International Journal of Recycling of Organic Waste in Agriculture (2018) 7:11–23
https://doi.org/10.1007/s40093-017-0185-3

ORIGINAL RESEARCH

Biochar-compost mixture as amendment for improvement of polybag-growing media and oil palm seedlings at main nursery stage

Rovica Radin[1] · Rosenani Abu Bakar[1] · Che Fauziah Ishak[1] · Siti Hajar Ahmad[2] · Lim Chin Tsong[1]

Received: 12 April 2017 / Accepted: 4 November 2017 / Published online: 17 November 2017

Abstract

Purpose Production of oil palm seedling in the nursery mainly utilises top soil as polybag medium. These soils, especially in tropical regions, are acidic and have low organic matter content. The aim of this study was to investigate the effects of oil palm empty fruit bunch (EFB) biochar and compost incorporation as amendment in polybag medium for oil palm seedlings growth at the nursery stage.

Methods A polybag experiment was conducted with four biochar rates (0, 0.5, 1.0 and 1.5% w/w C addition), two compost rates (0 and 30% v/v), and two fertiliser application rates (75 and 100% of recommended rate). The effects of biochar, compost, and biochar-compost combination on oil palm seedling growth was evaluated and the effectiveness of EFB biochar in retaining soil nutrients was determined indirectly by measuring amount of nutrient leached through the polybag medium.

Results Biochar, compost, and biochar-compost amendment improved polybag media's chemical properties (pH, total C and N, C:N ratio, CEC, Mg, and Ca). There were no significant effects of the amendments on shoot biomass. However, root growth and shoot:root ratio significantly improved with 1.5% w/w C addition and 30% (v/v) compost with 75% recommended fertiliser rates applied. Furthermore, nutrient leaching measurement indicates that, EFB biochar significantly reduced ammonium-N leaching up to 21–46%.

Conclusions Overall, this study demonstrates the potential of biochar and compost co-application to improve the chemical properties of polybag medium and root development of oil palm seedlings.

Keywords Oil palm nursery · Oil palm waste · Biochar · Compost · Nutrient retention

Introduction

The Malaysian oil palm industry has grown tremendously over the past few decades and has become a major contributor to the gross domestic product (GDP) from agriculture sector, amounting to 46.9% in 2015 (DOSM 2017). Currently, oil palm plantation occupied 5.39 million ha of total planting area with production of 20 million tonnes of crude palm oil (MPOB 2016), making the most significant plantation commodity in Malaysia.

There are two main stages in oil palm cultivation: nursery stage and renewal or definitive area, where the palms are grown for 20–25 years, the economic life period of oil palm (Zulkifli et al. 2010). Seedlings are established in the nursery stage for 10–14 months before field planting. For good oil palm establishment after transplanting in the field, it is uttermost importance to produce good quality oil palm seedlings (Gillbanks 2003; Mathews et al. 2008). A common practice of oil palm seedling production in the nursery is using top soils as the polybag medium. Malaysian soils (mostly Ultisols and Oxisols) are known to be highly weathered acidic soils with low organic matter content. Mineral fertilisers are normally used as sources of nutrients for raising a good vegetative growth of oil palm seedlings (Paramananthan 2003; Verheye 2010). However, the efforts to maintain soil nutrient status through chemical fertilisation come with certain cost,

✉ Rovica Radin
r.rovica@gmail.com

[1] Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia

[2] Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, Malaysia

negative environmental impact, and increase in production cost of oil palm seedlings. Thus, there is a need for sustainable production of good oil palm seedlings, potentially with recycled organic waste in the form of compost and biochar, hence leading to less chemical fertiliser usage.

Several studies of oil palm seedling in the nursery stage showed a positive effect of soil amended with organic material on the vegetative growth of oil palm seedlings (Danso et al. 2013; Suryanto et al. 2015). The most common organic material used as soil amendment are compost and animal manure (Scotti et al. 2015). Compost, a by-product of organics recycling programme, contains significant amount of humic substances, valuable plant nutrients, and essential trace elements (Donn et al. 2014; Bedada et al. 2014). It restores soil organic matter which has direct effects on soil microbial biomass and enzyme activities (Ouni et al. 2013; Blanchet et al. 2016), consequently improving crop growth and yield (D'Hose et al. 2014; Ninh et al. 2015).

In the past decade, the use of biochar as a soil amendment and tool for C sequestration has a good potential in increasing crop productivity. Biochar is a carbonaceous material produced by pyrolysis of biomass in a limited oxygen condition (Schahczenski 2010). Numerous studies showed that adding biochar into infertile soils can potentially increase the cation exchange capacity of the soil and nutrient sorption (Jien and Wang 2013; Gray et al. 2014); stimulate soil microorganisms activities (Ducey et al. 2013), and reduce plant nutrients leaching losses from the soil (Kameyama et al. 2012). Moreover, several studies have highlighted the positive effects of biochar on root growth (Ogawa and Okimori 2010; Prendergast-Miller et al. 2014), particularly increased root biomass (Xiao et al. 2016) and root length (Solaiman et al. 2012; Olmo et al. 2016). There is also increasing interest in the combination of biochar with compost for improvement of soil quality other than C sequestration. The synergistic effects of biochar-compost combination theoretically could be achieved through the stability of biochar which promotes C sequestration, apart from improvement of soil properties and source of plant available nutrients as compost mineralises and eventually adds to the organic matter pool (Kammann et al. 2016).

In Malaysia, there are several available biomass wastes that have the potential to be converted into biochar as an alternative in waste management. The conversion of oil palm waste into biochar is a promising strategy towards obtaining carbon credit for the oil palm industry as part of the efforts to achieve sustainability in palm oil production. Biochar and compost may have important contribution in waste management and nutrient recycling in the oil palm industry. The oil palm waste based compost and biochar may be returned into oil palm field as fertiliser and amendment in the nursery for oil palm seedling production. However, limited research has been carried out to demonstrate the impact of biochar and compost, particularly those derived from oil palm waste, on crop such as oil palm. Applying organic amendments to polybag medium may improve soil physico-chemical properties and enhance root development. Biochar and compost may provide essential nutrients for oil palm seedling growth, thus reducing fertiliser usage and improving sustainable production of oil palm seedlings. Incorporation of oil palm empty fruit bunch (EFB) compost (commercially produced) and biochar (a trial EFB biochar by Nasmech Technology Sdn Bhd and UPM) in polybag media may lead to post-transplanted benefits in the field, especially when the seedlings are transplanted together with the biochar- and compost-amended polybag medium to the field. Hence, this may contribute to faster establishment of seedlings and soil C sequestration in the oil palm plantation in the long term. Therefore, this study was conducted (i) to evaluate the effects of EFB biochar, compost, and biochar-compost mixture amendments on oil palm seedling growth performance and chemical properties of polybag medium in the main nursery in varying chemical fertiliser rates, and (ii) to determine the effectiveness of EFB biochar in reducing loss of nutrients.

Materials and methods

Most of the oil palm nurseries in Malaysia practiced double-stage nursery system, which consists of pre- and main nursery stage. In pre-nursery stage, the germinated seeds are directly sown into small polybag and kept under shade for 3–4 months. The seedlings are then transferred into larger polybag in the main nursery, which are established in an open field condition. There, the seedlings are grown without protective shade for another 7–10 months, before the seedlings are ready for transplanting in the plantation.

This study was carried out in Universiti Putra Malaysia, (2° 59′ 59 N, 101° 42′ 25 E), over a period of 212 days (1st June 2014–6th January 2015), a standard period for oil palm seedling production in main nursery stage. The temperature ranged between 23.8 and 28.8 °C, while rainfall was higher during the end of the year due to Southwest Monsoon season in Malaysia (Fig. 1).

Experimental treatments and design

A three-factorial experiment was established in an open field condition, (exposed to direct sunlight and normal wind, air temperature and humidity condition) with the following treatments: four rates of EFB biochar (0, 0.5, 1.0, and 1.5% w/w C), with and without compost addition (30% v/v), and two rates of fertiliser (75 and 100% of fertiliser recommended rate). The 30% (v/v) compost to topsoil mixture was recommended by Rosenani and Mohd Zikri (2006) to

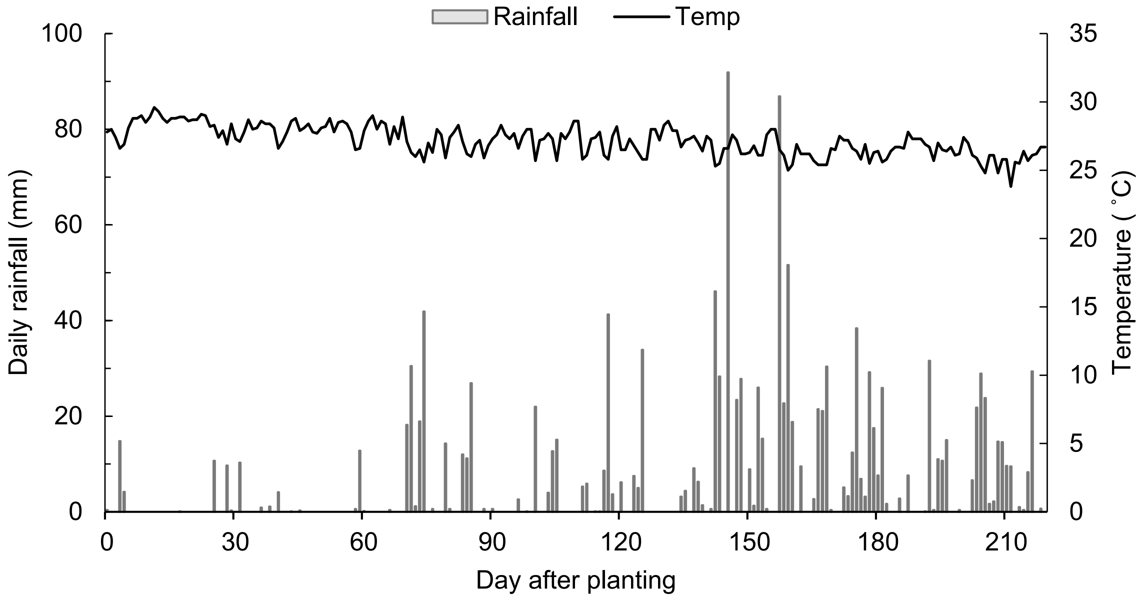

Fig. 1 Precipitation (mm) and air temperature (°C) distribution during the growing period

be the optimum polybag medium for oil palm seedling. The treatment combinations are presented in Table 1.

The texture of the top soil used in this study was sandy clay (52.1% sand, 6.5% silt, and 41.4% clay). The soil was air-dried and sieved to 2 mm prior to use. The EFB biochar was produced in a pilot carbonator with temperatures ranging from 300 to 350 °C. The compost used was oil palm empty fruit bunch (EFB) compost that is commercially available, with moisture content of 17–20% and has fine particle size of < 20.0 mm. Selected chemical properties of biochar and compost are given in Table 2. 3-month-old oil palm seedlings (about 27 cm high with 3–4 leaflets), from GH500 Series (cross breed of Elite Deli Duras and second generation of BM119 Pisiferas) were purchased from Sime Darby Seed and Agricultural Services (SDSAS), Banting, Selangor, Malaysia.

Treatments were assigned to the polybag medium and laid out in a randomised complete block design (RCBD)

Table 1 Combination treatment between fertiliser application rates (F), biochar (B) and compost (C)

Treatments	Fertilizer applied (F), (% recommended rate)	Biochar (B), [biochar C addition % (w/w)]	Compost (C), [% (v/v)]
F75B0C0	75	0	0
F75B0.5C0	75	0.5	0
F75B1.0C0	75	1.0	0
F75B1.5C0	75	1.5	0
F75B0C30	75	0	30
F75B0.5C30	75	0.5	30
F75B1.0C30	75	1.0	30
F75F B1.5C30	75	1.5	30
F100B0C0 (Control)	100	0	0
F100B0.5C0	100	0.5	0
F100B1.0C0	100	1.0	0
F100B1.5C0	100	1.5	0
F100B0C30	100	0	30
F100B0.5C30	100	0.5	30
F100B1.0C30	100	1.0	30
F100B1.5C30	100	1.5	30

Table 2 Characterisation of soil and amendment used ($n = 4$)

Parameter	Top soil	EFB biochar	EFB compost
Volatile matter (%)	–	41.1	–
Ash content (%)	–	16.2	–
pH	4.4	7.5	7.2
EC (μS cm^{-1})	40	6200	1940
C (%)	0.9	56.5	11.1
N (%)	0.1	0.6	1.2
C:N ratio	10.6	93.0	9.8
Total P (mg kg^{-1})	–	9400	2920
Total K (mg kg^{-1})	–	40,890	12,660
Total Mg (mg kg^{-1})	–	2130	3430
Total Ca (mg kg^{-1})	–	2270	6360
Available *P* (mg kg^{-1})	10.9	–	–
Exc. K $cmol_{(+)}$ kg^{-1}	0.2	–	–
Exc. Mg $cmol_{(+)}$ kg^{-1}	0.2	–	–
Exc. Ca $cmol_{(+)}$ kg^{-1}	1.4	–	–
CEC $cmol_{(+)}$ kg^{-1}	3.9	–	–

– not applicable, *Exc.* extractable

with four replications (total 64 experimental units) and equilateral triangle arrangement (80 cm within row and 80 cm between rows). The polybag medium with compost mixture was prepared before biochar addition. Compost was mixed thoroughly with the topsoil to achieve soil-compost mixture of 30% (v/v) in soil with or without biochar. Biochar treatments were prepared by adding the EFB biochar to the soil with and without compost mixture. Amounts of 0, 0.143, 0.286 and 0.429 kg of EFB biochar were mixed with 16 kg of polybag mixture (per 500 gauge polyethylene bag, with dimensions of 38 cm diameter and 45 cm height), which are equivalent to 0, 0.5, 1.0 and 1.5% w/w C addition to polybag mixture.

The polybag medium was left for 1 week to equilibrate, before a 3-month-old oil palm seedling was transplanted into each polybag. An amount of 15 g of P_2O_5 (triple super phosphate as fertiliser source) was added to each polybag as a basal application for early growth establishment (Mathews et al. 2010). Compound NPK fertiliser (12:12:17:2; N: P_2O_5: K_2O: MgO + Trace Element) was applied six times, based on the recommended dosage for seedling stage oil palm seedling as shown in Table 3. Black polyethylene sheets were placed on the ground surface before arranging the polybags on the sheet with a brick under each polybag to prevent root growing into the ground. The seedlings were watered once daily with equal volume of water and weeding was done manually. For pest and disease control, insecticide (a.i: chlorpyrifos and cypermethrin) was applied every 2 weeks while fungicide (a.i: difenoconazole) was applied when necessary.

Table 3 Fertiliser programme for oil palm seedlings at main nursery

Day of application ($DAP^{\$}$)	Dosage per palm (g $palm^{-1}$) [NPK 12-12-17-2 + TE]	
	75% recommended rate (F75)	100% recommended rate (F100)
26	7.5	10.0
54	7.5	10.0
88	11.25	15.0
118	11.25	15.0
148	15.0	20.0
180	15.0	20.0

$DAP^{\$}$ day after planting

Vegetative growth measurement and harvesting

Plant height was measured and defined as the length from soil surface to the tip of highest leaf. Rachis length of frond number three was taken from the lowest rudimentary leaflet to the tip of rachis. The bole diameter was measured using a digital calliper and number of frond was recorded by counting the total number of open green fronds.

Based on ten samples of oil palm seedlings obtained from Nafas Agri Nursery Sdn. Bhd that were ready for transplanting at 10–12 months, the morphological measurement were: height, 129 cm; number of fronds, 15; bole diameter, 7.8 cm; rachis length of frond number three, 74 cm. Morphological measurement indicated that it was harvested at 10 months (212 days of planting period in the main nursery stage), seedlings' standard growth for transplanting to the field. Seedlings were harvested for shoot and root dry matter weight measurement and analysed for nutrient uptake.

For above-ground biomass, the palm was chopped off at soil level while root was removed carefully. Dry weight of the above ground biomass and root was determined after oven-dried at 60 °C to a constant weight. The above ground parts (leaflets and frond) were ground to < 2 mm and digested for macronutrients analysis.

Analysis of biochar, compost, polybag medium and plant tissue

Biochar and compost were air-dried and sieved through a 2-mm sieve for analysis. The following analysis were conducted: ash content and volatile matter according to ASTM D1762-84 method (ASTM standard 1762-84 Reapproved 2007), pH in a 1:20 *w*/*v* water suspension (Cheng and Lehmann 2009), total C and N via dry combustion analysed using LECO CNS-2000 Elemental Analyser (Nelson and Sommers 1982), and macronutrients content via dry ashing method (Campbell and Plank 1998).

The amended and un-amended polybag medium was collected and analysed before planting and after harvesting. Samples were air-dried and sieved through a 2-mm sieve and analysed for the following: soil pH in a 1:2.5 *w*/*v* water suspension, total C and N (LECO CNS-2000 Elemental Analyser), available P via Bray and Kurtz Method II (Bray and Kurtz 1945), CEC and extractable basic cations (K, Ca, Mg) displacement of cations with 1.0 N of NH4OAc (pH 7.0) and displacement of adsorbed NH_4^+, respectively, with 0.1N K_2SO_4 (Hendershot et al. 1993). Bulk density was determined according to the core method (de Boodt and Verdonck 1972). Soil water content at field capacity (− 33 kPa) of polybag medium before planting was determined using pressure plate technique (Dane and Hopmans 2002). Meanwhile, plant tissue samples were then digested using wet digestion with concentrated H_2SO_4 and 30% H_2O_2 (Wolf 1982).

Determination of nutrient retention

Nutrient retention was determined indirectly by measuring the amount of nutrients leached through the polybag medium from biochar-amended and un-amended soil. Lower total amount of nutrients in the leachate collected indicates less soluble nutrients loss through water movement out of root zone. The treatments selected were the four rates of biochar (0, 0.5, 1.0, and 1.5% w/w C addition) without compost (C0) but with 100% recommended rate of fertiliser (F100). Three replicates were selected for each treatment. A polybag was placed in a 6-L plastic basin with a cylindrical PVC pipe (10 cm in height × 10 cm in diameter). A tube was attached to the basin to collect any overflow leachate so as to prevent the polybag from soaking in the leachate especially after heavy rain.

Leachates were collected and the volume was recorded twice a week. During heavy rainfall, leachates were collected more frequently. The collected leachates were filtered with Whatman No. 42 filter paper, and acidified with a drop of 5.76M HCl (only for NO_3^--N) and kept frozen (− 20 °C) until analysis. The NH_4^+-N, NO_3^--N and PO_4^{-3} concentrations in the leachate were analysed with an autoanalyser (LACHAT Instrument, QuikChem FIA + 8000 series). Soluble K^+ concentrations were determined with atomic absorption spectrophotometer (AAS; PerkinElmer PinAAcle 900T).

Statistical analysis

Analysis of variance (ANOVA) was conducted using SAS version 9.4 (SAS Institute, Inc., Cary, NC, USA.). The significant differences between treatment means were analysed using Least Significant Difference (LSD) test at $P < 0.05$. Regression analysis was performed using SigmaPlot software version 12 (Systat Software, Inc., San Jose California USA) to predict oil palm biomass (shoot and root dry weight) response towards biochar amendment. Pearson's correlation analysis was conducted to test relationships between variables.

Results

Characteristics of amended and un-amended polybag media before planting

Physical and chemical properties of polybag medium with and without amendment are shown in Table 4. The un-amended polybag medium was an acidic sandy clay soil

Table 4 Selected physical and chemical properties of polybag medium before planting ($n = 4$)

Compost % (v/v)	0	0	0	0	30	30	30	30
Biochar C addition % (w/w)	0	0.5	1	1.5	0	0.5	1	1.5
Bulk density (g cm^{-3})	1.1^b	1.2^a	1.0^c	1.0^c	1.0^c	1.0^c	0.9^d	0.9^d
Moisture content$^\$$ (%)	16.7	16.5	17.5	17.5	17.1	17.8	20.9	20.0
Soil pH	4.4^g	4.6^f	4.8^e	5.0^d	6.5^c	6.7^b	6.8^a	6.7^b
Total C (%)	0.8^f	1.7^e	2.1^e	3.0^d	3.6^c	4.3^b	4.8^b	5.4^a
Total N (%)	0.10^c	0.10^c	0.11^c	0.14^b	0.37^a	0.39^a	0.37^a	0.39^a
C:N ratio	9.7^f	17.5^c	19.3^b	21.0^a	9.7^f	11.2^e	12.8^d	13.9^d
Av. P (mg kg^{-1})	11^f	13^{ef}	13^{ef}	17^e	544^d	601^b	551^c	649^a
Ext. K (mg kg^{-1})	86^h	260^g	1529^f	1920^e	5035^d	6220^c	7272^b	7294^a
Ext. Mg (mg kg^{-1})	26^g	36^f	126^e	156^d	991^c	1112^a	1073^b	1068^b
Ext. Ca (mg kg^{-1})	277^h	398^g	1054^f	1230^e	5902^a	5340^c	5463^b	4983^d
CEC ($cmol_{(+)}$ kg^{-1})	3.3^f	4.5^e	7.3^d	7.4^d	12.6^c	13.6^b	13.5^b	14.5^a

Av. available, *Ext.* extractable

Moisture Content$^\$$ percentage of moisture content at − 33 kPa ($n = 1$); within each row, means with different letters are significantly different at $P \leq 0.05$ according to LSD test with pH of 4.4 and low total carbon content of 8.1 g kg^{-1}. Polybag medium amended with biochar, compost, and their combination significantly improved pH value by 0.59, 2.14, and 2.45 units, respectively, as compared to un-amended soil. Total C, N, and CEC were also significantly improved with biochar application and further improved ($P < 0.05$) with compost addition. This was accompanied by significant increase of cations concentrations (K, Mg, and Ca). C:N ratio for all amended soil were increased slightly (9.7–21.0). The volumetric soil moisture content at field capacity was 16.7% in un-amended soil, and 16.5–20.9% in all amended soil. Therefore, the results showed that treatment with soil amendment, either biochar or compost exhibited a positive effect on chemical properties on oil palm seedling media as compared to control (Table 4).

Plant growth response to biochar and compost amendment

Regression analysis showed that shoot dry weight (DW) biomass responded as quadratic relationship ($P < 0.05$) with increasing biochar carbon addition in polybag media without compost for both 75 and 100% fertiliser rates (Fig. 2). Treatment with 100% recommended fertiliser rate yields the highest shoot biomass production. However, shoot biomass initially declined with increasing biochar rates (up to 1.0% w/w C) before it started to show a positive response at higher biochar application rate. In contrast, shoot biomass of compost-amended treatments followed a positive quadratic relationship ($P < 0.05$) for 100% fertiliser application rate with increasing biochar addition. The maximum shoot DW biomass was recorded at biochar-compost treatment, peak of 370 g $plant^{-1}$ when applied with 0.77% w/w C at 100% fertiliser application rate. In general, although co-application of compost and biochar amendment tend to show positive effect on shoot DW, none of the combination treatment significantly outperformed ($P < 0.05$) the control treatment (without biochar and compost but fertilised with 100% fertiliser rate).

Root DW response fitted into a quadratic relationship model with biochar application with and without compost amendment (Fig. 3). Among all treatments, the highest root

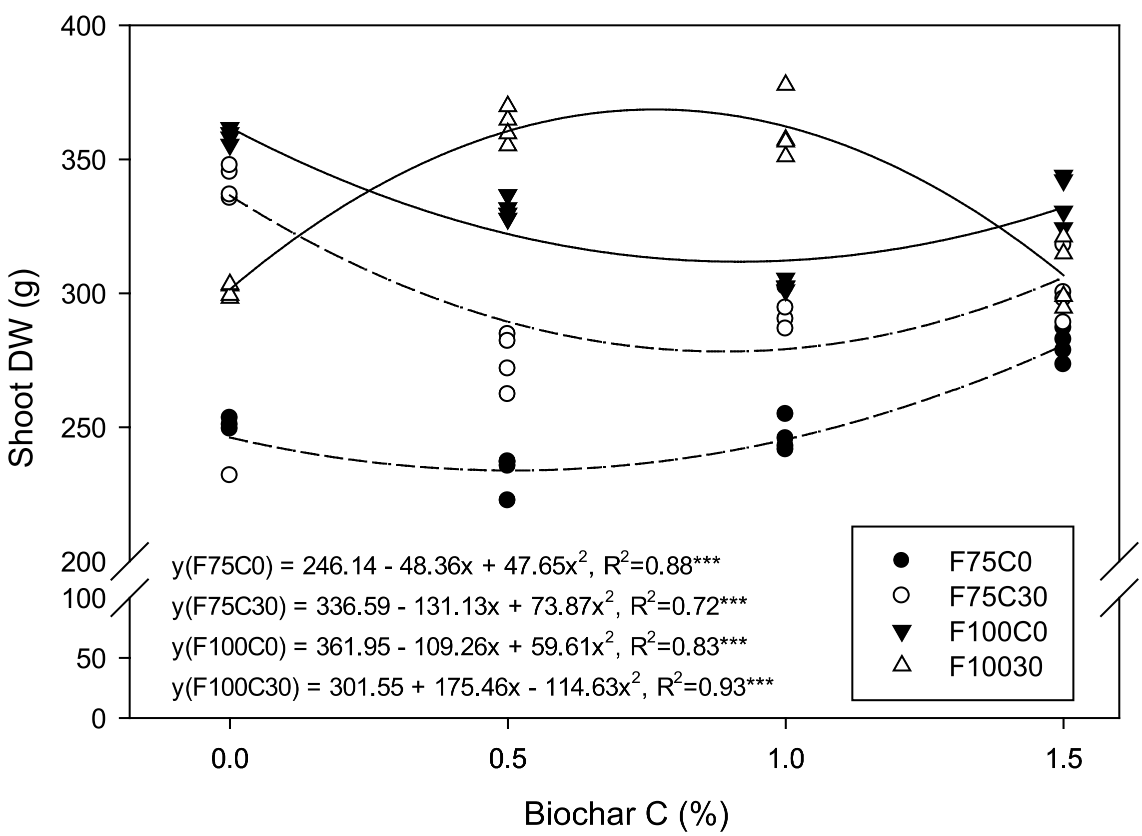

Fig. 2 Shoot dry weight of oil palm seedling as affected by fertiliser recommended rates (75 and 100%) and biochar rates (0, 0.5, 1.0 and 1.5% biochar C) in media without and with compost treatment (0 and 30% v/v). Asterisk symbols indicates a significant regression trend at $^{***}P \leq 0.001$, ($n = 4$). Notes: *F75C0* 75% fertiliser recommended rate in soil without compost; *F75C30* 75% fertiliser recommended rate in soil with 30% v/v compost; *F100C0* 100% fertiliser recommended rate in soil without compost; *F100C30* 100% fertiliser recommended rate in soil with 30% v/v compost

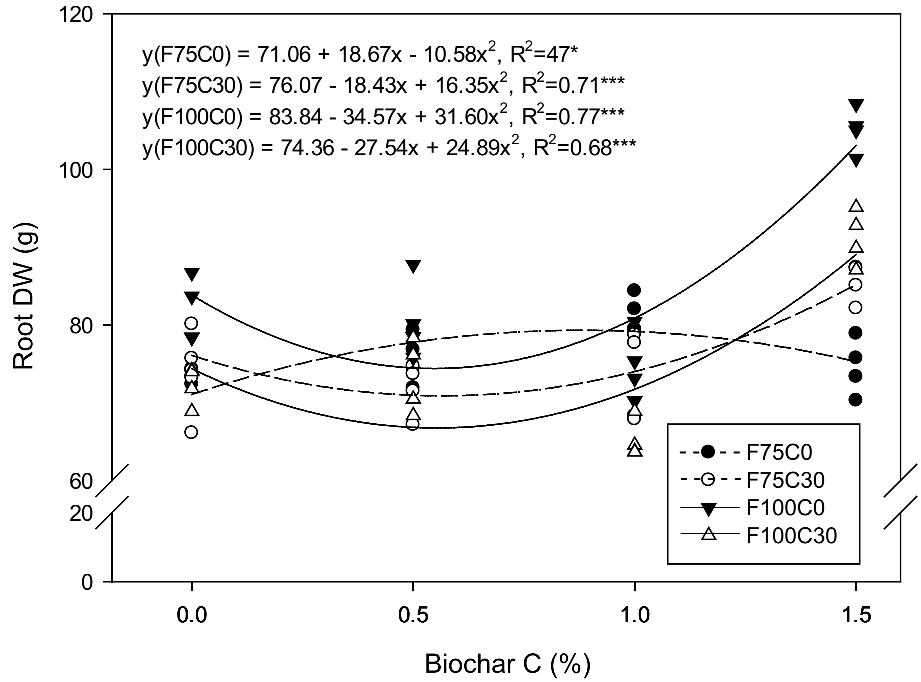

Fig. 3 Root dry weight of oil palm seedling as affected by fertiliser recommended rates (75 and 100%) and biochar rates (0, 0.5, 1.0 and 1.5% biochar C) in media without and with compost treatment (0 and 30% v/v compost). Asterisk symbols indicates a significant regression trend at *$P \leq 0.05$ and ***$P \leq 0.001$ respectively, ($n = 4$). Note: *F75C0* 75% fertiliser recommended rate in soil without compost; *F75C30* 75% fertiliser recommended rate in soil with 30% v/v compost; *F100C0* 100% fertiliser recommended rate in soil without compost; *F100C30* 100% fertiliser recommended rate in soil with 30% v/v compost

DW was obtained with 1.5% w/w C application in polybag media without compost and applied with 100% fertiliser rates. Meanwhile, with compost amendment, biochar applied at 1.5% w/w C with 75% fertiliser rates was able to achieve same root biomass as 100% fertiliser application and was comparable with control treatment.

The shoot to root ratio is commonly used to estimate relative biomass allocation between roots and shoots. It gives estimation of the distribution of dry matter between the root and the shoot systems. Oil palm seedlings fertilised with 100% fertiliser rate have higher shoot:root ratio value as compared to 75% fertiliser rate (Fig. 4). However, treatments with highest biochar rate (1.5% w/w C) showed reduced shoot:root ratio in both with and without compost amendment, and this was found to be significantly lower than control.

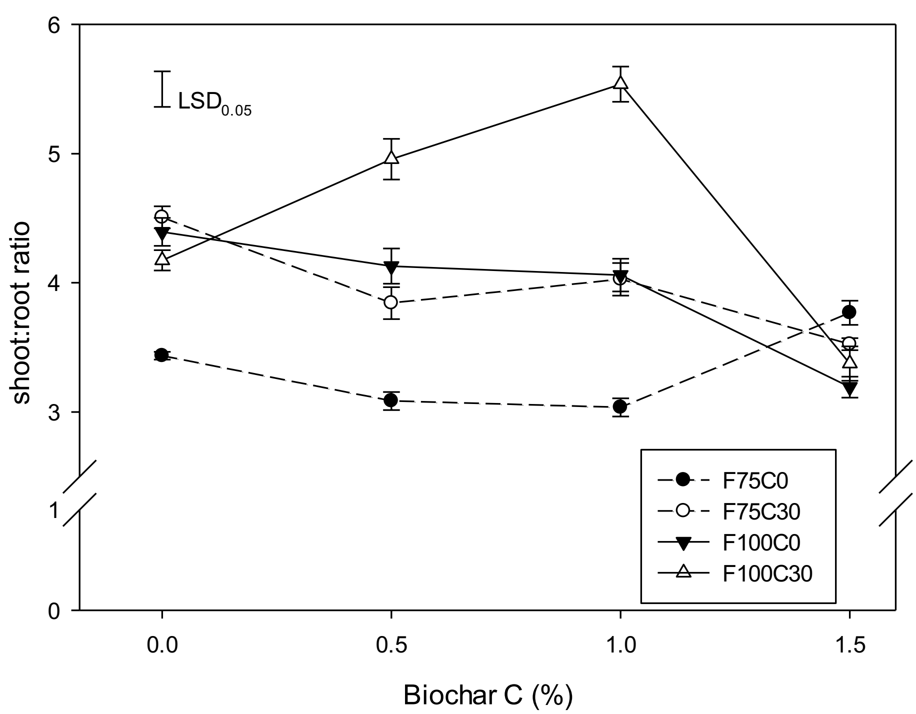

Fig. 4 The interactive effect of fertiliser rates (75 and 100%) and biochar rates (0, 0.5, 1.0 and 1.5% biochar C) in media without and with compost treatment (0 and 30% v/v compost) on shoot:root ratio (mean ± standard error) of oil palm seedling, ($n = 4$). Note: *F75C0* 75% fertiliser recommended rate in soil without compost; *F75C30* 75% fertiliser recommended rate in soil with 30% v/v compost; *F100C0* 100% fertiliser recommended rate in soil without compost; *F100C30* 100% fertiliser recommended rate in soil with 30% v/v compost

Plant nutrient uptake as influenced by biochar and compost amendment

Biochar treatment(s) without compost did not affect N uptake for both 75 and 100% fertilizer rates, but showed significant interaction effect between biochar and compost; increasing rate of biochar applied decrease N uptake when co-applied with compost amendment (Fig. 5). Co-application of compost and biochar up to 1.0% w/w C addition with 100% fertiliser rate positively affect P uptake and was significantly higher than control treatment. However, for soil without compost, application of biochar had no significant effects on P uptake. There was no significant improvement of K uptake in both soil with and without compost as compared to control treatment, but 100% fertiliser with biochar–compost mixture (application up to 1.0% w/w C addition) showed a comparable K uptake with control.

Soil chemical properties after 212 days of amendment application

Biochar amendment significantly improved soil pH by 0.2–0.5 units (application from 0.5–1.5% w/w C rates) as compared to control and 0.1 units as compared to soil with compost-only amendment (Table 5). Total C and N also increased with biochar rates with the highest impact recorded in media with compost amendment. The highest biochar application rate (1.5% w/w C) improved CEC in polybag media, by 45% as compared to control and 16% compared to media applied with compost alone. There was no significant difference of C:N ratio between control treatment and treatment with compost-only amendment, but in the presence of biochar, C:N ratio value proportionally increased with increasing biochar rates, where greatest changes were observed in media without compost.

Biochar did not affect soil K, but available P, Mg and Ca showed significant increase with biochar application rates. With compost amendment, concentrations of K, Mg, and Ca were positively affected by biochar, application up to 1.0% w/w C addition. Meanwhile for available P, the highest concentration was found at 0.5% w/w C rates, but, further application reduced available P in the presence of compost amendment.

Effects of biochar on nutrient leaching

Results showed that biochar significantly reduced NH_4^+-N leaching loss by 21, 44, and 46% in the 0.5, 1.0, and 1.5% w/w C addition, respectively, when compared with control (Fig. 6). NH_4^+-N leached was relatively low (10.8–125.5 mg polybag^{-1}) during the first 114 days of planting before a sharp increase was detected across all treatments thereafter. In contrast, the amount

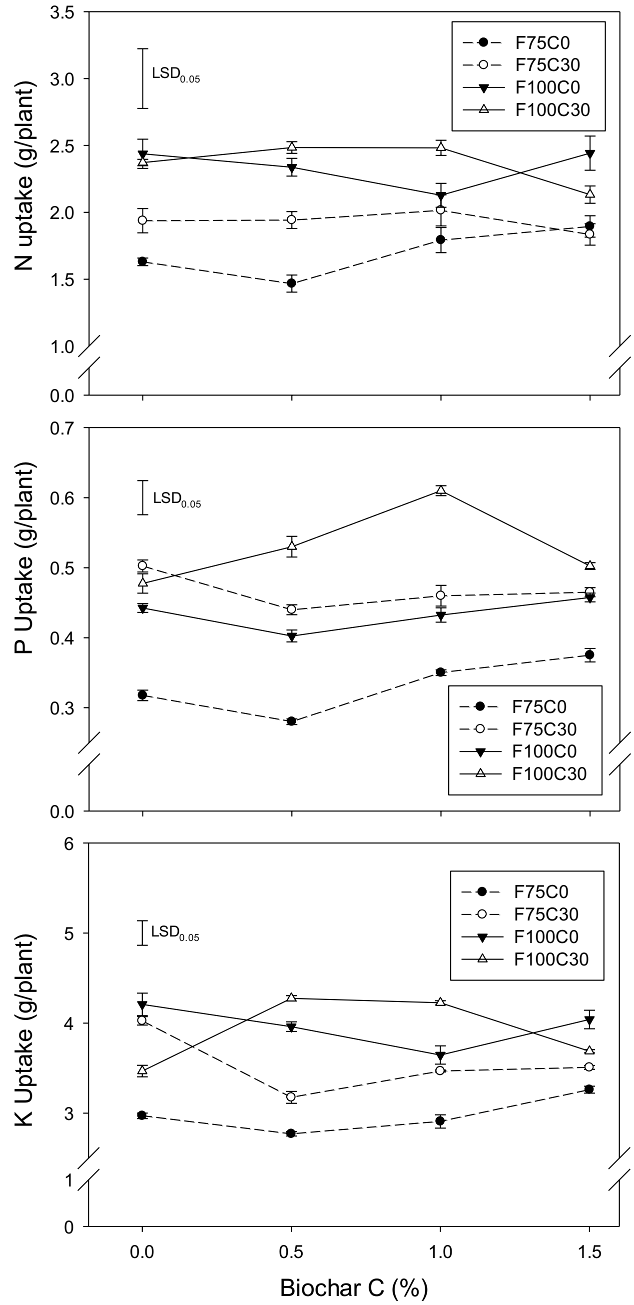

Fig. 5 The interactive effect of fertiliser rates (75 and100%) and biochar rates (0, 0.5, 1.0 and 1.5% C addition) in media without and with compost treatment (0 and 30% v/v compost) on N, P and K uptake (mean ± standard error), (n = 4). Note: *F75C0* 75% fertiliser recommended rate in soil without compost; *F75C30* 75% fertiliser recommended rate in soil with 30% v/v compost; *F100C0* 100% fertiliser recommended rate in soil without compost; *F100C30* 100% fertiliser recommended rate in soil with 30% v/v compost

of NO_3^--N leached steadily increased up to 114 days and thereafter become more gradual until the end of this study period. Overall, biochar amendment showed no significant influenced on total NO_3^--N leached over

Table 5 Effects of biochar rates (0, 0.5, 1 and 1.5% w/w C addition) on chemical properties of polybag medium without and with compost amendment after 212 days cultivation (n = 8)

Compost % (v/v)	0	0	0	0	30	30	30	30
C addition % (w/w)	0	0.5	1	1.5	0	0.5	1	1.5
Soil pH	4.5^{d}	4.7^{c}	5.0^{a}	4.9^{b}	6.6^{B}	6.7^{A}	6.7^{A}	6.6^{B}
Total C (%)	0.9^{d}	2.0^{c}	2.6^{b}	3.5^{a}	3.1^{D}	3.9^{C}	4.6^{B}	5.2^{A}
Total N (%)	0.10^{b}	0.10^{b}	0.11^{b}	0.14^{a}	0.30^{A}	0.31^{A}	0.31^{A}	0.33^{A}
C:N ratio	12.9^{c}	19.6^{b}	22.9^{a}	24.9^{a}	11.1^{C}	12.6^{B}	14.4^{A}	15.5^{A}
Av. P (mg kg^{-1})	309^{b}	324^{ab}	349^{a}	295^{b}	873^{C}	1095^{A}	961^{B}	780^{D}
Ext. K (mg kg^{-1})	71^{a}	67^{a}	73^{a}	71^{a}	202^{B}	238^{A}	240^{A}	212^{B}
Ext. Mg (mg kg^{-1})	30^{b}	32^{b}	40^{a}	40^{a}	168^{D}	203^{C}	257^{A}	214^{B}
Ext. Ca (mg kg^{-1})	351^{b}	372^{b}	434^{a}	447^{a}	1552^{D}	1618^{C}	1992^{A}	1744^{B}
CEC (cmol$_{(+)}$ kg^{-1})	4.0^{d}	4.5^{c}	5.2^{b}	5.8^{a}	8.0^{B}	8.5^{B}	9.8^{A}	9.3^{A}

Within each row, means with different letters (small and capital letter) are significantly different at respective compost rates (0 and 30% v/v, respectively) at $P \leq 0.05$ according to LSD test

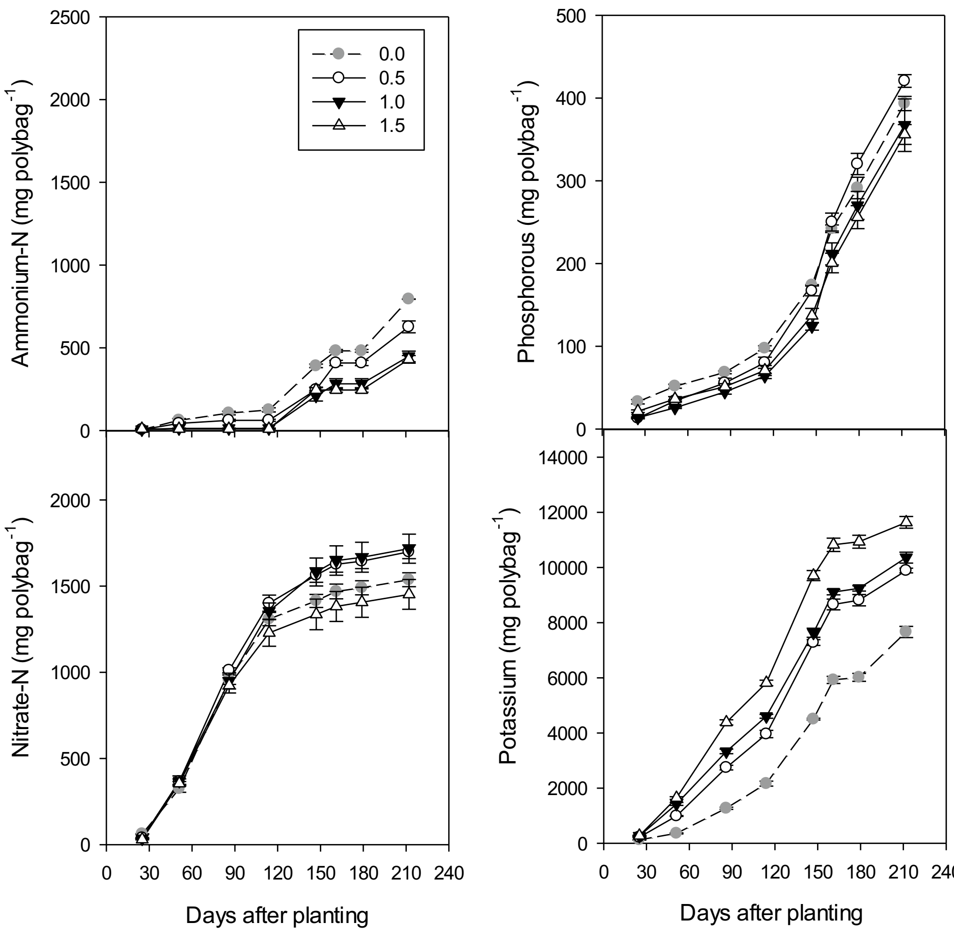

Fig. 6 Effects of biochar (0, 0.5, 1.0 and 1.5% C addition) application rates on cumulative leaching of NH_4^+-N, NO_3^--N, PO_4^{-3}, and K^+ (mean ± standard error) throughout the study period. (n = 3)

the experimental period. Similar to NO_3^--N, cumulative data of PO_4^{-3} leached showed that biochar amendment was not effective in retaining PO_4^{-3}. However, during the first 114 days, biochar amendment apparently reduced P loss in biochar-treated media by 18–34% as compared to control treatment, but the effects become negligible thereafter, especially during the period with excess rainfall (115–212 days). Potassium was leached out and this was more significant especially for soil with biochar amendment. The highest biochar rates resulted in the higher K concentration leached.

Discussion

The application of biochar, compost, and biochar-compost mixture as soil amendment for oil palm seedling significantly improved physico-chemical properties of the polybag medium and root development of the seedling. Biochar amendment had an important impact on the growth of root and shoot:root ratio. Reduction of bulk density in amended polybag media (Table 4) could be attributed to the increase in pore spaces due to biochar application, facilitating better root branching and root penetration depth (Bruun et al. 2014). In addition to root growth response, the application of biochar at 1.5% w/w C with and without compost amendment positively affect seedling shoot to root ratio. A lower shoot:root ratio meant that plant may have less water stress as the roots are better developed with respect to the aboveground parts. Furthermore, plants with higher shoot:root ratio are likely to be susceptible to water stress, particularly during dry season or under condition of high evaporative demand, while in this case was during the transplanting of oil palm seedling from polybag to the field. A number of studies have reported that plant seedling with more root volume have higher chances of survival after field transplanting (Haase and Rose 1994; Davis and Jacobs 2005). Better root system may led to greater capability for absorption and transportation of water, thus improving the plant's ability to handle environmental stress (Jacobs et al. 2005; Grossnickle 2012). However, there were minimal observable positive effects of biochar on shoot biomass and nutrient uptake of oil palm seedling. This insignificant response on plant growth was probably associated with the insignificant improvement in nutrients uptake. The delayed effects of biochar on plant nutrients uptake (especially N, P and K) was likely due to temporary unavailability of nutrients for plant uptake (Lentz and Ippolito 2012) and N immobilisation when C:N ratio was above 16 (Alburquerque et al. 2014; Walter and Rao 2015). The C:N ratio of EFB biochar was 93, and therefore, it potentially induced the immobilisation of mineral N. This was also supported by the observation in plant N, P, and K uptake, where the treatments with biochar showed no significant contribution in both 75 and 100% fertiliser rates. However, for medium with compost, biochar showed positive effects on shoot biomass, particularly when combined with recommended fertiliser rate (100%). For instance, significant increment (by 37.9%) in P uptake as compared to control treatment was observed in co-application of compost and biochar (1.0% w/w C) and treated with 100% fertiliser rate. According to Khan and Joergensen (2012) and Agegnehu et al. (2016), the incorporation of biochar and compost in soil could potentially improve P availability and significantly stimulate P uptake by ryegrass and maize plant, respectively. This was probably due to biochar's liming effects that decreased P fixation by Al and Fe oxide in the soil (Yuan and Xu 2011; Cui et al. 2011). In this study, notable pH improvement was observed especially in biochar-compost amendment (pH 6.6) as compared to control treatment (pH 4.4). Macronutrients (particularly N, P and K) played a vital role, especially to the growth of young oil palm. For instance, N and K are the essential nutrients for improvement of vegetative dry matter production and leaf area index of young oil palm (Corley and Mok 1972; Squire 1984). This was supported by correlation coefficients analysis, which revealed that the shoot biomass was positively correlated with N ($R = 0.80$, $P < 0.001$) and K uptake ($R = 0.79$, $P < 0.001$). In general, nutrient level in polybag media with biochar-compost amendment remained high as compared to control treatment at the end of the study period (Table 5). High nutrients content remaining in polybag medium could benefit root establishment once seedlings with amended media were transplanted into the field.

This study also suggests that application of biochar may have inhibited C losses when the amendments were combined together (Table 6); the drastic losses of total C were detected in compost-only amendment (15.83%) and lowest biochar rates (0.5% w/w C; 9.31%). In contrast, with higher biochar C rates (1.0 and 1.5% w/w C), the total C of media before planting were statistically not different as compared to after planting. In polybag medium without compost amendment, total C remained unchanged until the end of the study (Table 6). Thus, the stabilisation of C in polybag medium highlighted the potential of EFB biochar for long-term carbon accumulation once the seedlings were transferred into the field. The recalcitrance of biochar C following its application was observed by Steiner et al. (2007).

Leaching of nutrient might be influenced by sorption capacity of biochar. Lower amount of nutrient leached in

Table 6 Effects of EFB biochar rates (0, 0.5, 1, 1.5% w/w C addition) on total C in soil without (C0) and with compost (C30) amendment before planting and after 212 days cultivation

C addition % (w/w)	Total C (%)			
	C0		C30	
	Before	After	Before	After
0	0.8^a	0.9^a	3.6^A	3.1^B
0.5	1.7^a	2.0^a	4.3^A	3.9^B
1	2.1^a	2.6^a	4.8^A	4.6^A
1.5	3.1^a	3.5^a	5.4^A	5.2^A

C0 0% v/v compost, *C30* 30% v/v compost

Means with different letters are significantly different between before and after treatments each of biochar rate at $P \leq 0.05$ according to LSD test biochar amended soil may indicate higher retention of nutrient in the medium, and more nutrients available for plant uptake. The capability of biochar to reduce NH_4^+-N losses was frequently reported under controlled environment (Sika and Hardie 2014; Kammann et al. 2014) and natural leaching condition (Ventura et al. 2013; Sorrenti et al. 2012). These evidence suggested that the physico–chemical characteristics of biochar, which has high cation exchangeable capacity (Liang et al. 2006) and surface area with the presence of polar and non-polar surface site (Cheng et al. 2008; Ding et al. 2010) make it a good soil nutrient-retaining additive. Another possible theory is that NH_4^+-N may have remain clogged inside biochar pores structures (Saleh et al. 2012) as biochar pore sizes varies due to its production method and types of feedstock. In contrast, biochar showed insignificant effect on NO_3^--N leaching throughout the study period. Theoretically, anion exchange capacity of biochar is usually very low (Mukherjee et al. 2011; Taghizadeh-Toosi et al. 2011) and eventually decreased over time (Cheng et al. 2008). Thus, NO_3^- ions were not strongly held on biochar surfaces. Regardless of the treatment rates, most of inorganic N leached was mainly in the form of NO_3^--N. The ammonium-nitrate based of compound fertiliser (NPK blue) used in this study was presumably responsible for the greater concentration of NO_3^--N leached. Biochar amendment also did not influence the cumulative concentration of P in leachates. Previous studies suggested that P was not likely sorbed to the surface of the majority types of biochar (Yao et al. 2012; Hale et al. 2013; Zheng et al. 2013) due to the negative surface charges. Therefore, negligible effect of EFB biochar on P release pattern was expected and confirmed by the leaching results. The amount of K leached was highest as compared to control and corresponded well with the amount of biochar applied. This reflected the relatively high K content from EFB biochar (Tables 2 and 4) which led to higher K released, especially at the early stage.

Conclusions

Considering the potential effect of EFB biochar on root growth and shoot:root ratio obtained from this study, the optimum treatment was the co-application of EFB biochar at 1.5% w/w C addition and compost at 30% (v/v) as amendment in oil palm polybag media and fertilised with 75% fertiliser recommended rate. With biochar and compost amendment, there is an option to reduce chemical fertilizer usage, thus offering a more sustainable solution for the production of oil palm seedling and oil palm waste recycling. In addition, the results also provided the evidence of EFB as a potential feedstock for biochar production to effectively retain $NH4^+$ -N in polybag medium under field conditions. Total C of biochar-amended soil remained the same after 7 months of application indicating that biochar C is stable and may contribute to carbon storage in oil palm field. This indicates the potential of EFB biochar to sequester carbon in oil palm field which consequently contributes towards C credit in oil palm plantation sector.

Acknowledgements The authors would like to thank Universiti Putra Malaysia for providing the facilities.

Compliance with ethical standards

Conflict of interests The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Agegnehu G, Bass AM, Nelson PN, Bird MI (2016) Benefits of biochar, compost and biochar—compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. Sci Total Environ 543:295–306. https://doi.org/10.1016/j.scitotenv.2015.11.054

Alburquerque JA, Calero JM, Barrón V, Torrent J, Del Campillo MC, Gallardo A, Villar R (2014) Effects of biochars produced from different feedstocks on soil properties and sunflower growth. J Plant Nutr Soil Sci 177:16–25. https://doi.org/10.1002/jpln.201200652

ASTMD1762-84 (2007) Standard test method for chemical analysis of wood charcoal. ASTM International, West Conshohocken PA. http://www.biochar-international.org/sites/default/files/ASTM%20D1762-84%20chemical%20analysis%20of%20wood%20charcoal.pdf. Accessed 14 Feb 2016

Bedada W, Karltun E, Lemenih M, Tolera M (2014) Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. Agric Ecosyst Environ 195:193–201. https://doi.org/10.1016/j.agee.2014.06.017

Blanchet G, Gavazov K, Bragazza L, Sinaj S (2016) Responses of soil properties and crop yields to different inorganic and organic amendments in a Swiss conventional farming system. Agric Ecosyst Environ 230:116–126. https://doi.org/10.1016/j.agee.2016.05.032

Bray RH, Kurtz LT (1945) Determination of total, organic, and available forms of phosphorus in soils. Soil Sci 59:39–46

Bruun EW, Petersen CT, Hansen E, Holm JK, Hauggaard-Nielsen H (2014) Biochar amendment to coarse sandy subsoil improves root growth and increases water retention. Soil Use Manag 30:109–118. https://doi.org/10.1111/sum.12102

de Boodt M, Verdonck O (1972) The physical properties of the substrates in horticulture. Acta Hortic 26:37–44. https://doi.org/10.17660/ActaHortic.1972.26.5

Campbell CR, Plank CO (1998) Preparation of plant tissue for laboratory analysis. In: Kalra YP (ed) Handbook of reference methods for plant analysis. CRC Press, Boca Raton, pp 37–49

Cheng CH, Lehmann J (2009) Ageing of black carbon along a temperature gradient. Chemosphere 75:1021–1027. https://doi.org/10.1016/j.chemosphere.2009.01.045

Cheng CH, Lehmann J, Engelhard MH (2008) Natural oxidation of black carbon in soils: changes in molecular form and surface charge along a climosequence. Geochim Cosmochim Acta 72:1598–1610. https://doi.org/10.1016/j.gca.2008.01.010

Corley RHV, Mok CK (1972) Effects of nitrogen, phosphorus, potassium and magnesium on growth of the oil palm. Exp Agric 8:347–353. https://doi.org/10.1017/S0014479700005470

Cui HJ, Wang MK, Fu ML, Ci E (2011) Enhancing phosphorus availability in phosphorus-fertilized zones by reducing phosphate adsorbed on ferrihydrite using rice straw-derived biochar. J Soils Sediments 11:1135–1141. https://doi.org/10.1007/s11368-011-0405-9

D'Hose T, Cougnon M, De Vliegher A, Vandecasteele B, Viaene N, Cornelis W, Van Bockstaele E, Reheul D (2014) The positive relationship between soil quality and crop production: a case study on the effect of farm compost application. Appl Soil Ecol 75:189–198. https://doi.org/10.1016/j.apsoil.2013.11.013

Dane JH, Hopmans JW (2002) Water retention and storage. In: Dane JH, Topp GC (eds) Methods of soil analysis part 4, 5th edn. Soil Science Society of America, Madison, pp 671–796

Danso F, Adu C, Opoku A, Danso I, Anim Okyere S, Larbi E (2013) Raising oil palm seedlings using sole and amended green-gro compost. Int Res J Agric Sci Soil Sci 3:362–368

Davis AS, Jacobs DF (2005) Quantifying root system quality of nursery seedlings and relationship to out planting performance. N For 30:295–311. https://doi.org/10.1007/s11056-005-7480-y

Ding Y, Liu YX, Wu WX, Shi DZ, Yang M, Zhong ZK (2010) Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. Water Air Soil Pollut 213:47–55. https://doi.org/10.1007/s11270-010-0366-4

Donn S, Wheatley RE, McKenzie BM, Loades KW, Hallett PD (2014) Improved soil fertility from compost amendment increases root growth and reinforcement of surface soil on slope. Ecol Eng 71:458–465. https://doi.org/10.1016/j.ecoleng.2014.07.066

DOSM (2017) Press release selected agricultural indicators Malaysia 2016. Department of Statistics Malaysia Official Portal. http://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=72&bul_id=T2Z3NkhLSFk2VjZ5dkdUL1JQUGs4dz09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09. Accessed 6 Mar 2017

Ducey TF, Ippolito JA, Cantrell KB, Novak JM, Lentz RD (2013) Addition of activated switchgrass biochar to an aridic subsoil increases microbial nitrogen cycling gene abundances. Appl Soil Ecol 65:65–72. https://doi.org/10.1016/j.apsoil.2013.01.006

Gillbanks AR (2003) Standard agronomic procedures and practices. In: Fairhust T, Hardter R (eds) Oil palm: management for large and sustainable yields. Potash & Phosphate Institute of Canada & International Potash Institute, Singapore, pp 115–150

Gray M, Johnson MG, Dragila MI, Kleber M (2014) Water uptake in biochars: the roles of porosity and hydrophobicity. Biomass Bioenerg 61:196–205. https://doi.org/10.1016/j.biombioe.2013.12.010

Grossnickle SC (2012) Why seedlings survive: influence of plant attributes. N For 43:711–738. https://doi.org/10.1007/s11056-012-9336-6

Haase DL, Rose R (1994) Effects of soil water content and initial root volume on the nutrient status of 2 + 0 Douglas-fir seedlings. N For 8:265–277. https://doi.org/10.1007/BF00025372

Hale SE, Alling V, Martinsen V, Mulder J, Breedveld GD, Cornelissen G (2013) The sorption and desorption of phosphate-P, ammonium-N and nitrate-N in cacao shell and corn cob biochars. Chemosphere 91:1612–1619. https://doi.org/10.1016/j.chemosphere.2012.12.057

Hendershot WH, Lalande H, Duquette M (1993) Ion exchange and exchangeable cations. In: Carter MR, Geogorich EG (eds) Soil sampling and methods of analysis, 2nd edn. Canadian Society of Soil Science, Boca Raton, pp 167–176

Jacobs DF, Salifu KF, Seifert JR (2005) Relative contribution of initial root and shoot morphology in predicting field performance of hardwood seedlings. N For 30:235–251. https://doi.org/10.1007/s11056-005-5419-y

Jien SH, Wang CS (2013) Effects of biochar on soil properties and erosion potential in a highly weathered soil. CATENA 110:225–233. https://doi.org/10.1016/j.catena.2013.06.021

Kameyama K, Miyamoto T, Shiono T, Shinogi Y (2012) Influence of sugarcane bagasse-derived biochar application on nitrate leaching in calcaric dark red soil. J Environ Qual 41:1131–1137

Kammann C, Haider G, Del Campo B, Mengel J, Schmidt HP, Marhan S, Steffens D, Clough T, Müller C (2014) Nitrate retention by biochar: mechanistic insights by 15N tracing. In: ELS2014—The earth living skin: soil, life and climate changes. Bari, Italy 22–25 September 2014

Kammann C, Glaser B, Schmidt HP (2016) Combining biochar and organic amendments. In: Shackley S, Ruysschaert G, Zwar K, Glaser B (eds) Biochar in European soils and agriculture: science and practice. Routledge, London, pp 136–164

Khan KS, Joergensen RG (2012) Relationships between P fractions and the microbial biomass in soils under different land use management. Geoderma 173:274–281. https://doi.org/10.1016/j.geoderma.2011.12.022

Lentz RD, Ippolito JA (2012) Biochar and manure affect calcareous soil and corn silage nutrient concentrations and uptake. J Environ Qual 41:1033–1043

Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'neill B, Skjemstad JO, Thies J, Luizao FJ, Petersen J, Neves EG (2006) Black carbon increases cation exchange capacity in soils. Soil Sci Soc Am J 70:1719–1730

Mathews J, Chong KM, Yong KK, Ip WM (2008) Raising pre-nursery oil palm seedlings in plastic pot tray-an IOI group experience. In: Planter The (ed) The incorporated society of planters. ISP Management Kuala Lumpur, Kuala Lumpur, pp 285–297

Mathews J, Tan TH, Yong KK, Chong KM, Ng SK, Ip WM (2010) Managing oil palm nursery: IOI's experience. In: Planter The (ed) The incorporated society of planters. ISP Management Kuala Lumpur, Kuala Lumpur, pp 771–785

MPOB (2016) Oil palm planted area 2015. Malaysian Palm Oil Board. http://bepi.mpob.gov.my/index.php/en/statistics/area.html. Accessed 1 Oct 2016

Mukherjee A, Zimmerman AR, Harris W (2011) Surface chemistry variations among a series of laboratory-produced biochars. Geoderma 163:247–255. https://doi.org/10.1016/j.geoderma.2011.04.021

Nelson DW, Sommers LE (1982) Total carbon, organic carbon and organic matter. In: Miller RH, Page AL, Keeney DR (eds) Methods of soil analysis: Chemical microbiological properties, part 2. Soil Science Society of America, Madison, pp 539–577

Ninh HT, Grandy AS, Wickings K, Snapp SS, Kirk W, Hao J (2015) Organic amendment effects on potato productivity and quality are related to soil microbial activity. Plant Soil 386:223–236. https://doi.org/10.1007/s11104-014-2223-5

Ogawa M, Okimori Y (2010) Pioneering works in biochar research, Japan. Soil Res 48:489–500

Olmo M, Villar R, Salazar P, Alburquerque JA (2016) Changes in soil nutrient availability explain biochar's impact on wheat root development. Plant Soil 399:333–343. https://doi.org/10.1007/s11104-015-2700-5

Ouni Y, Lakhdar A, Scelza R, Scotti R, Abdelly C, Barhoumi Z, Rao MA (2013) Effects of two composts and two grasses on microbial

biomass and biological activity in a salt-affected soil. Ecol Eng 60:363–369. https://doi.org/10.1016/j.ecoleng.2013.09.002
Paramananthan S (2003) Land selection for oil palm. In: Fairhust T, Hardter R (eds) Oil palm: management for large and sustainable yields. Potash & Phosphate Institute of Canada & International Potash Institute, Singapore, pp 27–57
Prendergast-Miller MT, Duvall M, Sohi SP (2014) Biochar–root interactions are mediated by biochar nutrient content and impacts on soil nutrient availability. Eur J Soil Sci 65:173–185
Rosenani AB, Mohd Zikri O (2006) Utilization of oil palm waste compost in polybag medium for oil palm seedling. In: Fauziah I, Shamshuddin J, Zin ZZ, Zauyah SD, Goh KJ, Jalloh MB, Osumanu HA, Rosazlin A (eds). In: Proceeding of soils conference on strategies for enhanced soil and crop quality. Kuantan, Malaysia 18–20 April 2006
Saleh ME, Mahmoud AH, Rashad M (2012) Peanut biochar as a stable adsorbent for removing NH_4^+-N from wastewater: a preliminary study. Adv Environ Biol 6:2170–2177
Schahczenski J (2010) Biochar and sustainable agriculture. ATTRA Publication, North Carolina
Scotti R, Bonanomi G, Scelza R, Zoina A, Rao MA (2015) Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. J Soil Sci Plant Nutr 15:333–352
Sika MP, Hardie AG (2014) Effect of pine wood biochar on ammonium nitrate leaching and availability in a South African sandy soil. Eur J Soil Sci 65:113–119. https://doi.org/10.1111/ejss.12082
Solaiman ZM, Murphy DV, Abbott LK (2012) Biochars influence seed germination and early growth of seedlings. Plant Soil 353:273–287. https://doi.org/10.1007/s11104-011-1031-4
Sorrenti G, Toselli M, Marangoni B (2012) Use of compost to manage Fe nutrition of pear trees grown in calcareous soil. Sci Hortic 136:87–94. https://doi.org/10.1016/j.scienta.2011.12.033
Squire GR (1984) Light interception, productivity and yield of oil palm. Palm Oil Research Institute of Malaysia, Kuala Lumpur
Steiner C, Teixeira WG, Lehmann J, Nehls T, de Macêdo JLV, Blum WE, Zech W (2007) Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. Plant Soil 291:275–290. https://doi.org/10.1007/s11104-007-9193-9
Suryanto T, Wachjar A, Supijatno (2015) The growth of oil palm (*Elaeis Guineensis Jacq.*) seedlings at various media and containers in double stage nursery. Asian J Appl Sci 3:664–671
Taghizadeh-Toosi A, Clough TJ, Condron LM, Sherlock RR, Anderson CR, Craigie RA (2011) Biochar incorporation into pasture soil suppresses in situ nitrous oxide emissions from ruminant urine patches. J Environ Qual 40:468–476
Ventura M, Sorrenti G, Panzacchi P, George E, Tonon G (2013) Biochar reduces short-term nitrate leaching from a horizon in an apple orchard. J Environ Qual 42:76–82. https://doi.org/10.2134/jeq2012.0250
Verheye W (2010) Growth and production of oil palm. Encyclopedia of Life Support Systems (EOLSS) UNESCO-EOLSS Publishers. http://www.eolss.net/sample-chapters/c10/E1-05A-27-00.pdf. Accessed 7 Apr 2016
Walter R, Rao BK (2015) Biochars influence sweet potato yield and nutrient uptake in tropical Papua New Guinea. J Plant Nutr Soil Sci 178:393–400. https://doi.org/10.1002/jpln.201400405
Wolf B (1982) A comprehensive system of leaf analyses and its use for diagnosing crop nutrient status. Commun Soil Sci Plant Anal 13:1035–1059
Xiao Q, Zhu LX, Zhang HP, Li XY, Shen YF, Li SQ (2016) Soil amendment with biochar increases maize yields in a semi-arid region by improving soil quality and root growth. Crop Pasture Sci 67:495–507. https://doi.org/10.1071/CP15351
Yao Y, Gao B, Zhang M, Inyang M, Zimmerman AR (2012) Effect of biochar amendment on sorption and leaching of nitrate, ammonium, and phosphate in a sandy soil. Chemosphere 89:1467–1471. https://doi.org/10.1016/j.chemosphere.2012.06.002
Yuan JH, Xu RK (2011) The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. Soil Use Manag 27:110–115. https://doi.org/10.1111/j.1475-2743.2010.00317.x
Zheng H, Wang Z, Deng X, Zhao J, Luo Y, Novak J, Herbert S, Xing B (2013) Characteristics and nutrient values of biochars produced from giant reed at different temperatures. Bioresour Technol 130:463–471. https://doi.org/10.1016/j.biortech.2012.12.044
Zulkifli H, Halimah M, Chan KW, Choo YM, MohdBasri W (2010) Life cycle assessment for oil palm fresh fruit bunch production from continued land use for oil palm planted on mineral soil (Part 2). J Oil Palm Res 22:887–894

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.