

EFFECTS OF AMELIORANT Cu²⁺, Fe³⁺, AND Zn²⁺ AND PALM OIL FROND COMPOST APPLICATIONS ON THE GROWTH AND PRODUCTION OF MUNG BEAN (*VIGNA RADIATA* (L.) R. WILCZEK) GROWN ON PEAT SOIL IN RIAU

SITI, Z.

Department of Agriculture, Faculty of Agriculture, Universitas Islam Riau, Jl. Kaharuddin Nasution, Marpoyan, Pekanbaru, Riau 28284, Indonesia
(e-mail: sitizahrah@agr.uir.ac.id; phone: +62-813-7104-6440)

(Received 22nd Jan 2020; accepted 25th May 2020)

Abstract. Low production of all crops cultivated due to the poor physical and chemical properties of such soil, including acid reaction; high organic acid content, which is toxic for crops; low macronutrient and micronutrient content. The use of the ameliorants Cu²⁺, Fe³⁺, and Zn²⁺ together with Palm Oil Frond (POF) compost can improve peat soil with a low impact on the environment. This research aimed to examine the effects of the ameliorants Cu²⁺, Fe³⁺, and Zn²⁺ and POF compost applications on the growth of mung bean. The first factor was the ameliorant application with four levels (without ameliorant Cu²⁺, Fe³⁺, and Zn²⁺). The second factor was the POF compost doses with four levels (0, 12, 24, and 36 g per plant). Results showed that the interaction of ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺ and POF compost applications significantly affect the percentage of fully filled pods, seed dry weight, and root volume of mung bean. The best treatment was achieved with the application of ameliorant Cu²⁺ and 24 g plant⁻¹ POF compost, which resulted in 26.67 g plant⁻¹ seed dry weight, 94.7% fully filled pods, and 27.4 cm³ root volume, comprising increased percentages of 175.5%, 32.8%, and 109.2%, respectively, compared to no treatment.

Keywords: *marginal land, organic acid, polyvalent cation, chelating, RGR, SFR, ESFP*

Introduction

Mung bean (*Vigna radiata* (L.) R. Wilczek) is a leguminous crop that grows well in tropical regions and has high nutritional value. Currently, the demand for mung bean in Indonesia increases each year, yet its production tends to decrease every year. Mung bean production decreased from 1739 tons in 2007 to 598 tons in 2015 (Bureau, 2016). This decreased production is caused by low land productivity with non-optimal soil and crop management. Agricultural land in Riau mostly consists of marginal land with low productivity, including dry and wet land. From this land area, peat soil reaches 3.87 million hectares or 59.94% from the total peat soil in Sumatera and 25.96% from the total peat soil in Indonesia (IAARD, 2011).

Peat soil for agriculture in Indonesia is used for both plantation and food crops. The development of peat land for agriculture increases continuously owing to the decreasing dry land area, which is a result of land conversion for other purposes, while the land requirement for food production persistently increases (Darmawan et al., 2015; Nurulita et al., 2016). Although dry land extensification can be conducted, the agricultural extensification of peat land is being further explored by policy makers and researchers because peat land area is sufficiently wide in Indonesia (Jaenicke et al., 2008; Siti et al., 2013). The average production of almost all crops cultivated on peat soil, including mung bean, remains low. This condition is due to peat soil having poor physical and chemical properties, such as acid reaction; high organic acid content, which is toxic for crops; and low macronutrient and micronutrient content (Troeh and Thompson, 2005; Lampela et al., 2014). The management and sustainability associated with the chemical and physical

aspects of peat soil must be performed correctly to increase peat soil productivity (Hooijer et al., 2012; Comte et al., 2013; Hoyos et al., 2015; Könönen et al., 2015).

Nutrient uptake (anion) of plant on peat soil is very low because peat soil has high negative charge. Thus, the adsorption and anion exchange capacity of peat soil is low, leading to low availability and nutrient uptake (Stevenson, 1994). Adding cations, such as Cu²⁺, Fe³⁺, and Zn²⁺, into peat soil is expected to increase anion exchange capacity and the availability and nutrient uptake of crops. The outcome is especially apparent in anions where the cations Cu²⁺, Fe³⁺, and Zn²⁺ function as metals bridging organic acid and NO₃⁻ or H₂PO₄⁻ in the chelating formation of peat soil. Complex compound formation between organic acid molecules and metal ions that form more than one bond will increase the stability of complex compounds (Abat et al., 2012).

The bond phenomenon between metal ion and organic acid enables the use of several cations in controlling the reactivity of phenolic acids so that they do not poison and endanger crops (Orlov, 1995; Shanmugam et al., 2018). The application of polyvalent cation on peat soil in Indonesia (Kalimantan and South Sumatera) can reduce the content and reactivity of phenolate acid and increase crop production (Hartatik and Nugroho, 2001; Brachia, 2006). In the current study, the application of polyvalent cations, such as Cu²⁺, Fe³⁺, and Zn²⁺, as ameliorant is expected to reduce toxic organic acids, including phenolic acids and carboxylic acids, through the formation of an organo-cation complex (Gyliene and Šalkauskas, 2001; Tan, 2010). Thus, the toxic properties of these acids will be reduced to improve the crop growth and development of mung bean. Peat soil also contains very low amounts of micronutrients, such as Cu²⁺, Fe³⁺, and Zn²⁺, which are strongly chelated with organic matter and are thus not available to crops (Abat et al., 2012; de A. Melo et al., 2014). The cations Cu²⁺, Fe³⁺, and Zn²⁺ act as ameliorant materials and are a source of nutrients for crops (Jones, 2012; Sullivan et al., 2013).

Besides applying an ameliorant material, an additional organic matter, such as compost, is required for the use of peat soil for crop cultivation. The application of Palm Oil Frond (POF) compost is expected to activate microorganisms in peat soil. The organic material is an energy source for soil microorganisms that can increase microorganism activity in the decomposition of organic materials to stabilize peat soil (Fan et al., 2007; Onwonga et al., 2010). Furthermore, the POF compost contains the macronutrients N (0.75%), P (0.47%), and K (0.80%) (Eviati, 2011). Thus, it can enrich the nutrients N, P, and K of peat soil to support the growth of mung bean. The article aimed to investigate the effects of ameliorant Cu²⁺, Fe³⁺, and Zn²⁺ applied with palm oil frond compost on the yield and growth of mung bean, grown on peat soil in Riau, Indonesia.

Material and Methods

This research was conducted at the experimental farm of the Faculty of Agriculture, Universitas Islam Riau, Pekanbaru, Indonesia for four months, from November 2018 to February 2019.

Experimental design

The experimental design used was a factorial 4×4 in a completely randomized design with three replications. The first factor was the ameliorant treatment application with four levels (without ameliorant, Cu²⁺, Fe³⁺, and Zn²⁺). The second factor was the dose of POF compost with four levels (0, 12, 24, and 36 g per plant). This experiment consisted of 48 experimental units, with each experimental unit consisting of 8 plants (8 pots). The

observational data were analyzed using analysis of variance and the honestly significant difference (HSD) test at 5% probability level ($P = 0.05$) (Stell and Torrie, 1980).

Variety and soil sampling

The mung bean variety used in this experiment was Vima 1. The peat soil sample originated from Pekanbaru, Riau, and was collected at a depth of 10–40 cm with the sapric decomposition level. Each pot was filled with 8 kg of peat soil (300% soil water content) or equivalent to 2 kg of absolute dry weight.

Treatment application and fertilization

The ameliorants Cu²⁺, Fe³⁺, and Zn²⁺ (5% maximum sorption) were applied in the form of CuSO₄, FeCl₃, and ZnSO₄, respectively. They were then mixed and stirred with soil three weeks before planting. POF compost was applied and stirred evenly in accordance with the treatment 1 week before planting. N fertilizer (urea 50 kg ha⁻¹), triple super phosphate (TSP) (150 kg ha⁻¹), KCl (100 kg ha⁻¹), and lime CaMg(CO₃)₂ were also applied a week before planting (1-ton ha⁻¹).

Observation parameters

The observed parameters in this study were relative growth rate (RGR), seed filling rate (SFR), effective seed filling period (ESFP), percentage of fully filled pods, seed dry weight, and root volume.

The study was conducted at the experimental farm of the Universitas Islam Riau, Riau Province, Indonesia. The experiment involved a completely randomized factorial design with three replications, *Figure 1* shows the location of experiment conducted.



Figure 1. Location of experiment in Pekanbaru city, Riau Province, Indonesia

Results and Discussion

RGR

From the observation of RGR (*Table 1*), the application of ameliorant materials and POF compost produce higher RGR than without both ameliorant and POF compost. This result is due to the improved plant growth response with the application of ameliorant

materials and POF compost. The POF compost contains plant nutrients and a source of energy for soil microorganism for survival and activity in the soil. Hence, microorganism activities in agricultural soils profoundly influence plant nutrient availability and OM transformation (Onwonga et al., 2010). In addition, the application of organic and inorganic ameliorants into the soil can improve soil conditions and enhance plant growth (Okwuagwu et al., 2003; Rudrappa et al., 2006).

Table 1. Relative growth rate of mung bean with ameliorant materials and POF compost treatments (g day⁻¹)

Days	Ameliorant materials	POF compost (g plant ⁻¹)				\bar{X}
		0	12	24	36	
14-21	Without ameliorant	0.106a	0.121a	0.175a	0.152a	0.139c
	Cu ²⁺	0.153a	0.189a	0.241a	0.226a	0.202a
	Fe ³⁺	0.135a	0.170a	0.219a	0.195a	0.180b
	Zn ²⁺	0.137a	0.163a	0.208a	0.184a	0.173b
	\bar{X}	0.133d	0.161c	0.211a	0.189b	
28-35	Without ameliorant	0.342a	0.372a	0.429a	0.394a	0.384d
	Cu ²⁺	0.423a	0.453a	0.504a	0.476a	0.464a
	Fe ³⁺	0.403a	0.435a	0.485a	0.460a	0.446b
	Zn ²⁺	0.396a	0.417a	0.472a	0.449a	0.433c
	\bar{X}	0.391d	0.419c	0.473a	0.445b	

The number in rows and columns followed by the same small letter show no significant difference (HSD test, at $P = 0.05$)

Table 1 also shows that the highest RGR was at the age of 14–21 and 28–35 days in the treatment of ameliorant Cu²⁺ for 0.202 and 0.464 g day⁻¹, respectively. The lowest RGR was found without ameliorant treatment at 0.139 and 0.384 g day⁻¹. Furthermore, in the main effect of POF compost application alone, the highest RGR was at the age of 14–21 and 28–35 days during the addition of as much as 24 g plant⁻¹ POF compost for 0.211 and 0.473 g day⁻¹, respectively. The lowest RGR was found without compost treatment at 0.133 and 0.391 g day⁻¹. The RGR of plants increased due to an increase in plant growth and photosynthesis process. The increased photosynthetic process increases plant biomass (Jumin et al., 2014).

The increased RGR is hypothesized to be caused by an increase of plant nutrient uptake by ameliorant addition. Zahrah (2010) found that the application of an ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺) on peat soil for several varieties of rice can increase the uptake of N, P, and K and seed dry weight. Maftu'ah et al. (2013) also reported that the application of ameliorant on peat soil increases the growth and nutrient uptake of N, P, and K on sweet corn.

Seed filling rate

The observation result of SFR of mung bean is summarized in Table 2. The data from Table 2 indicate that the interaction of ameliorant materials and POF compost treatments did not significantly affect the SFR of mung bean (analysis of variance). However, the main effect of each treatment factor was significant. The SFR results (Table 2) show that

all treatments with the addition of an ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺) and various doses of POF compost into the peat soil produced higher SFR than without both ameliorant addition (Cu²⁺, Fe³⁺, and Zn²⁺) and POF compost. The highest SFR was obtained from additional treatment with the ameliorant Cu²⁺ (0.060 g seed⁻¹day⁻¹) and the addition of as much as 24 g plant⁻¹ (0.061 g seed⁻¹day⁻¹) POF compost. The increased SFR generated by the addition of ameliorant materials was due to the improved plant growth as reflected by the growth of RGR owing to the addition of ameliorant materials and POF compost into the peat soil (Table 1). Thus, the accumulation of dry plant materials (biomass) also increased. Jones (2012) stated that the results of plant biomass and seed development are determined by the rate of plant growth.

Table 2. Seed filling rate of mung bean seed with ameliorant materials and POF compost treatments (g seed⁻¹day⁻¹)

Ameliorant Materials	POF compost (g plant ⁻¹)				\bar{X}
	0	12	24	36	
Without Ameliorant	0.038a	0.044a	0.051a	0.047a	0.045c
Cu ²⁺	0.053a	0.055a	0.070a	0.061a	0.060a
Fe ³⁺	0.050a	0.054a	0.063a	0.058a	0.056a
Zn ²⁺	0.049a	0.053a	0.059a	0.055a	0.054b
\bar{X}	0.047c	0.052b	0.061a	0.055b	

The number in rows and columns followed by the same small letter show no significant difference (HSD test, at $P = 0.05$)

Peat soil management with an additional appropriate ameliorant type and proper dosage improves chemical properties and soil microbiology activity to support plant growth (Bragazza et al., 2007). Therefore, a good ameliorant is one that can improve peat soil conditions, increase crop production, preserve peat soil, and reduce negative impacts on the environment (Husen and Agus, 2011; Agus et al., 2012).

Effective seed filling period

The ESFP of mung bean is presented in Table 3.

Table 3. Effective seed filling period of mung bean with ameliorant materials and POF compost treatments (day)

Ameliorant Materials	POF compost (g plant ⁻¹)				\bar{X}
	0	12	24	36	
Without Ameliorant	33.33a	35.89a	34.60a	36.11a	34.98c
Cu ²⁺	30.00a	31.27a	28.32a	30.47a	30.02a
Fe ³⁺	31.19a	33.64a	32.67a	33.24a	32.68b
Zn ²⁺	29.44a	29.85a	33.85a	30.76a	30.98b
\bar{X}	30.99	32.66	32.65	32.65	

The number in rows and columns followed by the same small letter show no significant difference (HSD test, at $P = 0.05$)

Table 3 illustrates that the effect of the interaction of ameliorant materials and POF compost treatments was not significant (analysis of variance). However, the main effect of ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺) application alone was significant on the ESFP of mung bean. The application of the ameliorant Cu²⁺ caused a shorter ESFP than the addition of the ameliorants Fe³⁺ and Zn²⁺ at 30.02 days. ESFP describes the time required by seeds to evolve perfectly and reach maximum dry weight (Salisbury and Ros, 1996). Therefore, the higher the SFR is, the shorter the ESFP will be. These results indicate that the highest SFR, namely, 0.070 g seed⁻¹day⁻¹, was obtained from the treatment combination of additional ameliorant Cu²⁺ and as much as 24 g plant⁻¹ (Table 2) POF compost with the fastest ESFP, namely, 28.32 days. The longest was 33.33 days without ameliorant and without POF compost (Table 3).

Percentage of fully filled pods

The percentage of fully filled pods of mung bean is shown in Table 4.

Table 4. Percentage of fully filled pods of mung bean with ameliorant materials and POF compost treatments (%)

Ameliorant materials	POF compost (g plant ⁻¹)				\bar{X}
	0	12	24	36	
Without ameliorant	71.3d	82.7c	84.5c	83.4c	80.48c
Cu ²⁺	85.9bc	86.6c	94.7a	89.1b	89.08a
Fe ³⁺	83.7c	83.7c	85.6bc	85.0bc	84.70b
Zn ²⁺	83.4c	83.5c	85.6bc	84.2c	84.17b
\bar{X}	81.08c	84.13b	87.75a	85.43b	

The number in rows and columns followed by the same small letter show no significant difference (HSD test, at $P = 0.05$)

Table 4 shows that the addition of ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺) and POF compost on peat soil produced a higher percentage of fully filled pods than without both ameliorant and POF compost. The highest percentage (94.7%) of fully filled pods was derived from the highest treatment with the application of ameliorant Cu²⁺ and as much as 24 g plant⁻¹ POF compost, and it was significantly different from the other treatment combinations.

These results revealed that Cu²⁺ cations had a better ability to neutralize the adverse effects of organic acids on mung bean growth compared with Fe³⁺ and Zn²⁺. Toxic organic acids in plants are neutralized through the occurrence of chelating the positive charge of metal cations with organic acids, which has a negative charge (Gyliene and Šalkauskas, 2001; Tan, 2010).

The results of the high fully filled pods were also associated with improved SFR and ESFP results with such treatment combination. The pods will be fully filled if the translocation of photosynthesis results in seeds that run smoothly and are effective. In addition, as a chelating agent of peat organic acids, Cu is a micronutrient that should be added to peat soil to achieve good growth and increase crop production. The use of tropical peat enriched with micronutrients can contribute to improving agricultural productivity because micronutrients can effectively stimulate plant growth²⁰. As a micronutrient, Cu acts as an enzyme activator, regulating carbohydrate and protein metabolism and chlorophyll formation (Jones, 2012; Sullivan et al., 2013).

Seed dry weight

The observation result of the seed dry weight of mung bean after analysis of variance showed that the interaction effect of ameliorant materials and POF compost treatments was significant on the seed dry weight. This result indicates that the seed dry weight of mung bean as a result of applying several doses of POF compost was not the same for different ameliorants (Cu²⁺, Fe³⁺, and Zn²⁺). The result of the seed dry weight of mung bean is presented in *Table 5*.

Table 5. Seed dry weight of mung bean with ameliorant materials and POF compost treatments (g plant⁻¹)

Ameliorant materials	POF compost (g plant ⁻¹)				\bar{X}
	0	12	24	36	
Without ameliorant	9.67j	19.00fghi	21.33de	20.33efg	17.58c
Cu ²⁺	19.67efgh	22.33cd	26.67a	24.33bc	23.25a
Fe ³⁺	18.00hij	19.67efgh	24.67ab	21.33de	20.92b
Zn ²⁺	17.33ij	18.67ghij	23.67bc	21.00ef	20.17b
\bar{X}	20.64d	19.92c	24.08a	21.75b	

The number in rows and columns followed by the same small letter show no significantly different (HSD test, at $P = 0.05$)

Table 5 shows that the addition of ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺) and POF compost into peat soil produced the higher dry weight of seed than without both ameliorant and POF compost. An increase in seed dry weight of mung bean with the application of ameliorant materials (Cu²⁺, Fe³⁺, and Zn²⁺) and POF compost improved soil conditions than without ameliorant. Thus, the plant roots grew well. Good root development enhances nutrient uptake, growth, and crop production (Rudrappa et al., 2006; Štursová and Baldrian, 2011). Chelation between Cu²⁺, Fe³⁺, and Zn²⁺ and organic acids neutralizes the organic acids of peat so that they do not poison the plant. Phenolic acids are an intermediate compound in humus formation. At a certain concentration, this compound is toxic and will inhibit plant growth and reduce crop production (Orlov, 1995). The results of the highest dry weight of mung bean with the addition of Cu²⁺ ameliorant and as much as 24 g plant⁻¹ POF compost were also related to SFR and the highest percentage of fully filled pods with such treatment (*Table 2* and *Table 4*).

Table 5 shows that the highest dry weight of the seeds was obtained from the addition of the ameliorant Cu²⁺ and as much as 24 g plant⁻¹ POF compost treatments, namely, 26.67 g plant⁻¹. The lowest dry weight without ameliorant and without POF compost treatments was 9.67 g plant⁻¹. This result indicates that the Cu²⁺ cation was more effective in chelating with the organic acids of peat compared with the cations Fe³⁺ and Zn²⁺. It can effectively suppress the adverse effects of organic acids of peat on growth and crop production. The stability of the chelating bond was Cu > Fe > Co > Ni > Zn = Mn [20]. These results also relate to the role of Cu²⁺ as a cation chelating organic acid of peat soil and a plant micronutrient involved in chlorophyll formation as well as an important coenzyme for activating several plant enzymes (Lampela et al., 2014).

Adding inorganic and organic fertilizers also improves the physical, chemical, and biological conditions of soil and, therefore, increases the production and quality of crops,

including seed quality (Hooijer et al., 2012). The application of inorganic and organic ameliorants can improve soil chemical properties and stabilize peat soil, reducing greenhouse emission and increasing crop production on peat lands (Murdiyarso et al., 2010; Könönen et al., 2015).

The results of regression and correlation analyses of seed dry weight are shown in *Figure 2*.

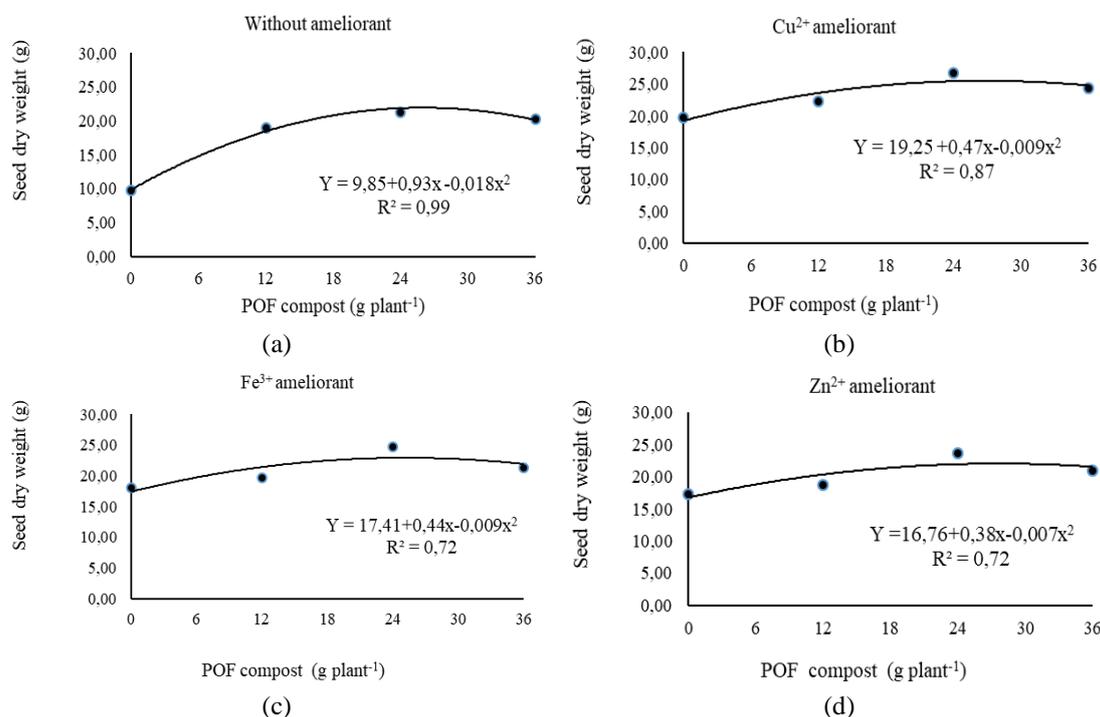


Figure 2. Relationship between dosage of POF compost and the seed dry weight per plant on the various ameliorant materials (a) without ameliorant, (b) with Cu²⁺ ameliorant (c) with Fe³⁺ ameliorant (d) with Zn²⁺ ameliorant

Figure 2 shows that the seed dry weight increase with increasing doses of POF compost from 0 to 24 g plant⁻¹ and decreases with the addition of 36 g plant⁻¹ for all ameliorant materials (Cu²⁺, Fe³⁺, and Zn²⁺).

Root volume

The average of root volume for mung bean is presented in *Table 6*.

The data in *Table 6* show that the highest root volume (27.4 cm³) was obtained from the ameliorant treatment addition of Cu²⁺ and as much as 24 g plant⁻¹ POF compost; it was also significantly different from that obtained from other treatment combinations. The lowest root volume was found without both ameliorant and POF compost treatments. These results relate to the improvement of the root zone (rhizosphere) with the addition of ameliorant materials and POF compost that can increase the growth and development of plant roots, thus increasing root volume. In addition, Cu²⁺ has a role in root respiration. As root respiration increases, the uptake of plant nutrients also increases as a result of improved plant growth (Könönen et al., 2015).

Table 6. Root volume of mung bean with ameliorant materials and compost and POF compost treatments (cm³)

Ameliorant materials	POF compost (g plant ⁻¹)				\bar{X}
	0	12	24	36	
Without ameliorant	13.1f	16.6e	19.3cde	18.9cde	17.0c
Cu ²⁺	19.9cd	21.5bc	27.4a	22.4bc	22.8a
Fe ³⁺	18.7cde	19.8cd	23.2b	21.8bc	20.9b
Zn ²⁺	18.2de	19.3cd	21.8bc	20.1bc	19.9b
\bar{X}	17.5d	19.4c	22.9a	20.8b	

The number in rows and columns followed by the same small letter show no significant difference (HSD test, at $P = 0.05$)

Conclusions

The interaction of ameliorant (Cu²⁺, Fe³⁺, and Zn²⁺) and POF compost applications significantly affected the percentage of fully filled pods, seed dry weight, and root volume of mung bean. The best treatment was found in the application of ameliorant Cu²⁺ and 24 g plant⁻¹ POF compost. The results showed 26.67 g plant⁻¹ seed dry weight, 94.7% fully filled pods, and 27.4 cm³ root volume at increased percentages of 175.5%, 32.8%, and 109.2%, respectively, compared with no treatment. The main effect of the application of ameliorant materials alone was significant on the RGR, SFR, ESFP, percentage of fully filled pods, seed dry weight, and root volume. The best treatment was found on the ameliorant Cu²⁺. The main effect of POF compost application alone was significant on the RGR, SFR, seed dry weight, percentage of fully filled pods, and root volume. The best treatment was achieved in the application of 24 g plant⁻¹ POF compost.

Acknowledgements. Author would like to thank you to Research Institute and Community Services (LPPM), Universitas Islam Riau for funding this project and Mr. Nursamsul Kustiawan for assistance in the research experiment.

REFERENCES

- [1] Abat, M., McLaughlin, M. J., Kirby, J. K., Stacey, S. P. (2012): Adsorption and desorption of copper and zinc in tropical peat soils of Sarawak, Malaysia. – *Geoderma* 176: 58-63.
- [2] Agus, F., Wahyunto, Dariah, A., Runtunuwu, E., Susanti, E., Supriatna, W. (2012): Emission reduction options for peatlands in the Kubu Raya and Pontianak Districts, West Kalimantan, Indonesia. – *Journal of Palm oil Research* 24: 1378-1387.
- [3] Bossio, D. A., Fleck, J. A., Scow, K. M., Fujii, R. (2006): Alteration of soil microbial communities and water quality in restored wetlands. – *Soil Biol Biochem* 38(6): 1223-1233.
- [4] Brachia, F. (2006): Peat: Agroecosystem and Carbon Transformation. – Yogyakarta, Gajah Mada University Press.
- [5] Bragazza, L., Siffi, C., Iacumin, P., Gerdol, R. (2007): Mass loss and nutrient release during litter decay in peatland: The role of microbial adaptability to litter chemistry. – *Soil Biol Biochem* 39(1): 257-267.
- [6] Bureau, S. C. (2016): Mung bean Production in Indonesia. – Jakarta, Institute, C. S.

- [7] Comte, I., Colin, F., Grunberger, O., Follain, S., Whalen, J. K., Caliman, J. P. (2013): Landscape-scale assesment of soil response to long-term organic and mineral fertilizer application in an industrial palm oil plantation, Indonesia. – *Agriculture, Ecosystems and Environment* 169: 58-68.
- [8] Darmawan, B., Siregar, Y. I., Sukendi, Zahrah, S. (2015): Physical and chemical peatsoil properties assesment in Kampar Peninsular Region, Sumatera, Indonesia. – *International Journal of Science and Research (IJSR)* 4: 64-68.
- [9] de A. Melo, C., de Oliveira, L. K., Goveia, D., Fraceto, L. F., Rosa, A. H. (2014): Enrichment of tropical peat with micronutrients for agricultural applications: Evaluation of adsorption and desorption processes. – *J. Braz. Chem. Soc.* 25: 36-49.
- [10] Eviati (2011): Nutrient Content of Palm Oil Frond Compost. – Laboratory of Soil Fertility, Bogor, Bogor Agriculture Institute.
- [11] Fan, T., Xu, M., Zhou, G., Ding, L. (2007): Trends in grain yields and soil organic carbon in a long-term fertilization experiment in The China Loess Plateau. – *Am-Euras. Journal of Agriculture and Environmental Science* 2: 600-610.
- [12] Gyliene, O., Šalkauskas, M. (2001): Sorption of complexed and uncomplexed Cu(II), Ni(II) and Zn(II) ions by peat. – *Chemija* 12: 183-188.
- [13] Hartatik, W., Nugroho, K. (2001): Effect of different ameliorant sources to maize growth in peat soil from Air Sugihan Kiri, South Sumatera. – In: Rieley, J. O., Page, S. E. (eds.) *Peatlands for People: Natural Resource Functions and Sustainable Management*. Jakarta.
- [14] Hooijer, A., Page, S., Jauhiainen, J., Lee, W., Lu, X., Idris, A., Anshari, G. (2012): Subsidence and carbon loss in drained tropical peatlands. – *Biogeosciences* 9: 1053-1071.
- [15] Hoyos, S. J., Lomax, B., Large, D., Turner, B., Boom, A., Lopez, O. (2015): Getting to the root of the problem: Litter decomposition and peat formation in low and neotropical peatlands. – *Biogeochemistry* 126: 115-129.
- [16] Husen, E., Agus, F. (2011): Microbial activities as affected by peat dryness and ameliorant. – *American Journal of Environmental Sciences* 7: 348-353.
- [17] IAARD (2011): *Agricultural Research and Development in Indonesia*. – Jakarta.
- [18] Jaenicke, J., Rieley, J. O., Mott, C., Kimman, P., Siegert, F. (2008): Determination of the amount of carbon stored in Indonesian peatlands. – *Geoderma* 147: 151-158.
- [19] Jones, J. B. (2012): *Plant Nutrition and Soil Fertility Manual* (2nd ed.). – New York, CRC Press.
- [20] Jumin, H. B., Rosneti, H., Agusnimar (2014): Application of crude palm oil liquid sludge sewage on maize (*Zea mays* L.) as re-cycle possibility to fertilizer. – *Journal of Agriculture Technology* 10: 1473-1488.
- [21] Kononen, M., Jauhiainen, J., Laiho, R., Kusin, K., Vasander, H. (2015): Physical and chemical properties of tropical peat under stabilised land uses. – *Mires Peat* 16: 1-13.
- [22] Lampela, M., Jauhiainen, J., Vasander, H. (2014): Surface peat structure and chemistry in a tropical peat swamp forest. – *Plant Soil* 382: 329-347.
- [23] Maftu'ah, E., Maas, A., Syukur, A., Purwanto, B. H. (2013): Effectivity of ameliorant in degraded peatland to increase the growth and NPK uptake on sweet corn (*Zea mays* L. *Varsaccharata*). – *J. Agron Indon* 41(1): 16-23.
- [24] Murdiyarso, D., Hergoualc'h, K., Verchot, L. V. (2010): Opportunities for reducing greenhouse gas emissions in tropical peatlands. – *Proc Natl Acad Sci* 107(46): 19655-19660.
- [25] Nurulita, Y., Adetutu, E. M., Gunawan, H., Zul, D., Ball, A. S. (2016): Restoration of tropical peat soils: The application of soil microbiology for monitoring the success of the restoration process. – *Agriculture, Ecosystems & Environment* 216: 293-303.
- [26] Okwuagwu, M. I., Alleh, M. E., Osemwota, I. O. (2003): The Effects of organic and inorganic manure on soil properties and yield of okra in Nigeria. – *African Crop Science Conference Proceedings* 6: 390-393.

- [27] Onwonga, R. N., Lelei, J. J., Mochoge, B. B. (2010): Mineral nitrogen and microbial biomass dynamics under different acid soil management practices for maize production. – *Journal of Agricultural Science* 2: 16-30.
- [28] Orlov, D. S. (1995): *Humic Substances of Soils and General Theory of Humification*. – USA, Balkema Publ.
- [29] Rudrappa, L., Purakayastha, T. J., Singh, D., Bhadraray, S. (2006): Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustep of Semi-arid Sub-tropical India. – *Soil Till. Res.* 88: 180-192.
- [30] Salisbury, F. B., Ros, C. W. (1996): *Plant Physiology*. – California, Wadsworth Publishing Co. Inc.
- [31] Shanmugam, S., Dalal, R. C., Joosten, H., Raison, R. J., Joo, G. K. (2018): SOC Stock Changes and Greenhouse Gas Emissions Following Tropical Land Use Conversions to Plantation Crops on Mineral Soils, with a Special Focus on Oil Palm and Rubber Plantations. – *MDPI Agriculture* 8: 133.
- [32] Siti, N., Agus, F., Syahbuddin, H. (2013): Ameliorant application on variation of carbon stock and ash content on peatland South Kalimantan. – *J. Trop. Soils* 18: 11-16.
- [33] Stell, R. G. D., Torrie, J. H. (1980): *Principles and Procedures of Statistics: A Biometrical Approach*. – McGraw-Hill Inc, New York.
- [34] Stevenson, F. J. (1994): *Humus Chemistry, Genesis, Composition, Reactions*. – New York, John Wiley & Sons Inc.
- [35] Štursova, M., Baldrian, P. (2011): Effects of soil properties and management on the activity of soil organic matter transforming enzymes and the quantification of soil-bound and free activity. – *Plant Soil* 338: 99-110.
- [36] Sullivan, T. S., McBride, M. B., Thies, J. E. (2013): Soil bacterial and archaeal community composition reflects high spatial heterogeneity of pH, bio available Zn, and Cu in a metalliferous peat soil. – *Soil Biology & Biochemistry* 66: 102-109.
- [37] Tan, K. H. (2010): *Principles of Soil Chemistry*. – Fourth Edition, New York, CRC Press, Taylor and Francis Group.
- [38] Troeh, F. R., Thompson, L. M. (2005): *Soils and Soil Fertility*. – New York, Blackwell Publishing.
- [39] Zahrah, S. (2010): The uptake of N, P, K and yield rice of various varieties with application of Cu, Zn, Fe ameliorants on peat soil. – *Journal Natur Indonesia* 12: 102-108.