Borneo Journal of Resource Science and Technology (2023), 13(1): 132-141
DOI: https:doi.org/10.33736/bjrst.5271.2023

Bacillus Composted Paddy Husk as a Plant Nutrient Source to Promote Vegetative Growth and Nutrient Uptake in Maize

CARLINA FREDDIE SIMOL[1], JOHN KEEN CHUBO[2*], KHALID NAWI[1] & IRA CARLBRENIE SIMOL[3]

[1]Putra Agriculture Centre, Universiti Putra Malaysia Bintulu Sarawak Campus, 97008 Bintulu, Sarawak, Malaysia; [2] Faculty of Agricultural and Forestry Sciences, Universiti Putra Malaysia Bintulu Sarawak Campus, 97008 Bintulu, Sarawak, Malaysia; [3] Rubber Industry Smallholders Development Authority, 94300 Kota Samarahan, Sarawak, Malaysia
*Corresponding author: johnkeen@upm.edu.my
Received: 23 December 2022 Accepted: 23 June 2023 Published: 30 June 2023

ABSTRACT

Paddy husk (PH) is a waste generated from rice production that can be composted into organic fertiliser. Ligninolytic active *Bacillus* spp. from termite gut were added during the composting process to enhance the agronomic properties of compost produced from PH. This pot study was conducted using maize (Thai Super Sweet hybrid F1) as a test crop to determine the effects of using *Bacillus* composted PH in supplementing essential nutrients when used in tropical agricultural soil. A total of 144 planting pots, consisting of 12 treatments, were arranged in a Randomized Complete Block Design (RCBD) with three blocks, three replications and four sub-samples per replication. Maize growth namely plant height and leave number were recorded from 14 until 48 days after planting. Maize plants were harvested at 48 days after planting (tasseling stage) and total plant dry weights were recorded. Each plant part was ground and analysed for total N, P, K, Mg and Ca. Soil samples from the pots were sampled and analysed for TOC, pH, EC, total N, total P, available P, K, Mg and Ca. The results at 48 days after planting showed that *Bacillus* composted PH contributed to an increased by 24.29 to 31.67% in plant height, 53.84 to 61.61% in total plant dry weight and 9.09 to 16.67% in leaf number when compared to plants supplied with standard fertiliser. The use of *Bacillus* composted PH also improved soil pH, increased soil total N, total P, exchangeable K, Ca, and Mg. Maize treated with *Bacillus* composted PH showed higher nutrient uptake by 42.79 to 67.89% N, 30.05 to 56.25% P, 61.39 to 70.34% K, 47.39 to 69.94% Ca, and 76.62 to 83.74% Mg when compared to maize treated with standard fertiliser. This study suggests that *Bacillus* composted PH can promote vegetative growth in maize by acting as soil amendment and providing sufficient nutrients to the plant. Therefore, *Bacillus* composted PH has great potentials in promoting a more environmentally friendly and sustainable cropping practices which can benefit the environment and society.

Keywords: *Bacillus* composted paddy husk, maize, nutrient uptake, soil nutrients, vegetative growth

INTRODUCTION

Maize is a crucial cereal for human consumption in the humid and sub-humid tropics. It is a major source of carbohydrate (70.4%) for human beings (Olowoake, 2017) and delivers more than 30% of the food calories to approximately 4.5 billion people (Shiferaw *et al*., 2011). Maize is also a key raw ingredient in animal feeds, industrial alcohol, pharmaceutical product, and fuel ethanol (Quintero *et al*., 2008; Wang *et al*., 2009; Samboko *et al*., 2017). Globally, 790 million tons of maize was harvested in 2010 and this yield has increased to approximately 1,099 million tons in 2018 (FAO, 2019). The demand for maize in developing countries is forecasted to double by 2050, making maize the highest crop produced worldwide (Nelson *et al*., 2010).

Soil with low fertility status is a major problem in most cultivated soils in Malaysia (Zaharah *et al.*, 2017). The soils are classified as highly weathered soils known as Oxisols and Ultisol which contain high Al and Fe but deficient in micronutrients (Harter, 2007; Anda *et al.*, 2008). Fragile nature of soil, combined with overuse of most arable crop lands for continuous crop cultivation, has made the application of fertiliser to soil something of a necessity. Liming application to increase soil pH often resulted in the accumulation of Ca in the topsoil and its excess can impede the uptake of other nutrients and induce deficiencies in other positively charged ions such as K and Mg. Meanwhile, N, P and K are important macro elements which are essential for plant growth but lacking in tropical soils. The application of N, P, and K fertilisers continues to put pressure on the environment and can harm the environment in the long run by polluting soils and water (Gu *et al*., 2021).

Composting is a biological process that converts organic waste into rich, nutrient-dense compost, which can then be used to improve soil fertility (Syuhadah *et al*., 2021) thus can significantly enhance plant growth and crop production. Composting breaks down organic matter into a stable form, making it more readily available for plant uptake. Compost contains a range of essential plant nutrients, including N, P and K as well as micronutrients such as Ca and Mg (Gondek *et al*., 2020). These nutrients are slowly released into the soil, providing a sustained supply of nutrients to plants and promoting healthy root development.

The use of compost as soil amendment is an alternative to increase soil nutrients and fertility by rejuvenating, ameliorating, and protecting the soil from further degradation. Compost can assist in improving agronomic properties of soil which include soil physical and chemical properties (Rusli *et al*., 2022) by reducing soil acidity, improving soil nutrient retention and microbial activities, increasing plant nutrient availability and uptake which increase plant growth and yield (Latifah *et al*., 2017). The by-product of the rice milling namely PH can be found in abundance wherever the rice industry exists. However, by-products of tropical agriculture are naturally high in lignin and low in biodegradability. The composting process of PH into high quality organic fertiliser is impeded by the high lignin content in PH (Goodman, 2020). Such wastes may cause environmental pollution when discarded indiscriminately. However, the addition of microbes has been found to improve the composting process. Bacteria obtained from termite guts have been found to be mostly effective in the decomposition of high lignin wastes by degrading about 28% of dealkalized lignin and up to 95% of lignin dimer compounds (Azizi-Shotorkhoft *et al*., 2016).

A pot study was carried out to determine the effects of using composted PH on selected soil chemical properties and uptake by maize when cultivated on tropical agricultural soil. In this experiment, it is hypothesised that *Bacillus* composted PH can effectively improve soil nutrients availability and uptake by maize. Thus, this research was conducted to determine the effect of *Bacillus* composted PH on the growth of maize plants, including plant height, leaf number, and total plant dry weight, assess the changes in soil properties, including pH and nutrient content (total N, total P, exchangeable K, Ca, and Mg), when treated with *Bacillus* composted PH and compare the nutrient uptake (N, P, K, Ca, and Mg) by maize treated with *Bacillus* composted PH against maize treated with standard fertiliser.

MATERIALS AND METHODS

Production of Paddy Husk Compost

Raw PH was obtained from a rice mill in Dalat, Sarawak, Malaysia while chicken feed and molasses were purchased from a local market in Bintulu, Sarawak, Malaysia. Leguminous leaves and chicken manure were obtained from the Shared Farm of UPMKB. The screening of ligninolytic microbes from termites (*Coptotermes curvignathus*) gut used in the composting of paddy husk has been detailed in Carlina *et al*. (2021) while the processes involved in the production of paddy husk compost (preparation, composting, maturation and curing) have been fully outlined in Carlina *et al.* (2022).

Bacillus spp. are known for their ability to solubilize and fix nutrients, making them important contributors to the nutrient content of compost. *Bacillus* inoculation can indirectly affect lignocellulose degradation by changing the bacterial community (Zhang *et al*., 2021). The use of different bacterial combinations in composting is based on the rationale that different *Bacillus* spp. have varying abilities to solubilize different nutrients (Setiawati *et al*., 2022). Additionally, certain strains of *Bacillus* spp. have synergistic effects that enhance the overall nutrient availability and make nutrients more accessible to plants (Saxena *et al*., 2020). Meanwhile, chicken manure is a common source of microbes used in the composting of organic wastes besides being a rich source of nitrogen and other essential plant nutrients.

Polybag Experiment of Maize

A polybag experiment was conducted at the Horticulture Nursery Unit (3°12'31.2"N, 113°04'41.9"E) of Putra Agriculture Centre, Universiti Putra Malaysia Bintulu Sarawak Campus. The rainout shelter with polyethylene film roof used for planting was approximately 72 m^2 in size. A total of 144 polybags representing 12 treatments (Table 1) were arranged in a Randomized Complete Block Design (RCBD) with three blocks, three replications and four sub-samples per replication. Distance between plots was 1 m while the distance between blocks was 2 m. RCBD was adopted in this study as light intensity reaching the rainout shelter floor varies throughout the day. The well fenced experimental site was cleared of any plant debris. The floor surface of the site was covered using silver shine plastic to control weeds and loss of soil. Maize (Thai Super Sweet hybrid F1) variety was used as the test crop. As the rainout shelter consisted of only the frame and roof, the area was netted to prevent birds from getting in and feed on the maize grains.

Polybags of 60 cm in height and 50 cm in width were filled with 8 kg of soil. The soil used in this study was characterised under the Bekenu series (Typic Paleudults) which is a sandy loam soil with a bulk density of 1.51 g m^{-3}. The chemical properties of soil used in the pot study is as shown in Table 2. Soil only (SO) treatment without any addition of fertiliser was used to calculate the amount of fertiliser taken up and used by the test crop versus the amount of fertiliser lost. The application of standard fertiliser (SF) and organic fertiliser (OF) were based on recommendation for maize by MARDI (Mohamed *et al.*, 2014) which were 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-2} for SF and 15 tons ha^{-1} for OF. These amounts were then scaled down based on the amount of soil used in the pot study which was 8 kg.

Table 2. Chemical properties of soil used in the pot study

Chemical Properties	Value
Soil pH	4.66
Organic matter (%)	2.06
Total organic carbon (%)	1.20
Total N (%)	0.15
Available P (mg kg^{-1})	4.16
Exchangeable K (cmol kg^{-1})	0.60
Exchangeable Ca (cmol kg^{-1})	1.41
Exchangeable Mg (cmol kg^{-1})	1.53

Bacillus composted PH was mixed with the potting soil a day before planting. Urea, TSP, and K_2SO_4 (equal amount) was applied twice viz at 10 and 28 days after planting. Plant height measurement and leaf number were done after 14 days of planting and then repeated at an interval of 7 days. Plant height was measured as the distance from the soil line to the highest point of the plant (Souza & Young, 2021) but excluding the tassel. Meanwhile, leaves that were completely out from the whorl were included in the leaf number count.

Table 1. Treatments evaluated in the pot study.

Treatments	Soil (g)	Amount of compost used (g)	Media type
SO	8000	0	Soil only
SF	8000	0	Standard fertiliser
OF	8000	360	Organic fertiliser
T1	8000	360	PH compost without microbe
T2	8000	360	PH compost produced with *Bacillus toyonensis* (*Bto*)
T3	8000	360	PH compost produced with *Bacillus cereus* (*Bce*)
T4	8000	360	PH compost produced with *Bacillus thuringiensis* (*Bt*)
T5	8000	360	PH compost produced with *Bto* + *Bce*
T6	8000	360	PH compost produced with *Bce* + *Bt*
T7	8000	360	PH compost produced with *Bto* + *Bt*
T8	8000	360	PH compost produced with *Bto* + *Bce* + *Bt*
T9	8000	360	PH compost produced with chicken manure

Plant Harvesting, Soil Sampling and Analyses

Maize plants were harvested at 48 days after planting which was during the tasseling stage. The tasseling stage was selected as it is a stage where the plant has reached full height (Nleya *et al*., 2016) or maximum growth for maize where significant amount of nutrients is required to support the development of the reproductive structures (Susilawati *et al*., 2009). At the same time, soil sampling was also conducted. Roots were removed carefully and washed from any soil using tap water followed by distilled water. All plant parts were oven dried at 60°C until constant weights and the total dry weights were determined. The dry plants were ground and analysed for total N, P, and K uptake. Total N for the plant was determined using Kjeldahl method, total P, K, Mg, and Ca were extracted using the dry ashing method (Tan, 2005). The blue method (Murphy & Riley, 1962) was used to determine total P which was analysed using a UV-Vis Spectrophotometer (Perkin Elmer Lambda 25, USA) while K, Mg, and Ca were determined using the Atomic Absorption Spectrometre (AAS; AAnalyst 800, Perkin Elmer Instrument, Norwalk, CT). Nutrient uptake was calculated using Eq. (1):

$$\text{Nutrient Uptake} = \text{Nutrient Content X Dry Weight of Plant} \quad \text{Eq. (1)}$$

The TOC of the soil samples were also analysed using the dry combustion method. Soil pH and EC were determined using the pH meter (Mettler Toledo SevenEasy, Switzerland) and EC meter (SevenEasy Conductivity Meter S30, New Zealand), respectively. Total N, total P, available P, and cation K, Mg, and Ca were determined using standard procedures (Bremner, 1965; Keeney & Nelson, 1982; Tan, 2005) and similar equipment used in the plant analyses.

RESULTS AND DISCUSSION

The effects of compost on vegetative parameters of maize were evaluated in terms of plant height and leaf number. Maize height and leaf number during successive growing stages with respect to type of fertiliser are as presented in Figure 1 and Figure 2, respectively. At 28 days after planting, maize applied with *Bacillus* composted PH (T1 to T8) grew significantly taller than maize supplied with SF by 16.62 to 29.71%. Similar trends were observed at day 35, 42, and 48 after planting with values ranging from 22.30 to 30.59%, 26.62 to 43.11% and 24.29 to 31.67%, respectively. The number of leaves for plants supplied with *Bacillus* composted PH were also significantly higher compared to OF, SF and SO at 28 days with values ranging from 18.18 to 45.45%. At tasseling, differences in the number of leaves between *Bacillus* composted PH plants and standard fertiliser were between 9.09 to 16.67%. As indicated in the graph, no difference among maize plants supplied with PH compost (T1 to T9) for both plant height and leaf number.

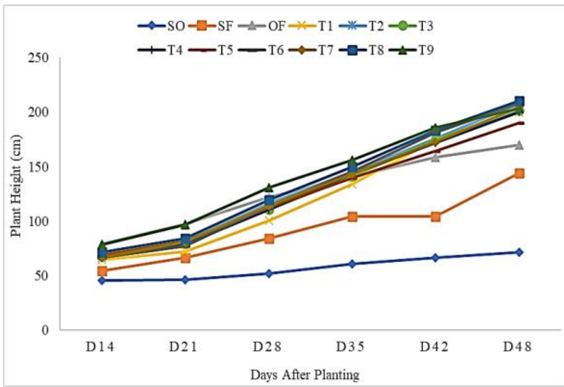

Figure 1. Effects of treatments on maize height from day 14 until tasseling stage at day 48

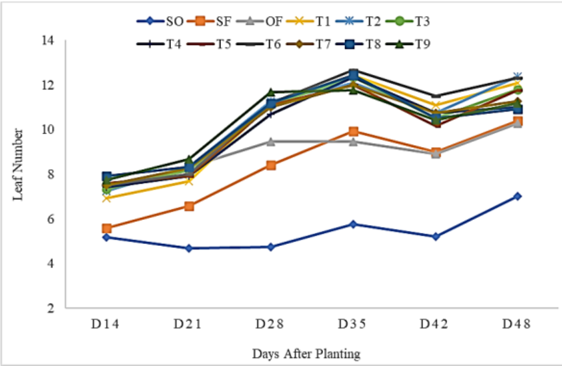

Figure 2. Accumulation of maize leaf number observed for different treatments from day 14 until tasseling stage

Plant height and leaf number recorded higher values when supplied with compost and OF than in the controls (SO and SF). This can be linked to the efficacy of the composts. Organic amendments particularly composts can significantly enhanced soil organic C and provided considerable effects on soil microbes, nutrient availability, and uptake for plant (Mahmood *et al.*, 2017). Increased in maize growth when applied with compost has also been reported by Budiastuti *et al*. (2023), thus indicating that compost is rich in micro and macronutrients which are essentials in promoting growth (Wright *et al*., 2022). The efficiency of compost could further be explained by its capacity to improve OM content, soil structure, nutrient retention, aeration, soil moisture holding capacity and water infiltration for plants (Lin *et al*., 2018).

Treatments with OF, and T1 to T9 showed significant improvement in the production of total dry matter (Figure 3). Plants treated with *Bacillus* composted PH indicated higher dry matter when compared to SF treated plants by 53.84 to 61.61%. Addition of compost has been known to impart a positive impact on root length and growth of plants (Cardenas *et al.*, 2017). Ahmad *et al*. (2022) documented that utilisation of organic amendment in the form of composted PH in this study may have improved soil structure that allows better root growth. Low bulk density, high porosity, and infiltration rate of organic amendment can serve as a bulking agent that will improve soil structure (Zhao *et al*., 2019; Adekiya *et al.*, 2020). This has contributed to the development of the maize roots in this present study which enable the plant to grow and absorb nutrients from the soil better to support and increase growth.

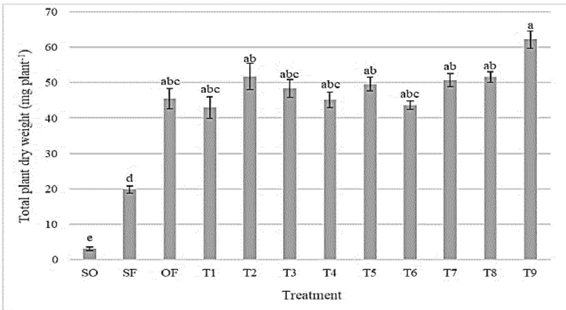

Figure 3. Effects of treatments on total dry weight of maize plant at tasseling stage. Different alphabets indicate significant difference among the treatment

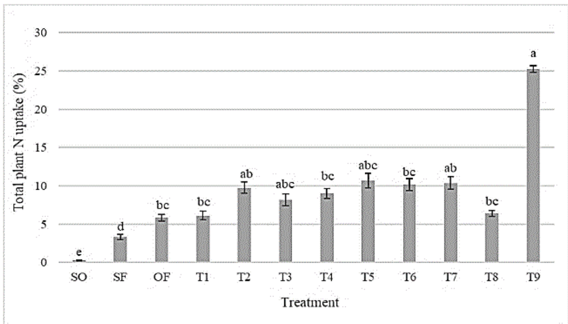

Figure 4. Effects of treatments on total nitrogen (N) uptake by maize during tasseling stage

The chicken manure used in this study also released additional macro and micro-nutrients which are essential for better growth and development (Zhang *et al*., 2020). Increase in the total dry weight (stem, leaves, and roots) in polybags supplied with OF and PH composts was perhaps related to the high soil nutrient contents (Table 3), leading to an increase in N, P, K, Ca, and Mg uptake as displayed in Figure 4 until Figure 8, respectively. Similar findings have also recorded by Siedt *et al.* (2021) where organic soil amendments were found to enhance soil fertility and positively improve poor soils' nutrient content and other soil chemical properties. Dang *et al*. (2021) and O'Connor *et al*. (2021) further reported that compost application increase concentration of soil nutrients including soil organic matter, dissolving organic carbon, total nitrogen, soil ammonium (NH_4^+), and nitrate (NO_3^-).

Figure 4 shows that N uptake by plants under treatments OF and PH composts were significantly higher compared to SF and SO treatments. Highest N uptake was observed in T9, followed by OF and other PH treatments, then SF, and finally SO with the lowest value Although the total N values for soil under OF and PH treatments were similar with that of SF (Table 3), the N uptake by maize treated with SF was significantly lower by 42.79 to 67.89% than those provided with *Bacillus* composted PH. Similar observations were also detected for P, K, Ca, and Mg as shown in Figure 5 until Figure 8, respectively. This finding was coherent with Rosenani *et al*. (2016), where increased N, P, K, Ca, Mg uptake were also observed in oil palm seedlings supplied with compost in the growing media as compared to conventional fertiliser. This result proved that not all N present in the soil was readily available for plant uptake. The presence of organic materials in the soil may not only improves soil structure but also improves soil water-holding capacity resulting in better plant growth and health (Aisyah *et al*., 2022) and allowed more movement of mobile nutrients (such as nitrates) to the root (Uchida, 2000; Latifah *et al*., 2017). Compost promotes better root growth and healthier roots that contribute to better nutrients intake (Soheil *et al*. 2012).

Treatments incorporated with *Bacillus* composted PH showed higher uptake of P by 30.05 to 56.25% when compared to SF (Figure 5). This is due to the high affinity for Al^{3+} and

Fe^{2+} in PH composts and organic fertilisers, minimise P fixation by Al^{3+} and Fe^{2+} in highly weathered acid soils (Latifah *et al*., 2020). Thus, it is expected that treatments using PH as amendment can help in reducing the possibility of P fixation and rendering the availability of P in the soil.

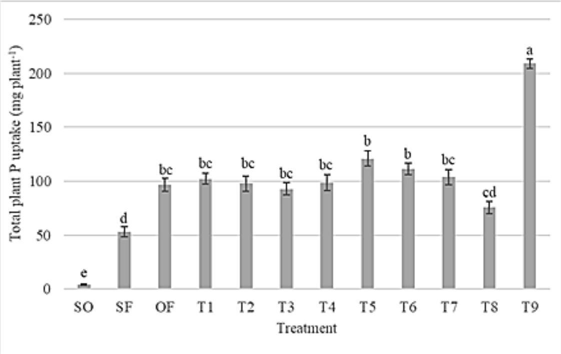

Figure 5. Effects of treatments on total phosphorus (P) uptake by maize during tasseling stage

Treatments with *Bacillus* composted PH showed significant increase in K uptake by 61.39 to 70.34% compared to inorganic fertilisers alone (SF) (Figure 6) as organic materials might have partly improved K uptake as the phenolic and carboxylic functional groups of the humic acids in the composted PH. This can be seen in the soil exchangeable K which were relatively similar among treatments, but SF showed lower K uptake as compared to composted PH and OF (Table 3). The phenolic and carboxyl groups have high negative charges that can retain NH_4^+, K^+, Ca^{2+}, and Mg^{2+} (Ng *et al*., 2022). The functional groups of the composts bind these positively charged ions, thus increasing their availability for plants uptake (Guo *et al*., 2019).

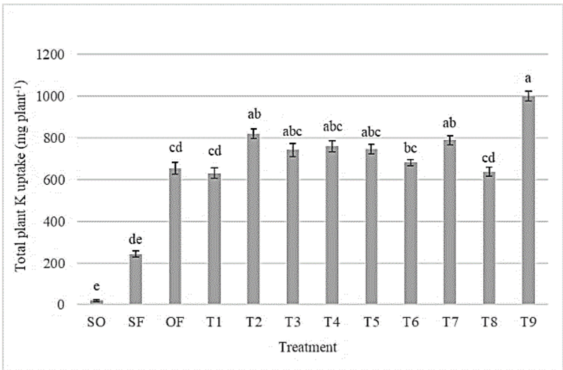

Figure 6. Effects of treatments on total potassium (K) uptake by maize during tasseling stage

Table 3 shows that the value for soil exchangeable Ca in treatments with composted PH was relatively similar to soil with SF but significantly higher than the SO treatment. However, most treatments with *Bacillus* composted PH showed higher uptake of Ca by 47.39 to 69.94% as compared to treatment with inorganic fertiliser alone (SF) (Figure 7). Similarly, Figure 8 shows that the uptake of Mg in treatments with *Bacillus* composted PH was significantly higher by 76.62 to 83.74% when compared to treatments with inorganic fertiliser (SF). The *Bacillus* composted PH contributed to the regulation of soil exchangeable Ca and Mg whereby the functional groups of humic substances were able to temporarily hold soil exchangeable Ca and Mg. Latifah *et al.* (2017) opined that the higher contents and uptake of N, P, K, Ca, and Mg in plants could be associated to the timely retention and release of exchangeable N, Ca, Mg, K and available P in soil with the addition of composted PH.

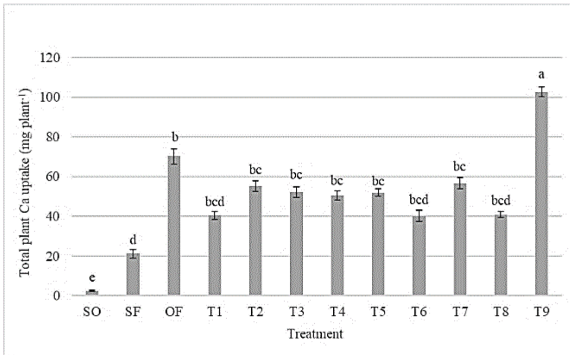

Figure 7. Effects of treatments on calcium (Ca) uptake by maize during tasseling stage

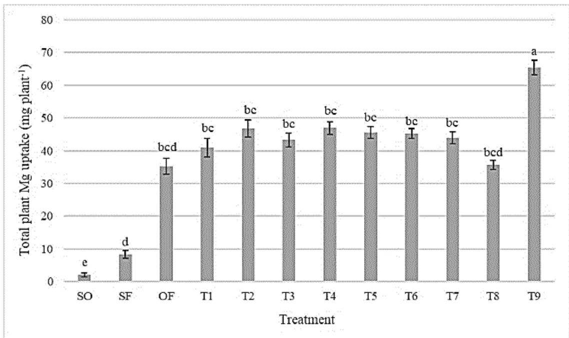

Figure 8. Effects of treatments on magnesium (Mg) uptake by maize during tasseling stage

Table 3. Selected chemical properties of the soils after maize harvesting

Chemical Properties	Treatments											
	SO	SF	OF	T1	T2	T3	T4	T5	T6	T7	T8	T9
Soil pH	$4.47^{f} \pm 0.10$	$5.00^{e} \pm 0.09$	$6.57^{b} \pm 0.14$	$5.69^{d} \pm 0.10$	$6.54^{b} \pm 0.11$	$6.50^{b} \pm 0.07$	$6.71^{ab} \pm 0.13$	$6.22^{bc} \pm 0.17$	$6.68^{ab} \pm 0.12$	$6.31^{bc} \pm 0.13$	$5.88^{cd} \pm 0.11$	$7.13^{a} \pm 0.08$
Soil EC, ($S\ m^{-1}$)	$114.75^{c} \pm 27.08$	$341.06^{a} \pm 9.73$	$247.77^{b} \pm 11.79$	$125.41^{c} \pm 6.16$	$116.51^{c} \pm 4.54$	$103.18^{c} \pm 1.70$	$128.65^{c} \pm 5.54$	$140.80^{c} \pm 4.98$	$146.63^{c} \pm 12.69$	$132.61^{c} \pm 10.31$	$135.18^{c} \pm 6.85$	$221.21^{b} \pm 10.90$
Organic matter, (%)	$3.89^{d} \pm 0.14$	$4.40^{d} \pm 0.20$	$6.29^{c} \pm 0.23$	$7.46^{bc} \pm 0.18$	$8.33^{ab} \pm 0.27$	$7.53^{bc} \pm 0.28$	$8.90^{a} \pm 0.45$	$8.69^{ab} \pm 0.37$	$9.30^{a} \pm 0.35$	$8.87^{a} \pm 0.31$	$6.31^{c} \pm 0.29$	$9.27^{a} \pm 0.29$
Total organic carbon, (%)	$2.26^{d} \pm 0.08$	$2.55^{d} \pm 0.12$	$3.65^{c} \pm 0.13$	$4.32^{bc} \pm 0.10$	$4.83^{ab} \pm 0.16$	$4.37^{bc} \pm 0.16$	$5.16^{a} \pm 0.26$	$5.04^{ab} \pm 0.21$	$5.39^{a} \pm 0.20$	$5.14^{a} \pm 0.18$	$3.66^{c} \pm 0.17$	$5.38^{a} \pm 0.17$
Total N, (%)	$0.01^{c} \pm 0.002$	$0.03^{ab} \pm 0.003$	$0.02^{ab} \pm 0.003$	$0.02^{ab} \pm 0.003$	$0.03^{ab} \pm 0.004$	$0.02^{ab} \pm 0.002$	$0.03^{ab} \pm 0.004$	$0.02^{ab} \pm 0.004$	$0.02^{ab} \pm 0.003$	$0.03^{ab} \pm 0.003$	$0.02^{ab} \pm 0.003$	$0.04^{a} \pm 0.006$
Total P, ($mg\ kg^{-1}$)	$75.49^{f} \pm 17.00$	$252.44^{de} \pm 20.42$	$229.07^{e} \pm 24.13$	$332.16^{bcd} \pm 4.21$	$347.53^{abc} \pm 17.82$	$342.23^{abc} \pm 9.05$	$395.51^{abc} \pm 20.49$	$377.04^{abc} \pm 15.95$	$410.41^{ab} \pm 20.99$	$379.58^{abc} \pm 16.26$	$316.81^{cd} \pm 8.62$	$419.54^{a} \pm 10.15$
Exchangeable K, ($Cmol\ kg^{-1}$)	$0.33^{e} \pm 0.02$	$0.40^{cde} \pm 0.02$	$0.48^{ab} \pm 0.02$	$0.45^{bcd} \pm 0.02$	$0.41^{cd} \pm 0.01$	$0.45^{bcd} \pm 0.01$	$0.48^{ab} \pm 0.03$	$0.45^{bcd} \pm 0.01$	$0.44^{bcd} \pm 0.02$	$0.42^{cd} \pm 0.03$	$0.38^{de} \pm 0.01$	$0.56^{a} \pm 0.01$
Exchangeable Ca, ($Cmol\ kg^{-1}$)	$0.03^{e} \pm 0.002$	$0.07^{c} \pm 0.006$	$0.18^{a} \pm 0.010$	$0.04^{d} \pm 0.002$	$0.05^{cd} \pm 0.003$	$0.05^{cd} \pm 0.003$	$0.05^{cd} \pm 0.003$	$0.05^{cd} \pm 0.002$	$0.05^{cd} \pm 0.002$	$0.05^{cd} \pm 0.002$	$0.04^{d} \pm 0.002$	$0.15^{ab} \pm 0.008$
Exchangeable Mg, ($Cmol\ kg^{-1}$)	$1.06^{e} \pm 0.05$	$1.14^{de} \pm 0.05$	$1.64^{bc} \pm 0.06$	$1.48^{d} \pm 0.05$	$1.62^{bc} \pm 0.04$	$1.61^{bc} \pm 0.05$	$1.78^{ab} \pm 0.08$	$1.74^{ab} \pm 0.04$	$1.79^{ab} \pm 0.04$	$1.73^{ab} \pm 0.05$	$1.44^{d} \pm 0.05$	$1.97^{a} \pm 0.05$

Note: Mean between columns with different letters indicates significant difference tested by Tukey's test at $p \leq 0.05$. Value indicated mean ± standard error.

CONCLUSION

The use of *Bacillus* composted PH not only improved soil pH but also increased soil total N, total P, exchangeable K, and Mg. The total N, P, K, Ca, and Mg uptake by maize treated with composted PH were also higher compared to maize treated with standard fertiliser. This study suggested that the use of *Bacillus* composted PH (T5, T6, and T7) and T9 (unidentified microbes from chicken manure) not only showed potentials as soil amendments but also in supplying sufficient nutrients to a nutrient demanding crop such as maize. The ability of *Bacillus* composted PH to provide sufficient nutrients to soils can assist farmers in reducing a total dependency on chemical fertilisers while promoting a more environmentally friendly and sustainable cropping practices that can benefit future environment and society. However, any conclusions drawn from this study should be limited to the tasseling stage of maize and should not be extrapolated to other stages of growth or other crops without additional research. A long-term economic viability study is also suggested to explore on how *Bacillus* composted PH can further reduce the dependency on SF. A field study to know the actual impact of PH composts on nutrient uptake by plants planted in the open field and how it affects plant growth and yield should also be conducted. Furthermore, a study to trace the movement of nutrients into different parts of the plants using isotopes is recommended.

ACKNOWLEDGEMENTS

This research was funded under the Putra Grant Scheme (UPM/800-3/3/1/GP-IPB/9557602) of Universiti Putra Malaysia. The authors would like to thank Universiti Putra Malaysia for the postgraduate scholarship financial support.

REFERENCES

Adekiya, A.O., Agbede, T.M., Olayanju, A., Ejue, W.S., Adekanye, T.A., Adenusi, T.T. & Ayeni, J.F. (2020). Effect of biochar on soil properties, soil loss, and cocoyam yield on a tropical sandy loam Alfisol. *The Scientific World Journal*, 2020: 1-9.

Ahmad, I., Rashid, M.H.U., Nawaz, S., Asif, M., Farooq, T.H., Shahbaz, Z., Kashif, M. & Shaheen, M. (2022). Effect of different compost concentrations on the growth yield of *Bombax ceiba* (Simal). *Natural Resources for Human Health*, 2(2): 222-227.

Aisyah, M.D., Asli, U.A., Khamis, A.K., Baharulrazi, N., Azman, N.R. & Yunus, N.A. (2022). Improving the water retention characteristics of sandy soil using food waste compost amendment and indigenous microorganisms. *Chemical Engineering Transactions*, 97: 211-216.

Anda, M., Shamshuddin, J., Fauziah, C.I. & Syed, O. S.R. (2008). Mineralogy and factors controlling charge development of three oxisols developed from different parent materials. *Geoderma*, 143:153-167.

Azizi-Shotorkhoft, A., Mohammadabadi, T., Motamedi, H., Chaji, M. & Fazaeli, H. (2016).

Isolation and identification of termite gut symbiotic bacteria with lignocellulose-degrading potential, and their effects on the nutritive value for ruminants of some by-products. *Animal Feed Science and Technology*, 221: 234-242.

Bremner, J.M. (1965). Total Nitrogen. In Black, C.A., Evan, D.D., Ensminger, L.E., White, J.L., Clark, F.E. and Dinauer, R.D. (eds.) *Method of soil analysis Part 2*. American Society of Agronomy. Madison, Wisconcin. pp. 1149-1178.

Budiastuti, M.T.S. Purnomo, D., Pujiasmanto, B. & Setyaningrum, D. (2023). Response of maize yield and nutrient uptake to indigenous organic fertiliser from corn cobs. *Agriculture*, 13(2): 309.

Cardenas, E., Gabriel, G.A. & Paz-Ferreiro, J. (2017). The effect of biochar and compost from urban organic waste on plant biomass and properties of an artificially copper polluted soil. *International Biodeterioration and Biodegradation*, 124: 223-232.

Carlina, F.S., John, K.C., Patricia, K.J.H., Ong, K.H., Chew, C. & Khalid, N. (2021). Qualitative and molecular screening of potential ligninolytic microbes from termite (*Coptotermes curvignathus*) gut. *Borneo Journal of Resource Science and Technology*, 11(1): 35-42.

Carlina, F.S., John, K.C., Patricia, K.J.H., Ong, K.H., Chew, C., Lirong, Y.A. & Khalid, N. (2022). Enhancing plant nutrient availability in composted paddy husk using *Bacillus* spp. isolated from termite (*Coptotermes curvignathus*) gut. *ScienceAsia*, 48: 23-31.

Dang, Q., Wang, Y., Xiong, S., Yu, H., Zhao, X., Tan, W., Cui, D. & Xi, B. (2021). Untangling the response of fungal community structure, composition and function in soil aggregate fractions to food waste compost addition. *The Science of Total Environment*, 769: 145248.

FAO (2019). Food and Agricultural Organization of the United Nations Production Statistics. Retrieved September 2, 2020 from http://www.fao.org/faostat.

Gondek, M., Weindorf, D.C., Thiel, C. & Kleinheinz, G. (2020). Soluble salts in compost and their effects on soil and plants: A review. *Compost Science & Utilization*, 28(2): 59-75.

Goodman, B.A. (2020). Utilization of waste straw and husks from rice production: A review. *Journal of Bioresources and Bioproducts*, 5(3): 143-162.

Gu, B.J., Chen, D., Yang, Y., Peter, V. & Zhu, Y.G. (2021). Soil-Food-Environment- Health Nexus for sustainable development. Research, pp. 1-4.

Guo, X.X., Liu, H.T. & Wu, S.B. (2019). Humic substances developed during organic waste composting: Formation mechanisms, structural properties, and agronomic functions. *Science of the Total Environment*, 662: 501-510.

Harter, R.D. (2007). Acid soils of the tropics. ECHO Technical Note. North Fort Myers, USA.

Keeney, D.R. & Nelson, D.W., (1982). Nitrogen-inorganic forms. In Page, A.G., Keeney, D.R., Baker, D.E., Miller, R.H. & Rhoades, J.D (eds.) *Methods of soil analysis, Part 2*. Agronomy Monograph 9. ASA and SSSA, Madison, Wisconsin. pp. 643-698.

Latifah, O., Ahmed, O.H. & Majid, N.M.A. (2017). Enhancing nutrients use efficiency and grain yield of *Zea mays* L. cultivated on a tropical acid soil using paddy husk compost and clinoptilolite zeolite. *Bulgarian Journal of Agricultural Science*, 23(3): 418-428.

Latifah, O., Ahmed, O.H. & Majid, N.M.A. (2020). Improving nutrient recovery of *Zea mays* L. using paddy husk compost and clinoptilolite zeolite. *Modern Environmental Science and Engineering*, 6(2): 235-246.

Lin, B.B., Egerer, M.H., Liere, H., Jha, S. & Philpott, S.M. (2018). Soil management is key to maintaining soil moisture in urban gardens facing changing climatic conditions. *Scientific Reports*, 8: 1-8.

Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., Abid, M. & Ullah, S. (2017). Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of Soil Science and Plant Nutrition*, 17(1): 22-32.

Mohamed, A.M., Shamshuddin, J., Christopher, T.B. S., Puteri, E.M.W. & Qurban, A.P. (2014). Influence of NPK fertiliser rates and irrigation frequencies on the biomass and yield components of sweet corn (*Zea mays* L.). *Journal of Food, Agriculture and Environment*, 12(2): 1308-1313.

Murphy, J. & Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytical Chemistry Acta*, 27: 31-36.

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R.D., Sulser, T.B., Ringler, C. & Msangi, S. (2010). Food security, farming, and climate change to 2050: Challenges to 2050 and beyond. *IFPRI Research Monograph*, 1-140.

Ng, J.F., Ahmed, O.H., Jalloh, M.B., Omar, L., Kwan, Y.M., Musah, A.A. & Poong, K.H. (2022). Soil nutrient retention and pH buffering capacity are enhanced by Calciprill and sodium silicate. *Agronomy*, 12 (1): 219.

Nleya, T., Chungu, C. & Kleinjan, J. (2016). Chapter 5: Corn growth and development. In Clay, D.E., Carlson, C.G. Clay, S.A. & Byamukama, E (eds). *iGrow Corn: Best Management Practices*. South Dakota State University.

O'Connor, J., Hoang, S.A., Bradney, L., Dutta, S., Xiong, X., Tsang, D.C.W., Ramadass, K., Vinu, A., Kirkham, M.B. & Bolan, N.S. (2021). A review on the valorisation of food waste as a nutrient source and soil amendment. *Environmental Pollution*, 272: 115985.

Olowoake, A.A. (2017). growth and nutrient uptake of maize (*Zea mays* L.) amended with compost-enriched palm kernel cake. *Ibadan Journal of Agricultural Research*, 12(2): 23-32.

Quintero, J.A., Montoya, M.I., Sánchez, O.J., Giraldo, O.H. & Cardona, C.A. (2008). Fuel ethanol production from sugarcane and corn: comparative analysis for a Colombian case. *Energy*, 33(3): 385-399.

Rosenani, A.B., Rovica, R., Cheah, P.M. & Lim, C.T. (2016). Growth performance and nutrient uptake of oil palm seedling in prenursery stage as influenced by oil palm waste compost in growing media. *International Journal of Agronomy*, 2016: 1-8.

Rusli, L.S., Abdullah, R., Yaacob, J.S. & Osman, N. (2022). Organic amendments effects on nutrient uptake, secondary metabolites, and antioxidant properties of *Melastoma malabathricum* L. *Plants (Basel)*, 11(2): 153.

Samboko, P.C., Zulu-Mbata, O. & Chapoto, A. (2017). Analysis of the animal feed to poultry value chain in Zambia. *Wider Working Paper* (No. 2017/59).

Saxena, A.K., Kumar, M., Chakdar, H., Anuroopa, N. & Bagyaraj, D.J. (2020). *Bacillus* species in soil as a natural resource for plant health and nutrition. *Journal of Applied Microbiology*, 128(6): 1583-1594.

Setiawati, T.C., Erwin, D., Mandala, M. & Hidayatulah, A. (2022). Use of *Bacillus* as a plant growth-promoting rhizobacteria to improve phosphate and potassium availability in acidic and saline soils. *KnE Life Sciences*, 7(3): 541-558.

Shiferaw, B., Prasanna, B. M., Hellin, J. & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*, 3: 307–327.

Siedt, M., Schäffer, A., Smith, K.E., Nabel, M., Roß-Nickoll, M. & van Dongen, J.T. (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *The Science of the Total Environment*, 751: 141607.

Soheil, R., Hossien, M.H., Gholamreza, S., Leila, H. Mozhdeh, J. & Hassan, E. (2012). Effects of composted municipal waste and its leachate on some soil chemical properties and corn plant responses. *International Journal of Agricultural Research and Review*, 2: 801-814.

Souza, A. & Yang, Y. (2021). High-throughput corn image segmentation and trait extraction using chlorophyll fluorescence images. *Plant Phenomics*, 2021: 9792582.

Susilawati, K., Ahmed, O.H., Majid, N.M.A., Khanif, M.Y. & Jalloh, M.B. (2009). Effect of organic based N fertiliser on dry matter (*Zea mays* L.), ammonium, and nitrate recovery in an acid soil of Sarawak, Malaysia. *American Journal of Applied Science*, 6: 128-187.

Syuhadah, N.A., Abu Zahrim, Y., Junidah, L., Mohd Al Mussa, U., Sariah, S. & Mariani, R. (2021). Production of food waste compost and its effect on the growth of dwarf crape jasmine. *Jurnal Kejuruteraan*, 33(3): 413-424.

Tan, K.H. (2005). Soil sampling, preparation and analysis. Second Edition. Taylor and Francis Group. Boca Raton, Florida, USA, CRC Press. pp. 154-174.

Uchida, R. (2000). Essential nutrients for plant growth: Nutrient functions and deficiency symptoms. *Plant Nutrient Management in Hawaii's Soils*, 4: 31-55.

Wang, K., Frame, B.R., Xu, X. & Lamkey, K.R. (2009). Strategies for the production of maize-derived pharmaceuticals using cytoplasmic male sterile lines: *In vitro* tissue culture/transformation and field breeding approaches. *Maydica*, 54(2): 199-210.

Wright, J., Kenner, S. & Lingwall, B. (2022). Utilization of compost as a soil amendment to increase soil health and to improve crop yields. *Open Journal of Soil Science*, 12: 216-224.

Zaharah A.R., Amin, S., Aysha, M.K., Samavia, B. & Muhammad, A.A. (2017). Soil fertility and management of Malaysian soils. Soils of Malaysia, pp. 167-196.

Zhang, Z., Dong, X., Wang, S. & Pu, X. (2020). Benefits of organic manure combined with biochar amendments to cotton root growth and yield under continuous cropping systems in Xinjiang, China. *Scientific Reports*, 10(1): 4718.

Zhang, S., Xia, T., Wang, J., Zhao, Y., Xie, X., Wei, Z., Zhang, X., Song, C. & Song, X. (2021). Role of *Bacillus* inoculation in rice straw composting and bacterial community stability after inoculation: Unite resistance or individual collapse. *Bioresource Technology*, 337: 125464.

Zhao, X., Tan, W., Dang, Q., Li, R. & Xi, B. (2019). Enhanced biotic contributions to the dechlorination of pentachlorophenol by humus respiration from different compostable environments. *Chemical Engineering Journal*, 361: 1565-1575.