (S). There were seven fertilizer treatments and four replications. Each experimental unit contained three trees, with the trace element application rates different for each treatment. T1 and T2 had the same application rates of trace elements, at 2 grams per plant, the rates increased to double for the following treatments, while T7 was the control receiving conventional fertilizer application. A brief explanation regarding the rate and calculations for trace elements 13.29% Calcium (Ca), 0.95% Boron (B), 19% Zinc (Zn) and 13% Sulphur (S) is given in table 1. The conventional fertilizer application used for the control treatment was the recommended one. It consists of 46-0-0, 18-46-0, 0-0-60, Boron (B) and $MgSO_4$. These fertilizers were applied twice a year in order to sustain the nutrient availabilities in the soil. The trace elements were applied together with the conventional fertilizer in each treatment. The mixtures of the trace elements along with the recommended fertilizer application were then poured into the holes. Every tree in the block has three holes, and each hole was located two meters away from the tree, at the end of the oil palm leaf range. The fertilizer mixtures were poured into the holes this way because the trace element fertilizers used release into the soil slowly, so this application method slowed the process of leaching during heavy rainfall; additionally, these fertilizer mixtures are easily absorbed by oil palm roots.

2.2 Soil sampling

The soil sampling was conducted at the beginning of the experiment. In order to obtain soil samples at every sampling palm, auger was used, and the depth for the soil sampling was 0.2 m. The soil samples were air-dried and then ground for laboratory analysis of texture (sand, silt, and clay), pH, soil organic carbon concentration, total N concentration, extractable P, and concentrations of exchangeable cations (K, Mg, and Ca). Soil pH was determined using KCl (1:2.5), and soil extractable P by the Bray II method. Soil exchangeable K, Mg, and Ca were determined using 1 M NH_4OAc (pH 7.0) [11].

2.3 Measuring fresh fruit bunch yield and flower sex

The fresh fruit bunches were harvested after six months of fertilizer and trace element application. Harvesting was done on all oil palms from each treatment block. The harvesting of fresh fruit bunches was done every 7-10 days in order to speed up the recovery of the crop [15-16]. Once harvested, bunches were counted and weighed. For each treatment block, the average individual bunch weight was calculated by dividing the fruit bunch yield by the bunch number. Flower sex was recorded every month by counting the number of female, male and hermaphroditic flowers at all the oil palms from each treatment block. Only the female flowers were marked, as they are the only ones that will develop into fruits. These data were recorded in order to predict the number of fresh fruit bunches for the following months.

2.4 Measuring leaf characteristics and nutrient analysis in leaf tissue

The leaf characteristics of the oil palms in the treatment blocks were measured three times, at the beginning of the experiment, at five months after applying the fertilizers, and at eight months after applying the fertilizers. The growth parameters recorded were plant height and all leaf characteristics which were frond length, leaf length, leaf width, petiole width, petiole diameter, leaf greenness and the number of leaves on the fronds. These parameters were all measured using the 17th frond of the palm. For plant height, oil palms were measured from frond 41 to the top of the soil. The leaf greenness was measured using a chlorophyll meter using SPAD unit.

Nutrient analysis in leaf tissue was performed on the same sampling palms that were analyzed for the soil analysis. The analyses were done twice, first at the beginning of the experiment and then second at the end of the experiment. The 17th fronds were cut to obtain samples of leaflets from each sampling palm [17]. Once the samples of leaflets were cut, they were then oven-dried at 70 ± 10 °C for 24 h, before undergoing laboratory analysis to determine tissue concentrations of N, P, K, Mg, Ca, Cl, and S. The Kjeldahl method was used to analyze the concentration of N in the vegetative tissue, P by spectrophotometry, K by flame photometry, Mg and Ca by atomic absorption spectroscopy, and S by gravimetry [11].

Table 1. The table shows the rate of trace elements used in each treatment.

Treatment	Fertilizer type
1	Recommended fertilizer + Ca 13.29%, B 0.95% for 2 g/plant
2	Recommended fertilizer + Ca 13.29%, B 0.95% for 4 g/plant
3	Recommended fertilizer + Zn 19%, S 13% for 2 g/plant
4	Recommended fertilizer + Zn 19%, S 13% for 4 g/plant
5	Recommended fertilizer + Ca 13.29%, B 0.95% for 2 g/plant + Zn 19%, S 13% for 2 g/plant
6	Recommended fertilizer + Ca 13.29%, B 0.95% for g/plant + Zn 19%, S 13% for 4 g/plant
7	Recommended fertilizer (0.8kg/plant of 46-0-0, 0.6kg/plant of 18-46-0, 0.8kg/plant of 0-0-60, 0.3 kg/plant of B, 0.5kg/plant of MgSO4,)

Note: T9 : 46-0-0, 18-46-0, 0-0-60, B, MgSO4.

3. Results and Discussion

The results obtained from this study show no significant effects from trace element application on plant growth, flower sex, or yield. However, the leaf characteristics at 8 months after fertilizer application showed a significant difference between palms receiving the trace element application and control, as well as leaf greenness at 5 months after fertilizer application for palms receiving the trace element application and control.

3.1 The effects of fertilizer treatments on growth

Leaf characteristics and plant height were measured in December, 2017 (Table 2). There is no significant difference between the treatments. For the cross section of the fronds, which included thickness and width, treatment 6 showed a tendency for larger leaf measurements at 44.96 mm and 82.70 mm, respectively, compared to treatment 7 with measurements of 38.03 mm and 72.80 mm respectively. Treatment 6 also tended to have the longest measurement of frond length, at 562.79 cm while treatment 7 measured 532.71 cm. Treatment 6 tended to have the highest measurements for leaflet width and leaf count at 5.91cm and 160.25 respectively, compared to treatment 7 measuring at 5.67cm and 157.92cm respectively. For plant height, treatment 6 tended to have the highest measurement, at 235.42cm, while treatment 7 recorded a height of 218.08cm. The reason for no significant differences in this data set could be that this set is the initial data collected only one month after fertilizer treatment. Further, there were also no significant differences in leaf characteristics and plant height measured in March, 2018 which was 5 months after fertilizer application (Table 3).

However, for leaf characteristics and plant height measured in June, 2018 (Table 4) which was 8 months after fertilizer application, there were significant differences, in both frond cross section and leaflet width, between treatment groups. There were two parameters measured for leaf characteristics for which treatment 6 showed higher measurements than treatment 7. For the cross section of the fronds, including thickness and width, treatment 6 recorded the highest measurement at 44.87 mm and 80.40 mm respectively, compared to treatment 7 with measurement of 37.58 mm and 68.61 mm respectively. However, for measurements of frond length, leaflet length, leaflet width, leaflet number and plant height, there were no significant differences between treatments 6 and 7. There was a significant difference in leaf greenness at five months after fertilizer application. However, comparing between the highest rate of fertilizer (T6) and control (T7), there was no significant difference.

An important factor that needs to be considered when applying fertilizer is the weather. According to [2], the rainfall required for optimal oil palm growth is about 2000 mm annually or more. During this field trial, it was rainy season in Thailand where the weather poses a high risk for nutrient leaching for recently applied fertilizer [18]. Although, the fertilizers were placed in the hole, leaching still occurred, as heavy rain caused flooding of the field where the trials were held. There were different rates of fertilizer application done in this study; it was assumed that the highest rate of fertilizer application (T6) would help increase the nutrient content and thus contribute to a higher fruit yield and improve nutrient use efficiency. As stated by [16], the highest rate of fertilizer application would not result in higher yields or a higher nutrient use efficiency. These were the outcomes seen for the rainy season, during which this trial was conducted. During the dry season however, results from trace element application might be much more positive, with nutrient loss caused by runoff and leaching being limited by the lower level of rainfall. On top of that, there was a slight increase in the growth of oil palms for the highest rate of fertilizer application (T6) compared to the control (T7). There is the possibility that an insufficiency of nutrient supply may cause a decline in nutrient concentrations in vegetative tissues.

3.2 The effects of fertilizer treatments on flower sex

The key factor for a high fruit yield is the inflorescences. There are three types of inflorescences, female, male and hermaphrodite. Tables 5 to 7 show the male flower count for the months of February, July, August, September and October 2018. There was no significant difference in the numbers of female, male and hermaphroditic flowers between the treatments. According to [19], the production of both female and male inflorescences by oil palms occurs in an alternating cycle throughout the year, which is influenced by genetics and environmental conditions. Examples of such environmental conditions are rainfall, day length and light intensity. Both female and male inflorescences take almost 30 months before they can be identified [3]. This is the reason no significant difference for flower sex was found. Besides that, the development of hermaphroditic inflorescences occurs during the changing phase between male and female batches. From the results obtained, fertilizer treatment had no significant effect on the sex determination of flowers. One study in the Congo showed that rainfall during the abortion stage of inflorescences, 12 months before fruit maturity, will give positive results on yield [20].

3.3 The effects of fertilizer treatments on yield

Another factor studied in this experiment was the effect of fertilizer rate on the yield of fresh fruit bunch. Based on the results obtained (Table 8), there was no significant difference between treatments. According to [21], the duration of fruits development takes about 30 months after oil palm planting, and then another six months for commercial harvesting. Ripening of the fruits occurs after 84 days of anthesis, and since the age of the oil palms in this study was only eight years old, the yields were relatively low. However, yield will continue to increase, eventually reaching peak production at year seven to 18, and then slowly decline after that. Additionally, the other possible factor affecting yield was the nutrient uptake by the trees. Since the oil palm is known as a crop needing high rainfall, the fertilizers applied to the field might leach due to the rainfall, resulting in low yield. In other words, there is no difference in fresh fruit bunch weight between the different rates of fertilizer treatment [16]. Since different rates of fertilizers were applied to the oil palms, the adjustment of the levels of nutrients might have slowed the effects on palm growth; this assertion is supported by [22], where the authors stated that the maturity of oil palm fruit bunches may take up to 2-3 years. One study observed an increase in the weight of oil palm bunches after the application of fertilizer, but that the weight decreased when rainfall was low [23]. The rainfall requirements may have a great impact on the female inflorescences, proportion of flower sex, mixing, development and maturity in the oil palm [29]. The justification for the usage of chemical fertilizers must be made since every soil has different soil fertility, especially for the soil used to grow oil palms. In addition, soil with high inherent fertility levels is crucial for oil palm growth [25]. The fertilizer requirements of the oil palm is about 2 to 3 applications a year and should be done according to the results of soil and leaf analysis along with distinguishable deficiencies that can be seen in oil palm plantations [23]. The oil palm is classified as a perennial plant and as such, has large fertilizer requirements for good yields due to the loss of nutrients to the harvesting of its fruits. The nutrients lost during harvesting periods are N, P, K, Mg and Ca. However, oil palms grown in soil with high K will produce more fruit and do not react to K fertilizers [26]. Regardless of that, it is important to increase the number of fertilizer requirements in order to get a good and high valued yield [27].

3.4 Soil analysis and leaf tissue analysis

Table 9 shows the soil nutrient analysis results. The analysis involved soil pH, $CaCO_3$ level in soil, soil composition, soil texture, level of organic matter, and the levels of P, K, Ca and Mg. For the first six tests, there were no significant differences between treatment 6 and treatment 7 in terms of soil pH, $CaCO_3$ level in soil, the soil composition and soil texture. However, there was a substantial difference in the levels of organic matter, P, K, Ca and Mg. Concerning organic matter, treatment 6 had the highest percentage (6.89%) while treatment 7 had a percentage of 6.73%. However, there was a large difference in the level P, treatment 7 had the highest level (26.83mg/kg) while treatment 6 had only 6.56mg/kg. The level of P in treatment 7 was four times higher than that in treatment 6. Levels of K, Ca and Mg recorded were highest in treatment 7 with 70mg/kg, 861mg/kg and 340mg/kg, while treatment 6 had 66mg/kg, 738 mg/kg and 245 mg/kg respectively. According to [19], soil pH does not affect the availability of N but the latter was affected by B added to the soil. Besides that, the level of K is normally not high in acidic soils. The ability of apple root to absorb important macronutrients is improved by the addition of B. Adding Zn to acidic soil has a more positive effect compared to when it is applied to limed soil.

Table 10 shows the leaf nutrient analysis results where nine nutrients were measured. There is no substantial difference among these nutrient readings. Treatment 6 had the highest level of total N, P and K with 2.05, 0.167 and 1.10, compared to treatment 7 with 1.89, 0.148 and 0.89 respectively. For total Ca, Mg and Mn, treatment 7 had the highest levels with 0.76, 0.32 and 725.90, while treatment 6 had 0.67, 0.29 and 644.10 respectively. Treatment 6 had the highest levels of total Zn, B and S with 14.10, 24.86 and 2,462 while treatment 7 had 9.30, 22.96 and 1,693 respectively. For this reason, the addition of S, Zn, B, and Ca in oil palms might increase the efficiency of macronutrient absorption by the root.

Table 2. Plant growth and leaf characteristics before fertilizer application.

Treatment	Thickness (mm)	Width (mm)	Frond Length (cm)	Leaflet Length (cm)	Leaflet Width (cm)	Number of leaflets	Plant Height (cm)
1	41.14	76.31	523.75	102.05	5.75	155.08	200.50
2	39.30	76.04	524.34	100.90	5.59	156.25	211.67
3	41.82	83.46	563.42	101.60	6.21	160.17	212.92
4	41.83	80.63	556.71	103.40	5.87	160.25	247.67
5	39.65	75.33	534.96	97.20	5.92	160.17	210.42
6	44.96	82.70	562.79	99.68	5.91	160.25	235.42
7	38.03	72.80	532.71	105.03	5.67	157.92	218.08
P- Value	NS	NS	NS	NS	NS	NS	NS
% CV	15.68	14.89	9.47	7.41	11.76	5.75	18.39

Table 3. Plant growth and leaf characteristics at 5 months after fertilizer application.

Treatment	Thickness (mm)	Width (mm)	Frond Length (cm)	Leaflet Length (cm)	Leaflet Width (cm)	Number of leaflets	Leaf Greenness (SPAD unit)
1	40.15	64.48	521.67	99.08	5.69	153.08	72.38 ab
2	43.36	74.49	519.08	100.40	5.55	159.25	69.63 b
3	44.03	79.85	551.42	99.18	6.11	161.08	75.10 a
4	43.09	79.58	550.50	108.05	5.82	160.92	74.10 ab
5	39.47	71.97	530.17	99.68	5.94	156.67	74.60 ab
6	41.60	77.98	549.25	99.03	5.82	160.50	75.82 a
7	38.03	71.53	518.92	100.93	5.62	156.33	71.76 ab
P-Value	NS	NS	NS	NS	NS	NS	**
% CV	17.98	4.29	8.42	7.45	8.90	5.58	5.83

Table 4. Plant growth and leaf characteristics at 8 months after fertilizer application.

Treatment	Thickness (mm)	Width (mm)	Frond Length(cm)	Leaflet Length (cm)	Leaflet Width (cm)	Number of leaflets	Plant Height (cm)	Leaf Greenness (SPAD Unit)
1	38.95 b	72.22 ab	503.49	97.07	5.62 ab	158.08	212.58	72.21
2	38.06 b	71.67 ab	501.33	98.42	5.55 b	159.25	211.33	71.94
3	40.45 ab	81.54 a	517.98	95.70	6.30 a	164.50	229.42	74.02
4	40.98 ab	79.23 ab	518.43	99.46	5.72 ab	164.17	254.83	72.36
5	38.49 b	77.73 ab	508.11	95.53	5.88 ab	163.17	216.25	73.18
6	44.87 a	80.40 a	520.39	98.32	5.72 ab	160.33	253.33	73.65
7	37.58 b	68.61 b	492.63	98.68	5.63 ab	160.33	225.83	72.69
P-Value	**	**	NS	NS	*	NS	NS	NS
% CV	9.85	11.74	7.87	6.87	9.77	6.10	20.02	4.44

Table 5. The average number of male flowers per plant from 4 to 12 months after fertilizer application.

Treatment	**4 MAF**	**9 MAF**	**10 MAF**	**11 MAF**	**12 MAF**
1	0.0832	0.0000	0.2498	0.0833	0.0000
2	0.1665	0.1665	0.2498	0.2498	0.1665
3	0.0000	0.1665	0.0000	0.0833	0.0000
4	0.0833	0.0833	0.0833	0.0833	0.2498
5	0.0000	0.0000	0.1665	0.1665	0.0000
6	0.0833	0.0000	0.0833	0.0000	0.1665
7	0.0000	0.1665	0.1665	0.0833	0.1665
P- Value	NS	NS	NS	NS	NS
%CV	223.11	157.36	111.94	147.96	139.96

Table 6. The average number of female flowers per plant from 4 to 12 months after fertilizer application.

Treatment	4 FAF	9 FAF	10 FAF	11 FAF	12 FAF
1	2.67	2.08	1.92	2.00	1.33
2	2.58	1.92	2.25	2.17	2.42
3	2.58	2.00	2.50	2.08	2.67
4	2.33	1.58	1.67	1.58	3.17
5	2.58	2.08	1.83	1.92	2.17
6	2.83	1.67	2.08	1.42	1.83
7	2.42	1.50	2.25	1.33	1.33
P- Value	NS	NS	NS	NS	NS
%CV	38.72	32.59	40.60	45.57	39.75

Table 7. The average number of hermaphroditic flowers per plant from 4 to 12 months after fertilizer application.

Treatment	4 HAF	9 HAF	10 HAF	11 HAF	12 HAF
1	0.0832	0.0000	0.2498	0.0833	0.0000
2	0.1665	0.1665	0.2498	0.2498	0.1665
3	0.0000	0.1665	0.0000	0.0833	0.0000
4	0.0833	0.0833	0.0833	0.0833	0.2498
5	0.0000	0.0000	0.1665	0.1665	0.0000
6	0.0833	0.0000	0.0833	0.0000	0.1665
7	0.0000	0.1665	0.1665	0.0833	0.1665
P- Value	NS	NS	NS	NS	NS
%CV	223.11	157.36	111.94	147.96	139.96

Table 8. The cumulative weight of fresh fruit bunches per plant from 6 to 12 months after fertilizer application.

Treatment	Bunch Weight (Kg)
1	88.99
2	93.57
3	99.39
4	93.81
5	86.41
6	86.77
7	76.94
P- Value	NS
% CV	14.13

Table 9. Soil analysis of each treatment at 11 months after fertilizer application.

Treatment	Soil pH	$CaCO_3$ / rai	Sand (%)	Silt (%)	Clay (%)	Texture of Soil
1	3.8	2,285	25	16	59	C
2	3.8	2,285	27	20	53	C
3	3.9	2,285	27	22	51	C
4	3.8	2,285	29	18	53	C
5	3.8	2,285	27	20	53	C
6	3.8	2,285	31	18	51	C
7	3.9	2,285	33	16	51	C

Table 9 (cont.). Soil analysis of each treatment at 11 months after fertilizer application.

Treatment	Organic Matter (%)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)
1	3.23	4.97	123	653	214
2	5.38	7.77	98	624	193
3	7.57	57.52	77	754	239
4	5.49	10.38	67	1,000	281
5	6.50	10.39	75	1,175	321
6	6.89	6.56	66	738	245
7	6.73	26.83	70	861	340

Table 10. Leaf tissue analysis at 10 months after fertilizer application.

Nutrients	**1**	**2**	**3**	**4**	**5**	6	7
Total N (%)	2.03	1.94	2.12	2.05	2.03	2.05	1.89
Total P (%)	0.159	0.153	0.166	0.159	0.160	0.167	0.148
Total K (%)	1.03	0.97	1.31	0.99	0.97	1.10	0.89
Total Ca (%)	0.73	0.82	0.71	0.74	0.81	0.67	0.76
Total Mg (%)	0.30	0.36	0.29	0.37	0.30	0.29	0.32
Total Zn (mg kg^{-1})	16.80	14.00	15.30	13.70	11.70	14.10	9.30
Total Mn (mg kg^{-1})	741.20	928.20	780.70	654.20	885.60	644.10	725.90
Total B (mg kg^{-1})	27.11	32.46	23.54	20.23	22.36	24.86	22.96
Total S (mg kg^{-1})	2,574	2,350	2,130	2,110	2,137	2,462	1,693

4. Conclusion

From these results, it is shown that treatment 6, recommended fertilizer with Ca 13.29% and B 0.95% at 4g per plant and Zn 19% and S 13% at 4g per plant, had the most beneficial effect on oil palms grown in acidic soil. The effect of higher rates of trace elements were more beneficial than the lower rates. Considering a rainfall of 2000 mm per year, applying higher rates of trace elements may prevent the trace elements from leaching. According to [29-30], B leaching from fertilizers could be much worse, especially in flood prone areas since these conditions are suitable for B leaching. Besides that, according to the data collected each month, treatment 6 had higher measurements and readings compared to the control (treatment 7). The combination of these trace elements can be obtained easily from markets. The purpose of using these trace elements was to elevate nutrient levels in acidic soil, improving oil palm growth and yield; these trace elements are key nutrients for the oil palm. This project is a continuous study, following previous research [8], because the effects of these trace elements applied to citrus grown in acidic soil could only be observed after three years. As such, after three years of applying the combinations of trace elements to the oil palm, positive results in fresh fruit bunch yield and flower sex ratio are expected. Importantly, the application of these trace elements must be continued adequately in order to prevent soil toxicity.

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