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VERMICOMPOST AND RICE HUSK BIOCHAR INTERACTION AMELIORATES NUTRIENT UPTAKE AND YIELD OF GREEN LETTUCE UNDER SOILLESS CULTURE

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ABSTRACT

Various kinds of substrates have been widely used for vegetables grown in soilless culture systems. The use of biochar is getting a lot of attention. However, the ideal proportion of biochar in the substrates combined with the use of vermicompost for high yields has not been thoroughly studied. This study aimed to examine in the pot experiment the effect of a combination of rice husk biochar (15% and 30%) and vermicompost (50, 100, 150, 200, and 250 g per pot) in growing substrate on nutrient uptake and yield of green lettuce. The other components of the substrates were cocopeat and sand. The results showed that the 30% of rice husk biochar in the growing substrate resulted in a significantly higher uptake of N, P, and K in leaves compared to lower biochar content with an average increase of 52%, 67%, and 117%, respectively. Maximum total fresh weight of marketable yield was obtained with 30% of biochar and 250 g per pot vermicompost in the substrate.

Key words: biochar, green lettuce, *Lactuca sativa*, nutrient uptake, rice husk, soilless culture

INTRODUCTION

The issues faced by human beings are being resolved through research and development, which has laid the foundation of human civilization. Along with basic needs, the development of auxiliary needs making life easier has proceeded. To advance technology further, research is going on in various fields such as fuel cells (Ahmed et al. 2022a, b, c; Wu et al. 2022), solar cells (Khadtare et al. 2014; Khadtare et al. 2019), semiconductors (Ansari & Sartale 2016a; Lee et al. 2020; Choi et al. 2021), catalysis (Sartale & Ansari 2013; Ansari & Sartale 2015a, b, 2016b), 2D materials (Raya et. al. 2020; Raya et al. 2021), and CO_2 reduction (Ansari et al. 2021). At the same time, human beings' basic needs, namely food, have to be addressed, which is becoming a serious issue. The agricultural sector will face many problems in the future, especially a decrease in agricultural land and agricultural production. These issues will arise due to many reasons, for example, land degradation. The arable land of Indonesia was degraded and became critically damaged and barren in 1993, covering an area of 18 million hectares in 1993 (CSARD 2004), 23.2 million hectares in 2003 (Baja 2005), and 27.3 million hectares in 2005 (CBS 2013). Based on these data, one can know that the damage to critical land in a period of 20 years increased by 9.3 million hectares. On the other hand, the restoration of degraded land is challenging and takes a long time. The increase in degraded land is caused by excessive use of chemical fertilizer, conversion of agricultural land to residential land with increasing human

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population, increasing temperature and water shortage as a result of climate change, etc. (Thornton et al. 2018). In the future, there will be a major threat to the sustainability of crop production and food security (Power & Jones 2016). Such a situation has begun to occur in Indonesia where a reduction in the agricultural land area and a decrease in soil quality due to the application of conventional agricultural systems along with high external chemical input. To meet this challenge, an agricultural production model is needed that not only limits the use of agricultural resources but also uses them thoroughly. Such an agricultural production model will be the goal of the agricultural sector in the future.

Based on the data on vegetable production in Indonesia from 2017 to 2021, one can observe that lettuce production increases continuously year by year. The production of lettuce in 2017 was 627,598 tons and increased to 635,990 tons in 2018. A major increase in lettuce production occurred in 2019, which was 652,727 tons, and continues in 2020 and 2021, which was 667,473 and 727,467 tons, respectively (CBS 2022). This is due to the increasing need for lettuce commodities in line with the development of the catering business, hotels, and the level of public awareness of the importance of nutrition. This need will continue to increase along with the increasing population of Indonesia and the world. Green lettuce is generally consumed fresh; therefore, the cultivation system should lead to a safe product. Soilless crop cultivation systems, which use nutrient solutions, are developing rapidly to provide food crops (Resh 2022). This cultivation system is widely applied to vegetable crops such as green lettuce. It has several advantages such as high crop yield, high-quality crop products, less water consumption, and precise management of water and nutrients for crop production. Accurate water and nutrient management results in the fast and healthy growth of crops. Further, the soilless and short growing life of plants results in relatively few problems of disease and pests (Maucieri et al. 2019). Suitable practice for plant production in soilless crop cultivation leads to less use of pesticides; thereby, it is an environmentally friendly crop cultivation system (Resh 2022).

Various solid materials other than soil, either alone or in a mixture, can be used as a substrate or growing media in soilless culture systems, including natural organic and inorganic materials. The appropriate solid substrates should have high water retention and air capacity, be cost-effective, and have less pollution; furthermore, they should not release toxins (Wallach 2008; Maucieri et al. 2019). Additionally, a good substrate must be able to promote plant growth. Along with soilless crop cultivation systems, various attempts are going on to enhance soil quality. One of them is the use of biochar, which enhances soil health in degraded tropical soils by improving both soil's physical and chemical properties. Use of biochar results in the increase of water retention in sandy and highly weathered soils (Lehmann et al. 2003; Novak et al. 2009), pH enhancement of acidic soils, improvement in nutrient uptake and cation exchange (Novak et al. 2009; Atkinson et al. 2010; Clough & Condron 2010; Nurhidayati & Mariati 2014). Awad et al. (2017) reported that the use of biochar in a soilless culture system enhances the nutritional status and growth of leafy vegetables, with restricting algal growth. It was also found that the population of beneficial microbes in the soil increased after the use of biochar (Lehmann et al. 2003). Although the effect of biochar on mineral soil systems has been extensively studied (Lehmann & Joseph 2015; Spokas et al. 2012), its effect on the soilless culture system has not yet been fully explored. Given the features of biochar and the characteristics of a soilless culture system, the interest in using biochar in soilless culture systems is obvious.

Many organic fertilizers such as biogas manure and vermicompost have been tested in soilless culture systems, which showed encouraging results to promote plant growth and yield in several plant species like lettuce, mustard, and cabbage (Liu et al. 2009; Manyuchi et al. 2013; Nurhidayati et al. 2017b; Nurhidayati et al. 2018). The purpose of these studies was to take advantage of the good properties of both manure and vermicompost fertilizers to enhance the nutrient in plants and microbes in substrates. Especially, vermicompost fertilizer results in higher macro and micronutrients than conventional organic fertilizers, which are essential for plant growth (Lazcano & Domínguez 2011; Celes et al. 2018).

Considering all these, the present study aimed to examine the effects of vermicompost and rice husk biochar on nutrient uptake and yield of lettuce plants in the soilless culture system.

MATERIALS AND METHODS

Site experiment

This paper is based on the results of a pot experiment conducted in the polyethylene house of the Faculty of Agriculture, Islamic University of Malang, Lowokwaru District, Malang City, East Java, Indonesia with an altitude of approximately 550 meters above sea level. The daily average temperature was in the range of 23–30 °C. This study was performed from the beginning of August 2020 till the end of December 2020. The making of vermicompost was carried out at the Compost Laboratory of the Faculty of Agriculture, Islamic University of Malang.

Vermicompost preparation

The vermicompost was made in a bin of size 80 cm × 120 cm × 30 cm. The materials used for making vermicompost were cow dung, leaf litter, fresh vegetable residue, spent mushroom media, *Lumbricus rubellus* earthworms, and additives consisting of fish bone meal, *Tithonia diversifolia* leaves, and eggshell flour. The complete processes consist of different stages, which are organic matter preparation, mixing the media, inoculating *Lumbricus rubellus* earthworms, vermicomposting, and composting process. The duration kept for vermicomposting and composting was one month and two weeks, respectively (Nurhidayati et al. 2017a). The vermicompost produced in this study contained total nitrogen (2.05%), total organic C (29.14%), C/N ratio (14.2), pH (8.81), total P (0.92%), total K (1.55%), total Ca (7.96%), total Mg (2.27%), and total Na (1.14%).

Treatments, plant material, and preparation

Two factors were studied. The first factor was the composition of the growing substrate, where M1 consisted of 55% cocopeat, 15% rice husk biochar, and 30% sand, and M2 consisted of 55% cocopeat, 30% rice husk biochar, and 15% sand. The size of the pots used was 14 cm in height and 18.5 cm in diameter, thus the volume of the pot was 3,761.3 cm3. The weight of the growing media material in the pots was 1 kg. The second factor was the amount of vermicompost in the substrate: V1 – 50 g per pot, V2 – 100 g per pot, V3 – 150 g per pot, V4 – 200 g per pot, and V5 – 250 g per pot. Each treatment involved five pots/plants in three replications.

Seeds of green lettuce (*Lactuca sativa* L.) ‘Grand Rapids’ were sown into seedbeds, filled with a mixture of coconut husk media and cow dung. The substrate was sprinkled with water every day morning for 3 weeks. The growing substrates were mixed evenly and incubated for one week in the pots. After that, two seedlings of green lettuce were transplanted into each pot. Watering was done twice a day in the morning and evening with 100 ml of water per pot each time. After two weeks, the water volume increased to 150 ml per pot.

Data evaluation

At the harvesting date, 30 days after transplanting seedlings (DAT), the variables were analyzed in terms of nitrogen (N), phosphorus (P), and potassium (K) nutrient uptake in plant and plant yield. Plant yield was evaluated as total fresh and dry weight of the plant, fresh weight of marketable yield, and fresh and dry weight of roots. Nutrient uptake is calculated by multiplying the nutrient content (%) by the dry weight of the plant to obtain nutrient uptake (gram per plant).

The content of N, P, and K in leaves was measured by using the wet combustion method. N content was analyzed using sulfuric acid (H_2SO_4) by adopting the Kjeldahl method. The plant samples of 0.250 g (< 0.5 mm) were taken into a digestion tube. A mixture of 1 g sulphuric acid and selenium powder and 2.5 ml H_2SO_4 p.a. was added to the tube. The digestion process was carried out at 350 °C (4 hours) until white vapor was released and a clear extract was obtained. Measurement of N content was carried out by distillation process. P content was analyzed by a spectrophotometer using nitric acid (HNO_3) and perchloric acid ($HClO_4$). A sample extract of 1 ml was taken into a chemical tube. Deionized water (9 ml) was added to the tube and shaken (10x dilution). 2 ml of the aqueous sample extract was pipetted and calculated the standard series P (0–20 ppm PO_4) into the test tubes. 10 ml of reagent P was added to the sample extract and shaken with a tube shaker till it become homogeneous, thereafter, left for 30 minutes. P content in the solution was measured by means of a spectrophotometer at a wavelength of 693 nm. The K content was analyzed by using nitric acid (HNO_3) and perchloric acid ($HClO_4$) with a flame photometer with a standard series as a comparison. 1 ml of extract samples were pipetted into a chemical tube and 9 ml of 0.25% La solution was added. The solution was shaken using a tube shaker until it became homogeneous. The K content was also measured with a flame photometer as well compared to a standard series. The element uptakes by the plants were calculated by multiplying the nutrient content with the total dry weight of the plant.

Experimental design and data analysis

The study was conducted as a 2x5 factorial in a randomized complete block design (RCBD) with three replications. The obtained data were tested by using analysis of variance (ANOVA) at the significance level of 5%. If the results of the variance analysis showed a significant effect, then the Tukey test was employed with a level of 5% significance to determine the differences between treatments.

RESULTS AND DISCUSSION

Yield characteristics

Significant differences derived from the composition of the growing substrates were observed between the yield-related averages. They were especially important in the fresh and dry weight of the total yield and fresh weight of the marketable yield. Increasing the proportion of rice husk biochar from 15% to 30% resulted in a significant increase in the values of all yield parameters. Similarly, these yield elements concerning aboveground parts were positively influenced by increasing the share of vermicompost to 250 g per pot in the M1 substrate and to 200 g per pot in the M2 substrate. The higher proportion of rice husk biochar also increased the fresh and dry mass of the roots, but for these features, the content of vermicompost was effective only up to 150 g per pot. For fresh plant weight, a medium containing more rice husk biochar and 200 g per pot of vermicompost was the most preferred (Table 1).

Table 1. The effect of growing substrate composition on yield components of green lettuce

Treatments	Total fresh weight of plant (g per plant)	Total dry weight of plant (g per plant)	Fresh weight of marketable yield (g per plant)	Fresh weight of roots (g per plant)	Dry weight of roots (g per plant)
M1V1	40.71 d	3.81 b	36.64 e	4.06 b	0.37 ab
M1V2	41.46 d	3.86 b	37.21 e	4.25 b	0.38 ab
M1V3	49.99 c	4.76 ab	44.75 d	5.23 ab	0.47 ab
M1V4	51.69 c	4.68 b	47.90 cd	3.79 b	0.30 b
M1V5	54.77 bc	4.76 ab	50.99 cd	3.78 b	0.35 b
M2V1	60.15 ab	5.03 ab	53.92 bc	6.24 a	0.58 a
M2V2	61.04 ab	5.62 ab	54.73 abc	4.97 ab	0.44 ab
M2V3	62.33 ab	6.11 ab	56.28 ab	4.70 ab	0.45 ab
M2V4	66.06 a	6.38 ab	61.62 a	4.44 b	0.53 a
M2V5	59.85 ab	7.18 a	54.62 abc	3.84 b	0.45 ab
HSD 5%	8.084	2.47	7.46	1.54	0.22
M1	47.72 b	4.37 b	43.46 b	4.22 b	0.37 b
M2	61.89 a	6.06 a	56.23 a	4.84 a	0.49 a
HSD 5%	4.65	1.43	5.32	0.54	0.06

Note: M1 – growing media: 55% cocopeat, 15% rice husk biochar, and 30% sand, and M2 – growing media: 55% cocopeat, 30% rice husk biochar, and 15% sand, V1–V5 – vermicompost rates of 50, 100, 150, 200, and 250 g per pot. Means followed by different letters in the same column are statistically significantly different at Tukey test, p = 0.05

The average total fresh weight of green lettuce grown on the M2 (61.89 g per plant) was higher than on the M1 substrate (47.72 g per plant). In addition, the fresh weight of marketable yield in the M1 (43.50 g per plant) was lower than in the M2 substrate (56.23 g per plant). The addition of 30% rice husk biochar proportion (M2) to the growing media was able to increase total crop yields by 29% compared with 15% (M1). An increase in rice husk biochar from 15% to 30% in the mixture resulted in a reduction in the amount of sand from 30% to 15%, which certainly changed the physical and chemical properties of the substrate. The rice husk biochar reduces the porousness and extremely low holding capacity of the sand. It removes a barrier to soilless cultivation. Sand has a low cation exchange capacity, which makes it simple for nutrients in the media to drain. When irrigated, sand gets moist quickly and, thanks to evaporation, also dries out quickly (Rosalina et al. 2019). Biochar is able to increase nutrient availability in the substrates, leading to enhance nutrient uptake by plants (Lehmann et al. 2003). Biochar enhances water and nutrient retention and promoted beneficial microbial activity, suggesting high input of biochar can lead to an increase in the yield of green lettuce (Sohi et al. 2010). Vaughn et al. (2013) examined different contents of biochar from 0% to 15% in the soilless substrate in the greenhouse. They found that increasing biochar amount increases the residual nitrate and phosphate release. The application of rice husk biochar alone and in combination with perlite has been tested on cabbage, red lettuce, dill, and mallow plants and has shown high plant yields (Awad et al. 2017). Graber et al. (2010) reported that biochar enhances the growth and productivity of pepper (*Capsicum annuum* L.) and tomato (*Lycopersicum esculentum* Mill.). The 50 g per pot of vermicompost in combination with 30% rice husk biochar was found to be beneficial for total fresh weight (M2). The higher quality of plants in the marketable yield was observed for the amendment of vermicompost ≥ 100 g per pot in M2 growing medium. Vermicompost supplies plants with N, P, K, Ca, and Mg, increases the amount of organic matter in the soil, improves soil quality, gives plant development hormones, and acts as soil support. It shows that vermicompost directly influences plant growth and yield (Lazcano & Domínguez 2011). Vermicompost has been shown to improve soil water retention, particularly in porous soils like the growing medium used in this study (Jouquet et al. 2010; Jouquet et al. 2011). The growth of organically grown vegetable plants in pots, such as Phak-coi mustard and broccoli, was accelerated by the use of vermicompost (Nurhidayati et al. 2015, 2016; Nurhidayati et al. 2017b).

The amount of dry matter in shoots and roots is determined by environmental factors, especially the availability of nitrogen nutrients. Low nitrogen concentrations in the soil reduce the shoot-to-root ratio (Laghari et al. 2004). They found that high rates of vermicompost can increase dry matter; meanwhile, lower vermicompost rates increases more fresh and dry weight of roots. Nitrogen supply increases shoot and root growth of the plant, but usually shoots grow relatively much more than the roots (Marschner 1988; Laghari et al. 2004).

It suggests that an increase in biochar to 30% in growing media provides a more efficient at a lower amount of vermicompost. This is probably because biochar is able to retain water and nutrients so that it can reduce nutrient leaching on porous growing media such as soilless culture. Nevertheless, the application of biochar combined with vermicompost may enhance and sustain the biophysical and chemical characteristics of growing media, so that plant growth and yields increase significantly.

N, P, and K uptake

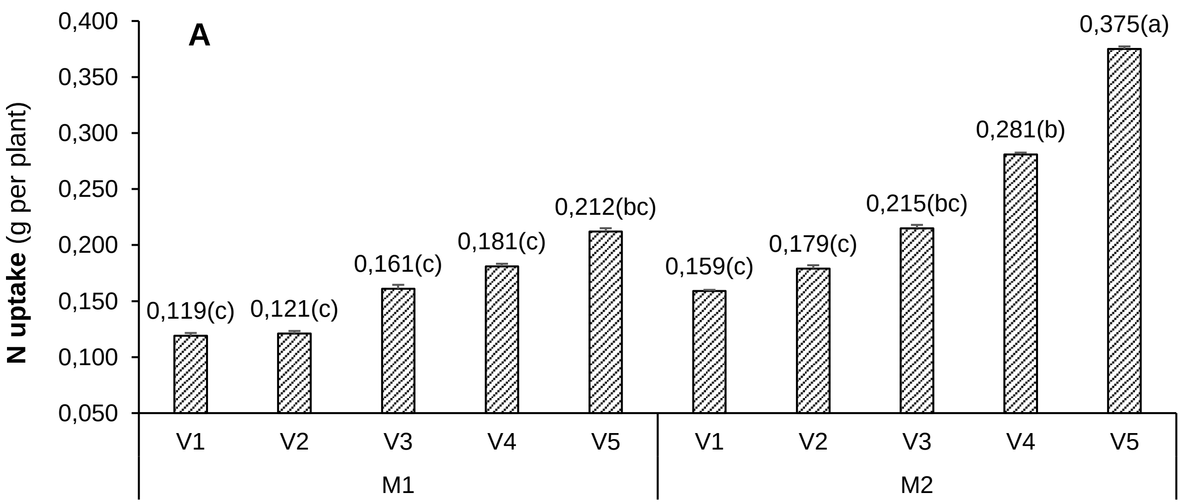
N, P, and K uptake in lettuce plants were dependent on substrate composition and was significantly higher in the substrates containing 30% of rice husk biochar compared with 15% (Fig. 1A–C). Also, an increase in vermicompost content in the substrates increased N, P, and K uptake, being the highest in the treatments with 200 and 250 g per pot (Fig. 2), although the reaction to the higher rate of vermicompost was not significant in the substrates with 15% rice husk biochar (Fig. 1A–C).

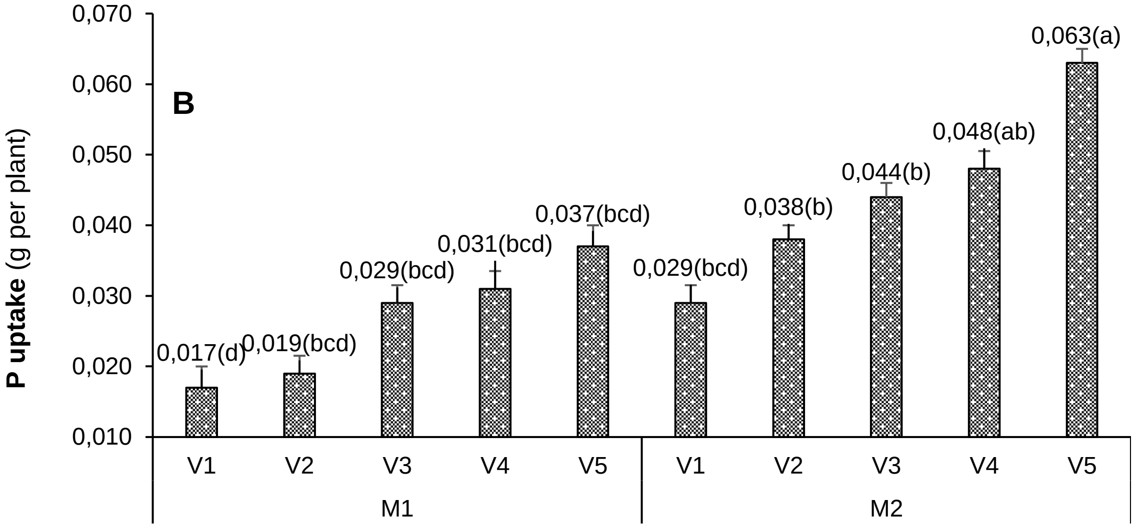
The magnitude of the increase in nutrients uptake with the higher proportion of rice husk biochar 30% versus 15% was 52%, 67%, and 117% for N, P, and K, respectively. This may be dependent on higher water or nutrient retention in M2 compared to the M1 substrate.

This is consistent with the earlier report of Wiedner et al. (2013). They showed that the change in water and nutrient retention in substrates affect the ability of the plant to absorb the nutrient, which enhances plant growth. Cai et al. (2016) reported that biochar can be produced from several organic matters at a higher temperature. It showed excellent retention ability in holding cations such as NH_4^+, which is related to the carboxyl and keto groups present in biochar-making process at a temperature of 200 °C. Biochar acts as a slow-releasing agent of nitrogen which is absorbed via the roots. Furthermore, biochar can indirectly affect nutrient availability by reducing nutrient leaching so that fertilizer application becomes more efficient (Lehmann et al. 2003; Major et al. 2009; Yao et al. 2012). Along with N, biochar increases the availability of P (Li et al. 2019). In addition, biochar provides a habitat for beneficial microorganisms because it increases pore size, and surface area (Ajema 2018). Moreover, biochar was reported as a useful carrier for increasing the population of *Enterobacter cloacae* (Hale et al. 2015) and *Azospirillum lipoferum* (AZ 204) (Saranya et al. 2011).

In the uptake of N, P, and K in lettuce plants, significant differences ($p < 0.05$) were observed, resulting from vermicompost rates. There was a tendency that the higher the vermicompost rates, the greater nutrients uptake. The N uptake in the plants grown in the substrates possessing 200 and 250 g per pot vermicompost was higher compared with lower vermicompost rates but they differed significantly only at the higher dose of rice husk biochar (Fig. 1A). Similar pattern was observed in P and K uptake (Fig. 1B, C). Generally, the increase of biochar dose increased significantly N, P, and K uptake (Fig. 2), which means that macro elements uptake was stimulated by biochar. Also, increased doses of vermicompost were accompanied with increasing uptake of macroelements (Fig. 3).

Vermicompost contains complete nutrients, the amounts of which vary depending on the raw materials used (Nurhidayati et al. 2017a). The vermicompost used in this study contained 2.05% N, 0.92% P, and 1.55% K. The nutrient contents in vermicompost are lower compared to inorganic fertilizers, but the advantage of this source is that they release nutrients gradually, up to four planting periods (Nurhidayati et al. 2018). Vermicompost contains higher nutrient contents compared to conventional compost and they are more balanced so their uptake by plant roots is more effective for plant growth stimulation (Vinothini et al. 2016).





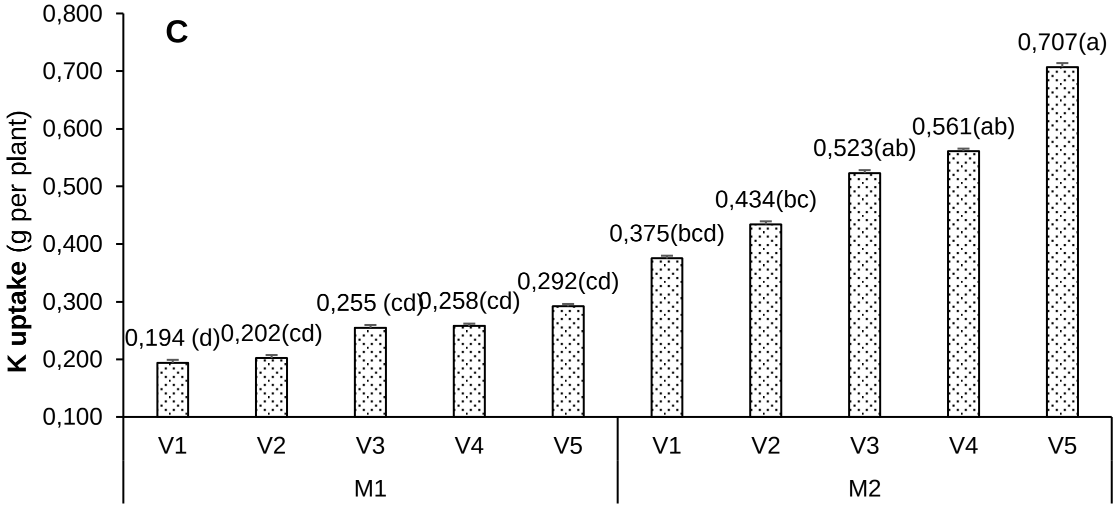


Figure 1. Nutrient uptake (a) N, (b) P, and (c) K in green lettuce leaves at different compositions of the planting substrate M1 – growing substrate: 55% cocopeat, 15% rice husk biochar, and 30% sand, M2 – growing substrate: 55% cocopeat, 30% rice husk biochar, and 15% sand, V1–V5 – vermicompost amounts: 50, 100, 150, 200, and 250 g per pot. The means accompanied by the same letter show no significant difference in the Tukey test 5%

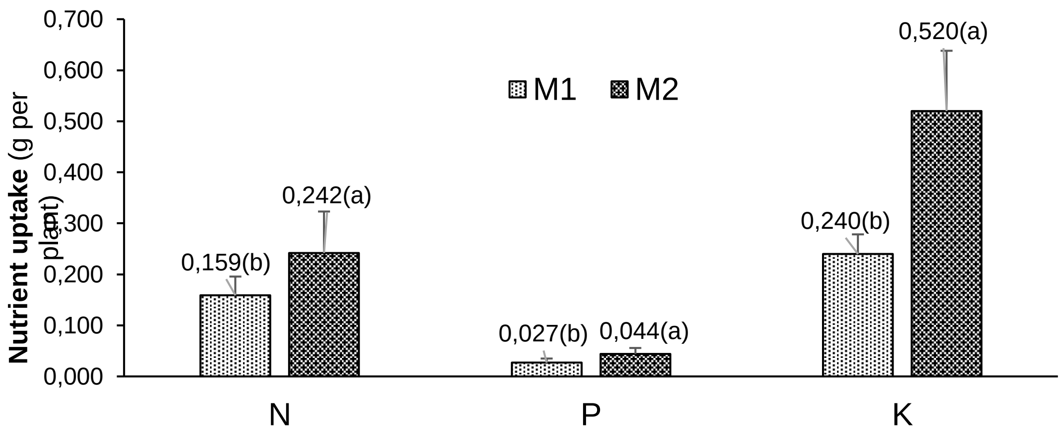


Figure 2. Comparison of the N, P, and K uptake in green lettuce plants grown in substrates containing different proportions of rice husk biochar 15% (M1) and 30% (M2)

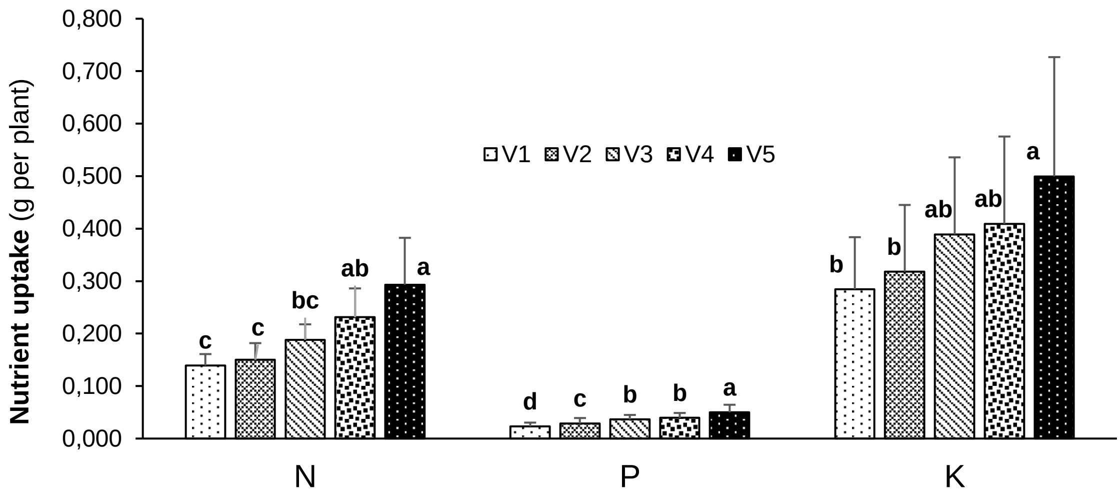


Figure 3. Comparison of the N, P, and K uptake in green lettuce plants grown in substrates containing different amounts of vermicompost (V1–V5: 50, 100, 150, 200, and 250 g per pot)

CONCLUSIONS

The present work sheds light on the effects of different proportions of rice husk biochar and vermicompost on green lettuce grown in a soilless cultivation system. The increase of rice husk biochar from 15% to 30% increased the uptake of N, P, and K by 52%, 67%, and 117%, respectively. As a consequence of the better uptake of macronutrients, the general and marketable yield expressed by fresh and dry weight increased with an increase of rice husk biochar and vermicompost doses. The results suggest that to increase the efficiency of nutrients and improve the productivity of green lettuce grown in soilless culture, the addition of high rice husk biochar (30%) along with vermicompost is beneficial.

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