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Effects of torrefied wood chip and vermicompost application on vegetation growth and nutrient uptake in the Saemangeum reclaimed land

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Abstract

Background: In reclaimed land, the growth environment for plants may be unfavorable and the initial establishment and growth of seedlings could be limited because of low nutrient and water availability. Fertilization and control of understory vegetation that competes with seedlings may be of help in ameliorating soil physical and chemical properties, resulting in better seedling growth and reclamation success. However, the amount of nutrients understory vegetation absorbs in this ecological process has been rarely studied. Thus, we aimed to investigate the effect of soil amendment on biomass production and nutrient uptake by weeds in the nutrient-poor reclaimed area. We applied three levels of torrefied wood chip (TWC; 0, 2.5, and 5 Mg ha^{-1}) and two levels of vermicompost (VC; 0 and 2.7 Mg ha^{-1}) as soil physical improvements and organic soil amendments in reclaimed land in the Republic of Korea, with *Populus euramericana* used as the crop tree.

Results: TWC did not influence weed biomass, but 2.7 Mg ha^{-1} VC significantly increased weed biomass by 21% compared to 0 Mg ha^{-1} VC treatments. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) concentrations in weeds were the highest in control, but there was no statistical difference among treatments. However, VC treatment did marginally increase nutrient uptake in weeds, especially P, K, Ca, and Na. No treatments influenced crop tree height.

Conclusion: We conclude that VC can be used as an organic source of nutrients in reclaimed soil and that weed management is necessary to increase treatment effects on crop trees in this salt-affected reclaimed land.

Keywords: Nutrient content, *Populus euramericana*, Saemangeum, Soil amendment, Weed biomass

Background

Global warming is accelerating due to increased use of fossil fuels and land use changes worldwide (IPCC 2018). In the 2005 Kyoto Protocol, forest restoration was identified as the only carbon sink among existing greenhouse gas sources that can mitigate climate change (UNFCCC 2013; de Coninck et al. 2018). In the Republic of Korea, about 65% (6.4 million ha) of land is composed of forest, but additional afforestation projects are difficult when the remaining land is overwhelmingly devoted to urban development and agricultural land use. Land reclamation is the most efficient way to increase the available land area in Korea (Shi et al. 2002). Korea has established 28,300 ha of reclaimed land in Gunsan and Buan in Jeollabuk-do on the west coast in April 2006 (Bitog et al. 2009). This reclaimed land is considered suitable for producing large quantities of wood biomass, such as wood chips because the area is flat and easily accessible to forestry machinery (KREI 2010). Therefore, Korea has established and

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implemented a poplar afforestation plan in the Saemangeum reclaimed land for afforestation and biofuel production in response to climate change (KFS 2013).

Unfortunately, there are certain constraints limiting the productivity of reclaimed land, which often has harsh growth conditions for plants. Soil salinization constitutes one of the major problems (Haque 2006). Salts mainly occur as NaCl and KCl (Yu et al. 2014). Salinization is the main problem limiting crop productivity, ecological restoration, and land development, and exerts significant toxicity on crops (Guo 2010). Salinization affects soil through both physical processes: poor structural stability because of low organic matter (Oo et al. 2015); and chemical processes: highly soluble salt concentrations (Sumner 2000). Another problem is the lack of soil nutrient availability for seedling growth, particularly low N in mineral soil (Sloan et al. 2016). Jung and Chang (2012) reported that available N was lower in reclaimed soils than in adjacent natural forest soils.

To ameliorate such soils, long-term studies have recommended using several methods—either singly or in suitable combinations—such as utilizing water, special crops, chemical amendments, organic amendments, electric current, phytoremediation, and tillage (De'sigmond 1924; Kelley and Brown 1934; Agarwal et al. 1979; Gupta and Abrol 1990; Oster et al. 1999). Ghafoor et al. (1986) mainly suggested the application of certain amendments to salt-affected soils that can either provide sufficient Ca^{2+} externally or help in the solubilization of native calcite. Even though chemical amendments have long been recognized for their ability to remediate soil salinity (Qadir et al. 2001), many researchers have recently suggested that organic amendments may be applied as preferable alternatives to regenerate soil and enhance fertility in salt-affected reclaimed areas (Tejada et al. 2006; Melero et al. 2007; Wang et al. 2014; Oo et al. 2015).

One of the most widely used and environmentally friendly organic matter applications is vermicompost, which is obtained from the interaction of earthworms and microorganisms in breaking down organic matter (Arancon et al. 2010). It is a kind of peat-like material that is finely divided, has high porosity, aeration, and drainage, and good water-holding capacity (Edwards and Arancon 2004). It also has water-soluble nutrients and is an excellent nutrient-rich organic fertilizer and soil conditioner (Coyne and Knutzen 2010).

Torrefied materials are forms of organic matter produced from the thermal pretreatment of biomass, where raw materials are heated in an inert atmosphere at 200–300 °C (Tran et al. 2013). The resulting product has the properties of lower atomic oxygen-to-carbon (O/C) and hydrogen-to-carbon (H/C) ratios, lower moisture content, and higher hydrophobicity or water-resistivity (Chen et al. 2015). A study on torrefied pine chips and logging residues reported a smaller particle size distribution and higher particle surface area than that of its parent biomass (Phanphanich and Mani 2011). Moreover, application of oak-derived biochar to a Midwestern agricultural soil could increase the Ca^{2+} level in the amended soil (Laird et al. 2010).

Generally, growth in crop trees is positively affected by soil amendments, but such treatments also increase the growth of herbaceous plants, which compete with crop trees for nutrients. Competition by weeds for above- and below-ground resources can slow down the growth of crop trees, leading to a reduction in the quantity and quality of crops. Therefore, weed control in the initial stage of seedling plantation can further help seedling growth by reducing competition for light and soil resources such as water and nutrients (Matsushima and Chang 2007). However, it is unclear exactly how much of the nutrients are absorbed by weeds and experimental data on this matter is still scarce, particularly in reclaimed land where the growth of seedlings may be limited by low nutrient availability.

In this study, we aimed to investigate vegetation growth and nutrient uptake by weeds in reclaimed tidal land applied with organic amendments. We applied torrefied wood chip (TWC) and vermicompost (VC) to improve soil conditions and plant productivity on reclaimed soil, growing *Populus euramericana* as a crop tree. The objectives of this study were (1) to measure weed biomass and crop tree growth, and (2) to quantify the elements that weeds absorbed from the reclaimed soils of Saemangeum amended with TWC and VC. This study will suggest the effective method of soil amendment and productivity management in the nutrient-poor reclaimed land.

Methods

Study site

The study site (35° 51′ 51′′ N, 126° 46′ 32′′ E) is located in the Saemangeum reclaimed land, which has the longest man-made sea dike (33.9 km) and is one of the largest reclaimed areas (8570 ha) in the world (Ryu et al. 2014). It was designed to reclaim land capable of ensuring about 10% of domestic rice production and create a freshwater lake with a storage capacity of 530 million tons to supply adequate water for the rice fields (Cho 2007). Mean annual temperature was 13.8 °C in 2016 and 13.2 °C in 2017, ranging from a maximum of 27.5 °C to a minimum of – 3.9 °C. Annual precipitation measured 1144 mm in 2016 and 771 mm in 2017. The highest rainfall (29%) occurred in July for both years. The pH of the site was slightly basic, with an average value of 8.1 at 0–45 cm soil depths. Nitrogen and organic matter concentrations were very low (Table 1) before treatments were applied.

Table 1 Physico-chemical soil properties of the study site before treatments were applied. Numbers in parentheses represent standard errors (n = 3)

Soil depths (cm)	pH (1:5)	OM (%)	Total N (%)	Available P (mg kg^{-1})	CEC (cmol$_c$ kg^{-1})	Exchangeable cations (cmol$_c$ kg^{-1})				EC (dS m^{-1})
						K^+	Na^+	Ca^{2+}	Mg^{2+}	
0–15	7.9(0.06)^b	0.92(0.07)	0.10(0.02)	29.4(1.4)	12.5(1.3)	1.01(0.05)	2.3(0.12)^b	1.4(0.07)	4.68(0.23)	0.59(0.09)
15–30	8.1(0.09)^{ab}	0.92(0.17)	0.10(0.01)	32.9(1.9)	13.2(1.2)	1.13(0.07)	2.8(0.21)^a	1.5(0.06)	5.15(0.22)	0.56(0.11)
30–45	8.2(0.08)^a	0.73(0.08)	0.11(0.02)	33.1(1.5)	14.5(2.4)	1.08(0.03)	3.0(0.17)^a	1.4(0.06)	4.70(0.19)	0.59(0.08)

Superscript letters on mean values denote significant differences among soil depths

Soil sampling and analyses

Soil samples (n = 3) from three depths (0–15, 15–30, 30–45 cm) were collected at the center of each plot before treatment. Collected soil samples were stored at 4 °C. Soil analyses were conducted based on the standard methods provided by National Institute of Agricultural Science and Technology (NIAST 2000). Soil pH and EC (electrical conductivity) was measured using a 1:5 (w/v) soil:distilled water suspension. Soil organic matter (OM) was determined using the Tyurin method. Total N was measured in 1 g soil using the micro-Kjeldahl method, and available P was measured using the Lancaster method. Cation exchange capacity (CEC) was determined in 1 N HN_4OA_c and CH_3COOH extracts using the Brown method. Exchangeable cations K^+, Ca^{2+}, Mg^{2+}, and Na^+ in the 1 N NH_4OA_c extract were determined using an atomic absorption spectrometer (model AA280FS, Agilent Technologies, Inc., Santa Clara, CA, USA).

Torrefied wood chip and vermicompost characteristics

We used wood chips of *Quercus acutissima* because dead or damaged trees of this species can be easily obtained in Korean forests. Moreover, the growth performance of seedlings was improved in the growing medium substituted by torrefied wood chips of *Q. acutissima* in previous studies (Cho et al. 2017; Han et al. 2017). A wood roaster was used to torrefy wood chips of *Q. acutissima*. It automatically conveys and carbonizes its source, with temperatures ranging from 200 to 250 °C (Lee and Kang 2015). The dimensions of the oak chips were about 2 cm × 2 cm × 0.5 cm. Details of torrefied wood chip (TWC) production are described in Cho et al. (2017).

Vermicompost was purchased from the market (Vermifarm, Goyang-si, Republic of Korea) and was produced by decomposing food and agricultural wastes with the help of earthworms (*Eisenia ferida* and *Eisenia andrei*). The final product is a finely divided peat-like material with high porosity, aeration, drainage, water-holding capacity, and microbial activity, which makes it an excellent soil conditioner (Atiyeh et al. 2000).

Experimental design and plot establishment

After tilling the site, we applied TWC to create better physical soil structure and vermicompost (VC) as an organic source of nutrients, taking into consideration its capacity to enhance nutrients in salt-affected soils. We used a 3 × 2 split-plot design with three replications (Table 2): the main plots consisted of three levels of TWC (0, 2.5, and 5 Mg ha^{-1}), and the subplots consisted of two levels of VC (0 and 2.7 Mg ha^{-1}). The amendments were spread manually on the surface of the study area in March 2016, and then mixed with the soil using tractor. Our study site occupied 1.5 ha of land in 18 experiment plots, each measuring 50 m × 15 m.

Populus euramericana Guinier was planted as the crop tree in this study. *P. euramericana*, an interspecific hybrid between *Populus nigra* and *Populus deltoides*, has been used for biomass production and ecosystem stability in forestry because of rapid growth, rooting ability, active transpiration, and high adaptability in severe environments (Laureysens et al. 2003; Djomo et al. 2011; Su et al. 2011). Also, Lee et al. (2017) reported that *P. euramericana* clones showed better physiological characteristics than *P. deltoides* hybrid clones in the Saemangeum reclaimed land. After amending the soil with TWC and VC, the seedlings were planted in April 2016 with a 1 m × 1 m spacing used both between and within rows, creating a density of 7200 seedlings per hectare. Each plot had 12 planting rows with 50 trees in a row, creating a total of 600 trees per plot. Three

Table 2 Amount of nutrients applied by torrefied wood chip (TWC) and vermicompost (VC) across treatments

Treatment		Elements					
TWC (Mg ha^{-1})	VC (Mg ha^{-1})	N	P	K	Ca	Mg	Na
		(kg ha^{-1})					
0	0	0	0	0	0	0	0
	2.7	19.2	10.1	10.3	61.2	14.2	0.2
2.5	0	1.8	2.4	2.4	25.8	2.1	1.6
	2.7	21.0	12.5	12.7	87.0	16.3	1.8
5.0	0	3.5	4.7	4.9	51.5	4.2	3.2
	2.7	22.7	14.8	15.2	112.7	18.4	3.4

meters of space between two plots was left for management purposes.

Measurement of vegetation growth and nutrient concentrations

We collected aboveground weed samples twice during study period, in August 2017 and September 2018. Weeds growing at the center of each plot were cut in an area of 1 m^2 at 1 cm from the ground level using sickles. Samples were then oven-dried at 65 °C for 72 h and weighed. The difference in weed biomass between 2017 and 2018 was not significant, and so we used average weight of weed biomass (n = 6). Green foxtail (*Setaria viridis* (L.) P. Beauv.) and Common reed (*Phragmites communis* Trin.) were determined to be the dominant weed species and occupied about 90% of the study site.

Weed samples collected in 2017 were used to analyze nutrient concentrations. We used 100 g of material from each treatment to analyze N, P, K, Ca, Mg, and Na concentrations (n = 3). Weed samples were oven-dried at 65 °C for 72 h, then ground in a Wiley mill to pass a 1 mm screen. Concentrations of total N, P, K, Ca, Mg, and Na were determined for weed samples. For total N, a pulverized subsample was analyzed using a carbon-nitrogen elemental analyzer (model NC2100, CE Elantech, Inc., Lakewood, NJ, USA). After dry ashing the samples at 470 °C, the ash was dissolved in 10 mL of 6 M HCl (Wilde et al. 1979). Concentrations of P, K, Ca, Mg, and Na in the acid solution were determined by inductively coupled plasma emission spectrometer (PerkinElmer Life and Analytical Sciences, Shelton, CT, USA). Nutrient content of weeds was determined by multiplying nutrient concentration by total biomass.

We measured crop tree height in August 2017 to investigate growth across treatments. Tree height was measured from ground level to the tip of the main stem. The innermost 60 trees of each plot were used as sample trees for each treatment (n = 3).

Statistical analyses

Two-way analysis of variance (ANOVA) was applied to test the interaction between TWC and VC on weed biomass, weed nutrient uptake, and tree height growth. If the interaction effect was not significant, we performed one-way ANOVA to test the main effects of TWC and VC on weed biomass, nutrient uptake, and tree height with Duncan's multiple range test. All statistical analyses were performed using R (version 3.5.1; R Core Team 2014) at a significance level of 0.05.

Results

Weed biomass and tree growth

TWC and VC did not show any interaction effect on weed biomass (P = 0.39) (Fig. 1). TWC as a main factor also did not show any significant difference among treatment levels (P = 0.26). However, VC significantly increased weed biomass by 21% in the 2.7 Mg ha^{-1} treatment (P = 0.02). Generally, the 2.7 Mg ha^{-1} VC treatments showed slightly higher tree height than those in the 0 Mg ha^{-1} treatments within the same TWC application rate. However, there was no interaction effect (P = 0.62) on crop tree height or for the main effects of TWC (P = 0.98) and VC (P = 0.38) on crop tree height (Fig. 2).

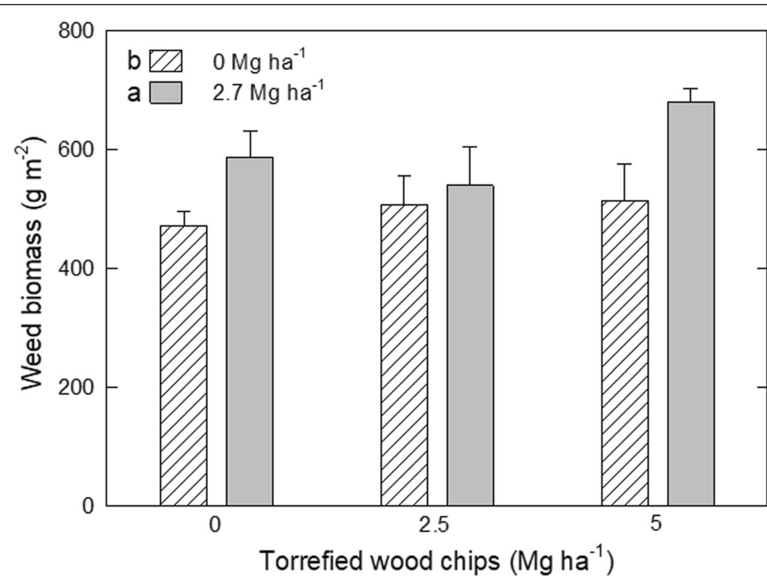

Fig. 1 Weed biomass response to three levels of torrefied wood chip (0, 2.5, and 5 Mg ha^{-1}) and two levels of vermicompost (0 and 2.7 Mg ha^{-1}) treatment. Vertical bars represent standard errors (n = 6). Different letters indicate significant differences between treatments at α = 0.05

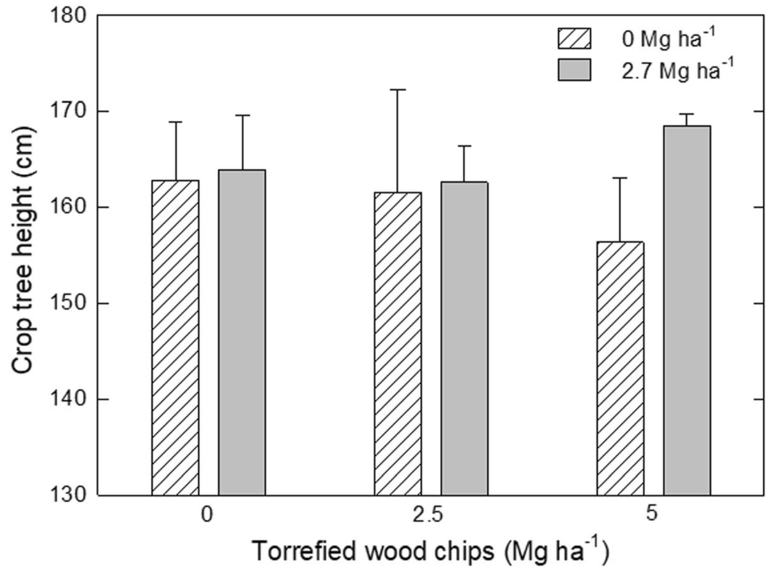

Fig. 2 Height of *Populus euramericana* in August 2017 in response to three levels of torrefied wood chip (0, 2.5, and 5 Mg ha^{-1}) and two levels of vermicompost (0 and 2.7 Mg ha^{-1}) treatment. Vertical bars represent standard errors (n = 3)

Element concentration and uptake by weeds

Concentrations of all the measured elements (N, P, K, Ca, Mg, and Na) in weeds consistently showed the highest values in the control treatment (0 Mg ha^{-1} TWC and 0 Mg ha^{-1} VC) (Table 3), but there was no significant difference among treatments. Nevertheless, P, K, Ca, Mg, and Na concentrations exhibited a decreasing pattern for non-VC applications and increasing pattern at VC treated plots as TWC application increased.

Generally, all element amounts were higher at VC-treated plots than non-VC-treated plots at all levels of TWC application, and non-VC-treated plots exhibited a decreasing pattern for all element amounts as TWC application increased (Fig. 3). Statistically, there was no interaction effect between TWC and VC on all element amounts. TWC showed a marginally significant effect on N content (P = 0.09), but not for other elements. VC application, however, had a significant positive effect on nutrient uptake of P (P = 0.04), and marginally significant effects on uptake of K (P = 0.09), Ca (P = 0.08), and Na (P = 0.07); with P content 23% higher, K 25% higher, Ca 24% higher, and Na 14% higher in the 2.7 Mg ha^{-1} VC application compared with the 0 Mg ha^{-1} VC treatment.

Discussion

Weed biomass, crop tree height, and element uptake of weeds consistently displayed the highest values in the 2.7 Mg ha^{-1} VC treatments compared to 0 Mg ha^{-1} VC treatments (Figs. 1, 2, and 3), which means that VC can be used to supply nutrients required by both weeds and crop trees. The 2.7 Mg ha^{-1} VC treatment in this study resulted in 21% higher weed biomass than the 0 Mg ha^{-1} VC treatment (Fig. 1). This result is in agreement with the results of Amlinger et al. (2007), who reported that using compost is one of the ways to obtain better

Table 3 Element concentrations in weeds after torrefied wood chip (TWC) and vermicompost (VC) treatments

Treatment		Elements					
TWC (Mg ha^{-1})	VC (Mg ha^{-1})	N (g kg^{-1})	P	K	Ca	Mg	Na
0	0	15.0(1.03)	2.8(0.19)	17.6(1.86)	2.7(0.34)	2.8(0.56)	2.8(0.18)
	2.7	12.6(1.73)	2.3(0.45)	15.4(3.17)	2.0(0.29)	1.8(0.44)	2.1(0.17)
2.5	0	10.4(0.55)	2.4(0.12)	15.1(1.51)	2.3(0.17)	2.2(0.22)	2.5(0.31)
	2.7	12.4(2.51)	2.6(0.18)	16.3(1.05)	2.5(0.25)	2.3(0.36)	2.7(0.31)
5.0	0	12.2(1.10)	2.3(0.25)	14.1(0.50)	2.1(0.45)	2.0(0.52)	2.3(0.29)
	2.7	10.7(0.52)	2.6(0.45)	16.1(1.34)	2.4(0.15)	2.3(0.50)	2.3(0.16)

Numbers in parentheses represent standard errors (n = 3)

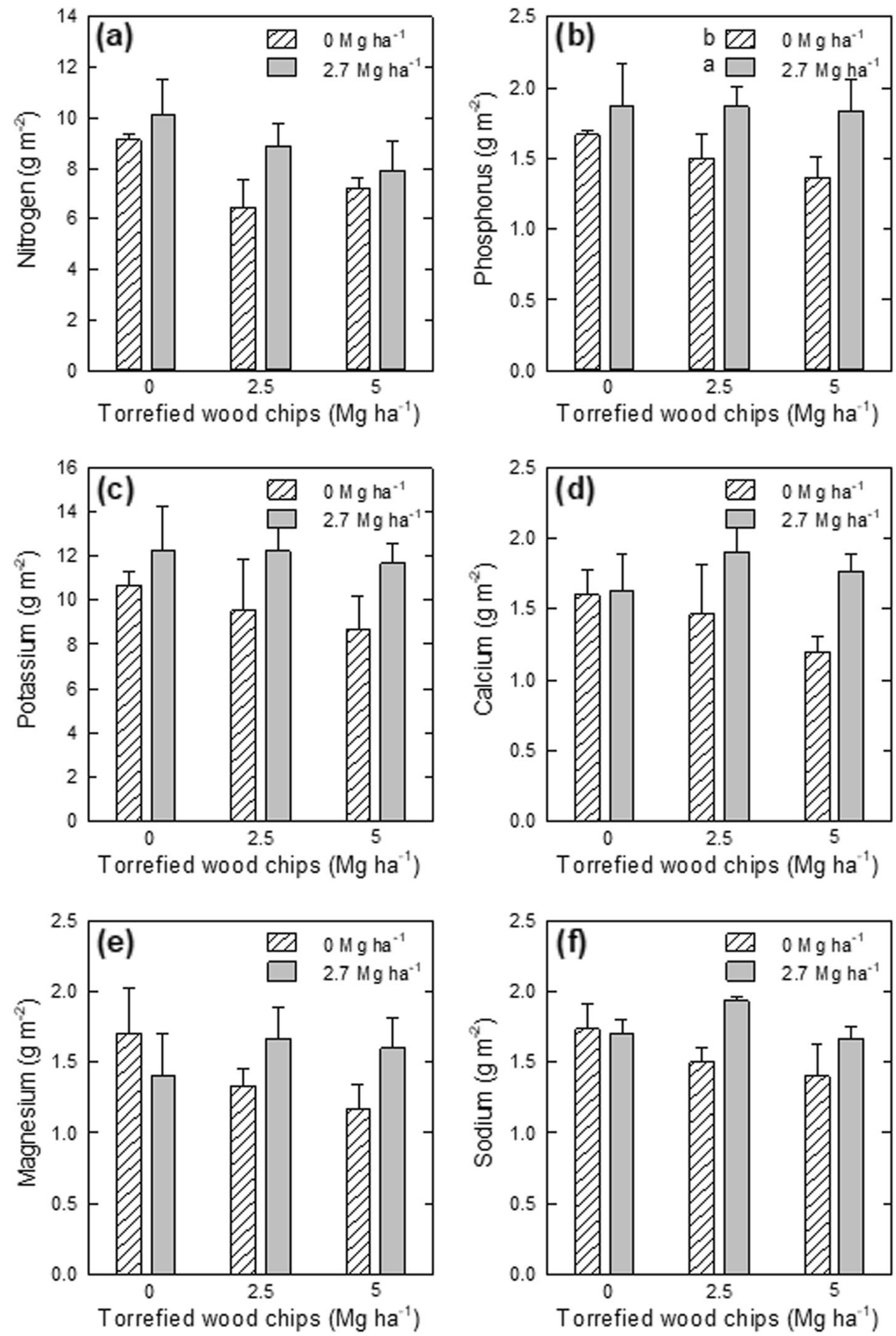

Fig. 3 Uptake of **a** N, **b** P, **c** K, **d** Ca, **e** Mg, and **f** Na by weeds in response to three levels of torrefied wood chip (0, 2.5, and 5 Mg ha^{-1}) and two levels of vermicompost (0 and 2.7 Mg ha^{-1}) treatment. Vertical bars represent standard errors (n = 3). Different letters indicate significant differences between treatments at α = 0.05

crop productivity and quality as it improves soil physical, chemical, and biological properties.

Although nutrient input was the highest in the 5 Mg ha^{-1} TWC/2.7 Mg ha^{-1} VC treatment (Table 2), nutrient uptake by weeds was not the highest in this treatment. In general, nutrient uptake by weed was higher in the 2.7 Mg ha^{-1} VC treatments than the 0 Mg ha^{-1} VC treatments for all measured elements (N, P, K, Ca, Mg, and Na) (Fig. 3). Nutrient uptake in weeds was most responsive to the 2.7 Mg ha^{-1} VC treatment in this study.

One reason for this may be the improvement in microbial properties, as Oo et al. (2015) reported that application of VC can increase soil microbial activities in both saline and non-saline soils. On the other hand, Truong and Marschner (2019) reported that high proportion of sheep manure increased shoot N uptake under N limiting conditions while shoot N uptake decreased with faba bean residues which release large amounts of N. Also, Le and Marschner (2018) showed that available N, microbial biomass N, and inorganic N in leachate was higher in wheat straw than in cow manure. However, available P and inorganic P concentration in leachate increased with increasing proportion of cow manure. Thus, their results suggested the reduction of N mineralization by cow manure whereas the stimulation of P release from cow manure by wheat straw amendment in the mixture.

Even though nutrient uptake by weeds was the highest in 2.7 Mg ha^{-1} VC treatments, nutrient concentration was not. In fact, element concentrations were consistently the highest in the control (0 Mg ha^{-1} TWC, 0 Mg ha^{-1} VC) for all analyzed elements (Table 3). As weed biomass increased by 21% on average in the 2.7 Mg ha^{-1} VC treatment compared to the 0 Mg ha^{-1} VC treatment (Fig. 1), biomass production increased more than nutrient uptake, especially since P, K, Ca, and Na showed positive effects in response to the 2.7 Mg ha^{-1} VC treatment (Fig. 3). According to Timmer and Munson (1991), a dilution effect occurs when nutrient concentrations decrease, while biomass and nutrient uptake increase. Our results are in agreement with those of Imo and Timmer (1992), who used single dose and constant top-dressing fertilization methods to observe the dilution of nutrients in growing mesquite (*Prosopis chilensis*) seedlings in a greenhouse. They found that the seedling growth rate was higher than the rate of nutrient uptake during the growing season.

TWC did not have a significant effect on weed biomass, crop tree height, or nutrient uptake by weeds, except for a marginally significant difference in N content (P = 0.09) (Figs. 1, 2, and 3). However, Lashari et al. (2013) reported the decreased soil pH and sodium contents in salt-affected soils amended by biochar. Also Akhtar et al. (2015) presented the positive effects of biochar on growth and yield of wheat. Particularly, Na^+ concentration was significantly reduced by biochar addition in saline conditions. Hammera et al. (2015) reported similar results that the salt stress was reduced by biochar's ion sorption capacity and the biochar also improved soil nutrient condition. The amount of TWC used in this study might not have been enough to remediate the soil in the study area. We applied a layer of TWC 0.5 cm thick, which is less than that used in other studies. Cogliastro et al. (2001) applied wastewater sludge and woodchips 2 cm thick (200 m^3 ha^{-1}) to soil at a restored site, and concluded that the thickness of woodchips used was insufficient for their study site. Moreover, two years may be not enough time to detect the effect of TWC in alleviating the harsh soil environment in a reclaimed area. Likewise, Amini et al. (2016) suggested that more studies using long-term field experiments across various biochar types and soil conditions are required to fully understand the mechanism of biochar effect on salt-affected soils.

Within the same TWC application rate, weed biomass and nutrient uptake by weeds were higher in the 2.7 Mg ha^{-1} than 0 Mg ha^{-1} VC treatment. The 2.7 Mg ha^{-1} VC treatment seemed to increase nutrients in soil compared to the untreated conditions (Table 1), resulting in better growth of *P. euramericana*. However, weeds also competed with the crop trees for nutrients in the field. For this reason, it is crucial to control weeds during the initial establishment period (Buhler et al. 1998) because competition for light, moisture, nutrient, and space are high at the initial stage of plantation (Sage 1999). Similarly, Hansen and Daniel (1985) reported that a lack of weed control practices can result in 50% or more reduction in crop production. Also, Buss et al. (2018) suggested that we need to be cautious practically when the fertilizer is applied to reclamation lands because it may induce an unexpected result of high production for undesirable plants with the loss of desirable crop trees. As the initial weed growth in this study was vigorous and well-established before the crop trees were planted, they could take up the soil nutrients better than the crop trees. Thus, comprehensive weed management practice is essential for the reclaimed land to benefit from treatment effects, which in turn, can increase the productivity and quality of crops.

Conclusion

Weed biomass and nutrient uptake by weeds increased in 2.7 Mg ha^{-1} vermicompost treatment. However, torrefied wood chip did not exhibit an effect on weed biomass or crop tree height and exhibited little effect on nutrient uptake by weeds. According to these results, we suggest that vermicompost be applied in nutrient-poor soils like those found in Saemangeum reclaimed land area alongside weed control practices to reduce competition between weeds and crop trees. During the initial plantation period, higher planting densities with closer spacing between target trees might also improve establishment of plantations, as weed dominance can be reduced due to higher demand for available resources (light, nutrients, and water) by crop trees. Future studies should focus on a higher application rate of torrefied wood chip and vermicompost in order to gain a better understanding of its effect on reclaimed lands.

Abbreviations

ANOVA: Analysis of variance; Ca: Calcium; CEC: Cation exchange capacity; EC: Electrical conductivity; H/C: Hydrogen-to-carbon ratio; K: Potassium; Mg: Magnesium; N: Nitrogen; Na: Sodium; O/C: Oxygen-to-carbon ratio; OM: Organic matter; P: Phosphorus; TWC: Torrefied wood chip; VC: Vermicompost

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Authors' contributions

Conceptualization: AA and BBP; methodology: AA and BBP; software: AA and JYA; validation: JYA and BBP; formal analysis: AA and BBP; investigation: AA, JMS, SHH, HTTD, and WBY; resources: JMS and WBY; data curation: AA and JYA; writing-original draft preparation: AA; writing-review and editing: AA, JYA, and BBP; visualization: AA and JYA; supervision: JYA and BBP; project administration: BBP; funding acquisition: BBP. All authors read and approved the final manuscript.

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Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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