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Screening for Optimum Concentrations of Boron, Copper and Manganese for the Growth of Three-Month Old Oil Palm Seedlings in Solution Culture

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ABSTRACT

Micronutrient application has been in general overlooked in oil palm fertilisation programmes. Considering the importance of a balanced fertiliser in plant nutrition, it was necessary to determine the requirements of important micronutrients for their further recommendation in oil palm fertilisation programmes to ensure better growth and good yield. An experiment was conducted to identify the optimum concentrations of B, Cu and Mn for the growth of oil palm seedlings. The concentrations tested were 0, 0.25, 0.50, 1 and 2 mg B /L; 0, 0.5, 1, 2 and 4 mg Cu /L; 5, 10, 15 and 20 mg Mn /L. Germinated oil palm seeds were supplied with different concentrations of the selected micronutrients for three months in soilless culture. The assessment of the growth and physiological parameters showed that 2 mg/L for both B and Cu gave better response, while all the tested Mn concentrations were suppressive to the growth of oil palm seedlings. Therefore, 2 mg/L for both B and Cu and a minimal concentration of 2 mg Mn/L are being tested in new experiments in single and different possible combinations on nutritional, biochemical and growth parameters of oil palm seedlings from two to eight months for their future incorporation in oil palm fertilisers

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INTRODUCTION

The increasing demand for oil and fats to meet the need of the increasing world population is one of the major concerns of the agricultural sector nowadays and will still be a concern in the future. The world's oil and fat consumption was estimated at 188 million tons in 2012/2013 (Mielke, 2014). Oil palm is the highest oil yielding crop with an average of 5 tons of crude palm oil (CPO) per hectare per year (Barison & Ma, 2000), almost three times the yield of coconut, and more 10 times that of soybean (0.4 ton per hectare) (Rajanaidu & Jalani, 1994).

In 2008, the major vegetable oil production was 111.13 million tons. Palm oil contributed about 40% and ranked first just before soybean oil (33%), amounting to about 67% of world export (Jackson *et al*., 2009). World palm oil production has multiplied 15-fold since 1948 to reach 38 x 10^6 tons in 2007 (Rival, 2007). Southeast Asia (Malaysia and Indonesia) contributed 86% of global palm oil production. Over the years, oil palm fertilisation has been a macronutrient-based practice involving N, P, K, and Mg, and has been carried out especially on mineral soils, overlooking micronutrients; however, boron application is based on leaf sampling level. Consequently, soils in oil palm plantations seem to have been depleted in micronutrients through continuous removal of these elements by high fresh fruit bunch production.

Currently, the total area planted with oil palm is approximately 15 million ha (FAO, 2009; Turner *et al*., 2011) with Malaysia and Indonesia, the two leading palm oil producing countries of the world, accounting for 14 million ha with about 5 and 9 million ha, respectively. Palm oil is the highest oil-yielding crop, producing 10 times more oil than soybean. However, there is still a big gap between its current yield (4.5-5 tons crude palm oil (CPO) $ha^{-1}year^{-1}$) and its potential yield of about 19 tons CPO $ha^{-1}year^{-1}$ (Corley, 2014), which could be in part due to unbalanced fertilisers, especially oversight in the use of micronutrients. The potential yield of a progeny for a given soil and climate can be seriously influenced by nutrient management. A good nutrient management and other practices can help to minimise or to close the gap between achievable yield and actual yield.

Boron, copper and manganese, besides their other physiological functions, are all involved in phenol synthesis in plants and have major effects on host susceptibility or resistance to disease (Graham, 1983). Boron is reported to be able to form boro-carbohydrate complexes with cis-hydroxyl groups. This affects the substrate flux between glycolysis and the pentose phosphate partway, resulting in the regulation of phenols and lignification, quinones and free radical production (Stangoulis & Graham, 2007). In oil palm, in addition to other functions, B is particularly important for the formation of pollen, its viability, its germination and the growth of pollen tubes (Fairhurst *et al*., 2005). Copper plays an important role in photosynthesis. As the metal component of plastocyanins, it is involved in electron transport in

photosystem I. In addition to its biocidal effect, which makes it a common component of many copper-based pesticides, copper constitutes the active site of laccase, a multi-copper enzyme involved in the polymerisation of monolignols during the lignin biosynthesis (Fairhurst *et al.,* 2005; Evans & Solberg, 2007; Chmielowska *et al.,* 2008). In oil palm, Cu is required for lipid and nitrogen metabolism and pollen viability (Fairhurst *et al*., 2005). Thanks to its high redox activities, manganese is among the most abundant elements in most surface environments. Manganese is an activator of several enzymes involved in the synthesis of important secondary metabolites (Thompson & Huber, 2007). Manganese activates the production of phenylalanine ammonia-lyase, the first enzyme committed to the common phenylpropanoid pathway leading to the biosynthesis of lignin precursors in the monolignol specific pathway (Boudet, 2000). Manganese deficiency symptoms are rare in oil palm, but are observed when Mn concentration in frond 17 is less than 25 mg/kg (Goh & Härdter, 2003). Considering the importance of B, Cu and Mn in oil palm, and their involvement in lignification and other plant defence mechanisms, the objective of this research was to gain an insight on how these micronutrients affect the growth of oil palm seedlings as a whole, prior to studying the necessity of their further consideration in oil palm fertilisation.

MATERIALS AND METHODS

The experiment was carried out in experimental field 2, Universiti Putra Malaysia, Serdang, Selangor, Malaysia (2°59'220.56''N, 101°42'44.42''E, about 45 m above sea level) in a shaded green house with 50% light filtration.

Oil palm germinated seeds

The commercial DxP (Yangambi ML 161) oil palm germinated seeds were supplied by FELDA Agricultural Services Sdn Bhd (FASSB), Sungai Tekam, Jerantut, Pahang, Malaysia. Homogeneous well differentiated seeds were selected and used when the radicle was 4 to 5 cm long.

Nutrient solution

The nutrient solution was prepared according to Hoagland and Arnon (1950). Each polypropylene tray containing 10 L of nutrient solution was planted with 3 germinated seeds supported by pieces of sponge and polystyrene. The solution was permanently aerated using an air pump and was renewed every week. The pH was adjusted at 5.5 with 0.1 N HCl or 0.1 N NaOH. The experiment was carried out for three months.

Growth parameters

The parameters measured were plant height (PH), net photosynthetic rate (*P*N), root fresh weight (RFW) and dry weight (RDW), root length (RL), root surface (RS), number of root tips (RT), root volume (RV), shoot fresh weight (SFW) and dry weight (SDW), SPAD chlorophyll value (SPAD Chl), total leaf area (TLA)and biomass dry weight i.e. total dry weight (TDW). Plant height and SPAD Chl were taken at 1.5 months and at

the end of the experiment while the other parameters were measured only at the end (3 months). The SPAD Chl was read on leaf 3 using Chlorophyll Meter SPAD – 502 Plus Konica Minolta Sensing, INC – Japan 20001421. The TLA was measured by the Leaf Area Meter LI – COR Model LI – 3100 Area Meter, USA, the PN by Portable LI – 6400 XT Photosynthesis System (LiCOR, Lincoln, NE, USA), and the RL, RS, RT and RV recorded by the Root Scanner Epson Expression 1680, Model G780B, Singapore, equipped with the software WinRHIZO – Pro.

Nutrient analysis

At the end of the experiment, the oil palm seedlings were washed with distilled water and separated into roots and shoot. The fresh weight was recorded and the samples were oven-dried at 65°C for three days, and the dry weights recorded. The samples were then ground to pass through a 1-mm sieve using Grinder Culleti Typ MEC CZ 13, Polymix Dispersing and Mixing Technology by KINEMATICA, Switzerland. Nutrients were extracted by dry ashing according to Benton Jones (2003). Nutrient analysis was basically focused on our nutrient of interest, namely B, Cu and Mn, to appreciate their levels in oil palm roots and shoots under our experimental conditions. Shoot samples were made up of composite of all leaves, including petiole and bulb. Boron was determined by inductively coupled plasma-mass spectrometry (ICP-MS), Model ELAN – DRC – e Canada, while Cu and Mn were determined by atomic absorption spectrophotometer (AAS) Perkin Elmer, A Analyst 400, Model SS 103, USA.

Experimental design

The treatments were arranged in a randomised complete block design (RCBD) with three replicates. Each experimental unit contained three oil palm seedlings.

Data analysis

All the data were analysed by analysis of variance (ANOVA) using Statistix 8.0 (USDA and NRCS, 2007). Least significant difference (LSD) test or Tukey's honestly significant difference (HSD) all-pairwise comparison test was used to detect statistical differences among the means at $P = 0.05$ significance level. Where necessary, data were subjected to log or square root transformation to achieve the Shapiro-Wilk normality test. Also, polynomial analysis was applied to identify the best trend when needed, especially for copper concentrations.

RESULTS AND DISCUSSION

Growth parameters

Effect of boron

The tested concentrations of boron (B) did not differ significantly ($P \geq 0.05$) in their effects on morphological and physiological growth parameters studied (Table 1). This may be due to the fact that B is not directly involved in any of those parameters. In plants, the number of growth processes which require B include new cell development in meristematic tissues;

proper pollination and fruit or seed set; translocation of sugars, starches, nitrogen, and phosphorus; synthesis of amino acids and proteins; nodule formation in legumes; regulation of carbohydrate metabolism; root elongation and nucleic acid metabolism, auxin and phenol metabolism (Havlin *et al.,* 1999; Gupta, 2007).

Since there were no significant differences among the B concentrations, the ranking with respect to the parameters studied was used to establish the optimum value (Table 2). As a result, 2 mg B/L was either first or second for the majority of parameters, allowing it to be considered as optimum concentration for subsequent studies. This 2 mg B/L lies within 1 – 2 mg B/kg adequate range for oil palm (Syed Omar, 2007 unpublished data), 0.4 – 5 mg B/kg available range reported by Mills and Jones (1996), and 0.1 – 2.5 mg B/kg available range for oil palm determined by Eschbach (1980).

Effect of copper

Highly significant differences ($P \leq 0.01$) were observed among the tested concentrations of copper (Cu) for shoot dry weight with 2 mg Cu/L giving the highest value (Fig.1). This suggests that at 2 mg Cu/L in nutrient solution, oil palm seedlings produce and accumulate more biomass in shoots compared to other concentrations. This may be due to the more efficient photosynthetic activity at 2 mg Cu/L.

Plant height values recorded in the middle of the experiment (1.5 months) were significantly different ($P \leq 0.05$). The graphic representation (Fig.2) showed 2 mg Cu/L to be the optimum concentration.

The polynomial analysis performed on this parameter and on the shoot dry weight allowed the identification of 2 mg Cu/L as the optimum concentration (Fig.3) after derivation of the equation describing the trend at the end of the experiment (3 months) as well as at mid-term.

This indicates that the maximum height of oil palm seedlings was achieved at 2 mg Cu/L, while the higher levels of Cu led to a decreased height. As observed in the case of boron, 2 mg Cu/L was within the range of 1 – 2 adequate for oil palm (Syed Omar, 2007, unpublished data), close to 0.5 – 1.5 considered as moderate by Munevar (2001). In another study, Sabrina (2011) found 2 mg Cu/L to be optimum for peroxidase activity, laccase activity and lignin content in the roots of oil palm seedlings under sand culture using tap water supplemented with various concentrations of copper.

For most of the parameters studied, the lowest values corresponding to reduced plant height were recorded with the control (0 mg Cu/L) and 4 mg Cu/L, indication of insufficiency and toxicity, respectively.

Effect of manganese

All the tested concentrations of manganese (Mn) showed a suppressive effect on all the parameters evaluated apart from the control (0 mg Mn/L), which gave significantly ($P \leq 0.05$) higher performance than the others for 11 parameters out of 14 (i.e. 78.57% of the cases) (Table 3). Even when no significant difference existed among the Mn

TABLE 1
Effects of boron concentrations on morphological and physiological growth parameters of oil palm seedlings

B concentration	Growth parameters													
	PH1	PH2	P_N	RFW	RDW	TRL	RSA	RT	RV	SFW	SDW	TLA	SPAD Chl1	SPAD Chl2
mg/L	—— cm ——		$\mu molCO_2m^{-2}s^{-1}$	—— g ——		cm	cm^2		cm^3	—— g ——		cm^2		
0	22.22[a]	29.05[a]	4.15[a]	1.71[a]	0.20[a]	350.87[a]	68.34[a]	2723[a]	1.07[a]	8.14[a]	1.42[a]	155.51[a]	42.03[a]	39.77[a]
0.25	22[a]	28.77[a]	4.30[a]	1.57[a]	0.17[a]	453.02[a]	90.75[a]	2928[a]	1.44[a]	6.99[a]	1.15[a]	176.86[a]	45.07[a]	37.60[a]
0.50	20.55[a]	27.04[a]	2.94[a]	1.37[a]	0.15[a]	377.98[a]	79.65[a]	2590[a]	1.34[a]	7.01[a]	1.17[a]	170.62[a]	42.53[a]	38.93[a]
1	22.64[a]	30[a]	2.38[a]	1.37[a]	0.17[a]	397.15[a]	78.79[a]	2855[a]	1.26[a]	5.80[a]	1.12[a]	162.94[a]	41.87[a]	34.23[a]
2	22.31[a]	29.33[a]	4.34[a]	1.75[a]	0.19[a]	538.03[a]	98.14[a]	3922[a]	1.42[a]	7.41[a]	1.28[a]	194.82[a]	45.30[a]	39.12[a]
Coefficient of variation (CV)	8.26	9.87	32.13	19.03	24.60	37.35	37.21	34.21	40.20	22.14	20.56	21.49	15.45	16.11

Means of boron concentration with the same letter within the same column are not significantly different at P = 0.05 (Tukey's HSD test)
PH1 = plant height 1 (first measurement at 1.5 month); PH2 = plant height 2 (second measurement at 3 months);
P_N = net photosynthetic rate; RFW = root fresh weight; RDW = root dry weight; TRL = total root length; RSA = root surface area;
RT = root tip; RV = root volume; SFW = shoot fresh weight; SDW = shoot dry weight; TLA = total leaf area;
SPAD Chl2 = SPAD Chlorophyll value 1 (first reading at 1.5 month); SPAD Chl2 = SPAD Chlorophyll value 2 (second reading at 3 months).

TABLE 2
Ranking of boron concentration with respect to growth parameters

B concentration	Growth parameters													
	PH1	PH2	P_N	RFW	RDW	TRL	RSA	RT	RV	SFW	SDW	TLA	SPAD Chl1	SPAD Chl2
mg/L	—— cm ——		$\mu molCO_2m^{-2}s^{-1}$	—— g ——		cm	cm^2		cm^3	—— g ——		cm^2		
0	22.22[a]	29.05[a]	4.15[a]	1.71[a]	0.20[a]	350.87[a]	68.34[a]	2723[a]	1.07[a]	8.14[a]	1.42[a]	155.51[a]	42.03[a]	39.77[a]
0.25	22[a]	28.77[a]	4.30[a]	1.57[a]	0.17[a]	453.02[a]	90.75[a]	2928[a]	1.44[a]	6.99[a]	1.15[a]	176.86[a]	45.07[a]	37.60[a]
0.50	20.55[a]	27.04[a]	2.94[a]	1.37[a]	0.15[a]	377.98[a]	79.65[a]	2590[a]	1.34[a]	7.01[a]	1.17[a]	170.62[a]	42.53[a]	38.93[a]
1	22.64[a]	30[a]	2.38[a]	1.37[a]	0.17[a]	397.15[a]	78.79[a]	2855[a]	1.26[a]	5.80[a]	1.12[a]	162.94[a]	41.87[a]	34.23[a]

TABLE 2 (*continue*)

2	22.31 [a]	29.33 [a]	4.34 [a]	1.75 [a]	0.19 [a]	538.03 [a]	98.14 [a]	3922 [a]	1.42 [a]	7.41 [a]	1.28 [a]	194.82 [a]	45.30 [a]	39.12 [a]
Coefficient of variation (CV)	8.26	9.87	32.13	19.03	24.60	37.35	37.21	34.21	40.20	22.14	20.56	21.49	15.45	16.11

PH1 = plant height 1 (first measurement at 1.5 month); PH2 = plant height 2 (second measurement at 3 months);
P_N = net photosynthetic rate; RFW = root fresh weight; RDW = root dry weight; TRL = total root length; RSA = root surface area;
RT = root tip; RV = root volume; SFW = shoot fresh weight; SDW = shoot dry weight; TLA = total leaf area;
SPAD Chl2 = SPAD Chlorophyll value 1 (first reading at 1.5 month); SPAD Chl2 = SPAD Chlorophyll value 2 (second reading at 3 months).
Note the position of 2 mg B/L in the ranking (either first or second).

TABLE 3
Effects of manganese concentrations on morphological and physiological growth parameters of oil palm seedlings

Mn concentration	Growth parameters													
	PH1	PH2	P_N	RFW	RDW	TRL	RSA	RT	RV	SFW	SDW	TLA	SPAD Chl1	SPAD Chl2
mg/L	—— cm ——		$\mu molCO_2m^{-2}s^{-1}$	—— g ——		cm	cm^2		cm^3	—— g ——		cm^2		
0	24.50^{a}	29.16^{a}	5.28^{a}	2.01^{a}	0.24^{a}	577.82^{a}	113.13^{a}	4260^{a}	1.76^{a}	8.94^{a}	1.61^{a}	214.66^{a}	54.43^{a}	53.83^{a}
5	20.83^{a}	26.46^{ab}	3.11^{a}	1.62^{ab}	0.18^{a}	413.52^{ab}	77.08^{ab}	3102^{a}	1.14^{ab}	6.90^{ab}	1.10^{ab}	171.06^{ab}	29.77^{b}	39.03^{bc}
10	19.66^{ab}	26.05^{ab}	3.72^{a}	1.25^{ab}	0.16^{a}	316.28^{ab}	56.89^{b}	2507^{a}	0.81^{b}	6.31^{ab}	1.07^{ab}	140.21^{bc}	37.07^{b}	43.80^{b}
15	20.22^{ab}	25.55^{ab}	5.99^{a}	1.46^{ab}	0.17^{a}	365.03^{ab}	76.99^{ab}	2541^{a}	1.29^{ab}	6.58^{ab}	1.07^{ab}	144.97^{bc}	37^{b}	38.63^{bc}
20	15.94^{b}	19.22^{b}	1.69^{a}	1.07^{b}	0.12^{a}	254.97^{b}	50.21^{b}	1984^{a}	0.79^{b}	4.30^{b}	0.65^{b}	92.33^{c}	29.43^{b}	31.47^{c}
Coefficient of Variation (CV)	8.93	11.57	52.46	22.25	26.58	26.72	22.57	43.03	20.38	25.05	32.07	15.15	15.64	13.13

Means of boron concentration with the same letter within the same column are not significantly different at P = 0.05 (Tukey's HSD test)
PH1 = plant height 1 (first measurement at 1.5 month); PH2 = plant height 2 (second measurement at 3 months);
P_N = net photosynthetic rate; RFW = root fresh weight; RDW = root dry weight; TRL = total root length; RSA = root surface area;
RT = root tip; RV = root volume; SFW = shoot fresh weight; SDW = shoot dry weight; TLA = total leaf area;
SPAD Chl2 = SPAD Chlorophyll value 1 (first reading at 1.5 month); SPAD Chl2 = SPAD Chlorophyll value 2 (second reading at 3 months).

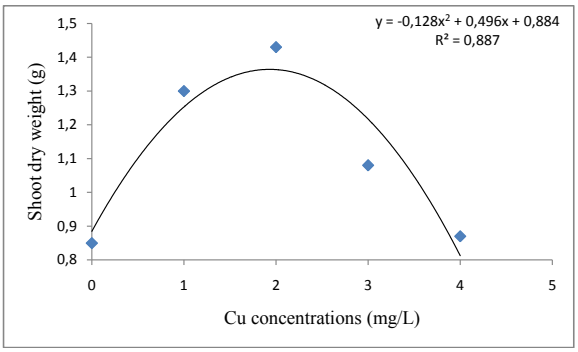

Fig.1: Effect of different concentrations of copper on shoot dry weight of oil palm seedlings at 3 months

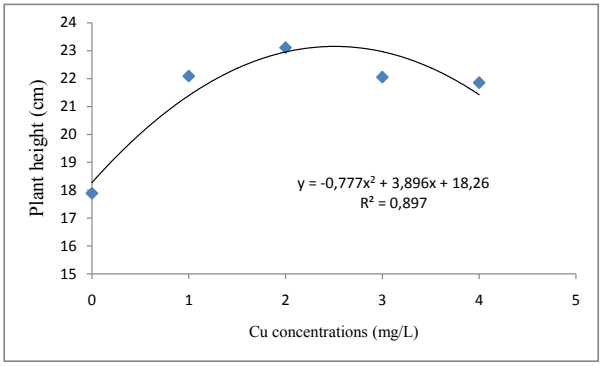

Fig.2: Effect of different concentrations of copper on the height of oil palm seedlings at 1.5 months

concentrations for a given parameter, such as PN, RDW and RT (Table 3), 0 mg Mn/L still gave the highest values.

The improving effect of 0 mg Mn/L and the suppressive effect of other concentrations, especially 20 mg Mn/L were more striking and more discernible on plant height (Fig.4) and shoot fresh weight (Fig.5).

These results suggest that the nutrient reserves in the endosperm of the oil palm kernel might be enough to sustain the adequate growth of the seedlings during the pre-nursery stage and probably for the early nursery stage or until their complete exhaustion. The nutrient analysis of oil palm kernel (Table 4) revealed 82 mg Mn/kg of dry matter indicating that Mn supply might not be necessary in the early stages of oil palm seedlings.

About 4.5 kg Mn is reported to be accumulated in mature oil palms per ha per year (Ng *et al*., 1968), while fresh fruit bunches (FFB) remove only 0.4 – 0.5 kg per ha (Fairhurst & Härdter, 2003). The high level of Mn reserves in kernel, the high accumulation of Mn in mature oil palms compared to low need for FFB production could explain why the requirement of Mn fertiliser application is very rare in oil palm cultivation, except in case of remarkable Mn deficiency.

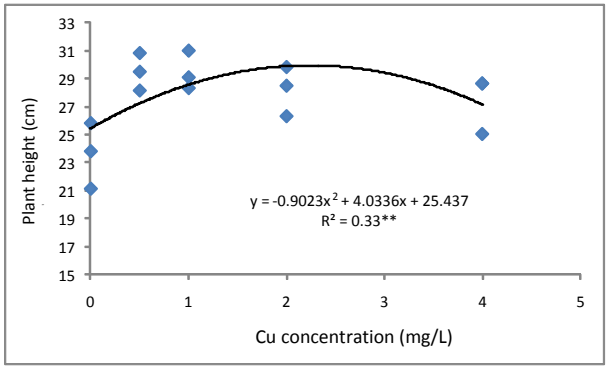

Fig.3: Effect of copper in different concentrations of copper on the height of oil palm seedlings at 3 months

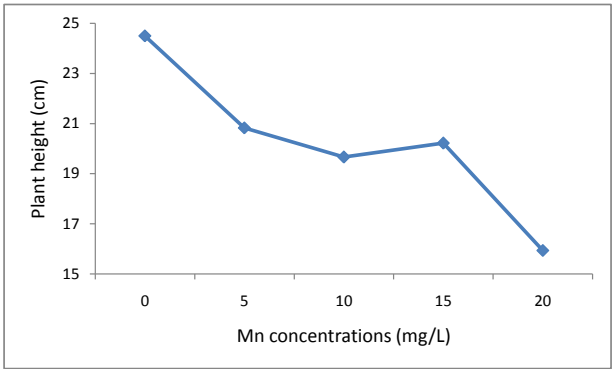

Fig.4: Effect of different concentrations of manganese on the height of oil palm seedlings at 1.5 months

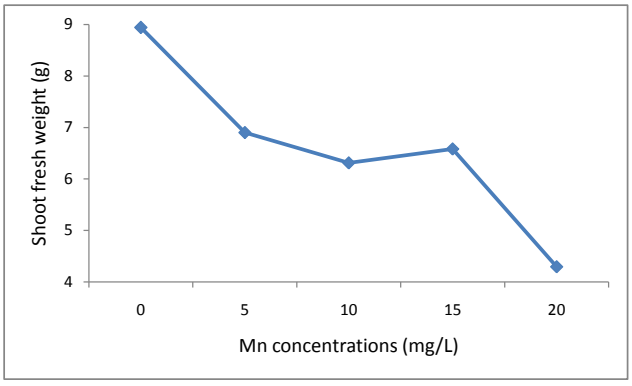

Fig.5: Effect of different concentrations of manganese on shoot fresh weight of oil palm seedlings at 3 months

Effects of Boron, Copper and Manganese on Total Dry Weight

As observed for the previous parameters, no significant differences ($P \geq 0.05$) were detected among B concentrations for total dry biomass (Table 5). Unexpectedly, the control gave the highest total dry weight, followed by 2 mg B/L. Once again the consistent conservation of 2 mg B/L at the first or second position supported the choice of this concentration as optimum for B.

Highly significant differences ($P \leq 0.01$) were found among Cu concentrations for total dry weight with 0.50 mg Cu/L surprisingly giving the highest value, followed by 2 mg Cu/L (Table 5). Lowest values were recorded at 0 mg Cu/L and 4 mg Cu/L with no statistical difference.

For Mn, as the concentration increased, the total dry weight decreased, indicating a negative correlation between Mn concentration and total dry biomass (Table 5). Once more, 0 mg Mn/L (control) gave the highest total dry weight and 20 mg Mn/L the lowest, confirming the overall suppressive effect of Mn on the growth of oil palm seedlings, with 20 mg Mn/L being more detrimental.

Nutrient Analysis: Effects of Boron, Copper and Manganese on their Concentrations in Roots and Shoots

With the exception of Mn, it could be noticed that a high concentration of each element in nutrient solution led to a high concentration of the said element in roots and shoots (Table 6). As found by Abidemi *et al*. (2006) for phosphorus, a high correlation may exist between B and Cu levels and B and Cu uptake in plants.

TABLE 4
Nutrient composition of oil palm kernel

	Element									
	Macroelements					Microelements				
	N	P	K	Mg	Ca	B	Cu	Fe	**Mn**	Zn
Concentration	g/kg					mg/kg				
	17.45	7.54	6.13	2.18	2.40	89	22	64	**82**	31

TABLE 5
Effects of boron, copper and manganese on biomass dry weight

B concentration	TDW	Cu concentration	TDW	Mn concentration	TDW
mg/L	g	mg/L	g	mg/L	g
0	1.62[a]	0	0.99[c]	0	1.85[a]
0.25	1.31[a]	0.5	1.63[a]	5	1.28[ab]
0.5	1.32[a]	1	1.24[bc]	10	1.23[ab]
1	1.29[a]	2	1.48[ab]	15	1.23[ab]
2	1.48[a]	4	1.01[c]	20	0.77[b]

Means of concentrations with the same letter within the same column are not significantly different at P = 0.05 (Least significant difference (LSD) test). TDW = Total dry weight.

TABLE 6
Effects of boron, copper and manganese on their concentrations in roots and shoots

B concentration	Root B	Shoot B	Cu concentration	Root Cu	Shoot Cu	Mn concentration	Root Mn	Shoot Mn
mg/L	——mg/kg——		mg/L	——mg/kg——		mg/L	——mg/kg——	
0	74.89^{a}	44.15^{b}	0	72^{b}	25.67^{a}	0	475^{a}	283.30^{b}
0.25	74.80^{a}	46.50^{b}	0.5	70.33^{b}	34.53^{ab}	5	1073.30^{a}	1038.70^{a}
0.5	73.14^{a}	49.13^{b}	1	63.17^{b}	28.38^{ab}	10	1128.30^{a}	975.30^{a}
1	76.91^{a}	62.42^{a}	2	99.17^{ab}	37.27^{ab}	15	1595^{a}	977.50^{a}
2	81.24^{a}	70.87^{a}	4	128.33^{a}	46.33^{a}	20	875^{a}	713.30^{a}
Coefficient of Variation (CV)	9.54	9.70		26.17	29.31		65.78	23.81

Means of concentrations with the same letter within the same column are not significantly different at P = 0.05 (Least significant difference (LSD) test)

However, the general pattern is not linear apart from B content in shoots which proportionally increased with the increase of B in the nutrient solution. The non-linearity could be due to multiple interactions that naturally exist between microelements themselves and between micro and macro elements. The different pattern observed particularly for Mn can be explained by the variation of Mn content in the oil palm kernel that might have interfered with Mn in solution. It is worth noting that the nutrient levels in roots and shoots are by far above the plant reference (Benton Jones, 2003) and oil palm reference (Ng *et al*., 1968) (Table 7), but no sign of toxicity was observed. This may suggest that oil palm at the earlier and active growing stage has the ability to accumulate high levels of nutrients. To date, no nutrient reference for oil palm seedlings has been established, probably because of the short period of pre-nursery and nursery, four and eight months, respectively.

CONCLUSION

The concentration of both B and Cu at 2 mg/L nutrient solution has been identified to be optimum for the growth of oil palm seedlings. The superior effect of 0 mg Mn/L (control) over other Mn concentrations is an indication that Mn might not be needed at the pre-nursery stage.

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TABLE 7
Nutrient reference concentrations in plant and oil palm

Elements		Plant reference (a)	Young palms (b)	Mature palms (b)
1- Macro nutrients (g/kg)	N	10 – 60	14	4.4 – 6.5
	P	2 – 5	1.4	0.52
	K	15 – 40	10 – 13	
	Mg	1.5 – 4	2.2	1.6
	Ca	5 – 15	1.4	2.5
	S	1.5 – 5	1.7 – 3.6	
	Cl	50 – 200	0.4 – 6	
2- Micronutrients (mg/kg)	**B**	**20**	**7.0 – 8.5 in above-ground biomass of oil palm. Optimum in frond 17: 15 – 25**	
	Cu	**2 – 20**	**7 – 10 in above-ground biomass of oil palm. Optimum in frond 17: 5 - 8**	
	Mn	**10 – 200 (10 – 50 acceptable)**	**64 – 166 in above-ground biomass of oil palm. Optimum in frond 17: 50 - 200**	
	Fe	150	107 – 221 in above-ground biomass of oil palm. Optimum in frond 17: 50 - 250	
	Zn	15 – 50	18 – 31 in above-ground biomass of oil palm	
	Mo	0.15 – 0.30	Optimum: 0.5 – 0.8 in leaf Deficiency when < 0.1	

a: Benton Jones, 2003; b: Ng *et al*., 1968

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