Seaweed (Gracilariopsis funicularis) biochar incorporation into goat manure-food waste vermicompost for optimized vermi-degradation and nutrient release

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Abstract

Vermicomposts are organic fertilizer sources that are being promoted, however their concentration of macro nutrients such as (NPK) are very low. This study therefore evaluated the biochar from seaweed (Gracilariopsis funicularis) incorporated into a goat manure-food waste mixture at 0% (control); 2%; 4%; 6% and 8% on compost degradation and macro-nutrient release. After 10 weeks of vermicomposting the highest pH of 9.06 was observed within the control whilst the lowest was 8.7 in the 8% treatment. The electrical conductivity showed a positive relationship with the level of biochar incorporation with the highest of 16.5 mS/cm from the 8% treatment whilst the lowest was within the control with 6 mS/cm. There were no significant differences between treatments on humification parameters, however there were significant differences on the changes of C/N ratio with the final C/N ratio of 14.4; 14.9; 16.7; 15.1 and 14.4 for the control; 2%; 4%; 6%; and 8% treatments respectively. Higher incorporation rate resulted in the higher concentration of potassium with a value of 32.3 g/kg at week 8. The final percentage change in Olsen P was 19%: 14.2%; 7.3%; 4.1% and 3.0% for the 8%; 6%; control; 4%; and 2% treatments, respectively. An optimized level of 6 to 8 % biochar incorporation ratio can be recommended. However, incorporation of G. funicularis biochar does not seem to influence changes in the vermi degradation efficiency, though it can significantly improve the macro nutrients like P, K and Mg concentrations as well as the macro element concentrations.

Introduction

The advent of the green revolution saw the introduction of huge industrialization and intensification of agricultural activities which has generated huge quantities of waste materials (Chen et al. 2020). Furthermore, the use of inorganic fertilizers to increase crop yields has resulted in increased crop yield though this has also contributed to soil degradation as these fertilizers only feed the crop and not the soil which is a living ecosystem. Traditionally composts have been used as organic sources of nutrients, with their limitations being slow release of nutrients into the soil coupled with low nutrient levels and the probability of introducing potentially toxic pathogens and heavy metals into the environment (Chen et al. 2020). Recently, research has focused on improved organic fertilizers in sustainable agriculture like vermicomposts which involve the use of solid organic materials such as food waste, animal waste and sewage sludge processed using earthworms such as *Eisenia fetida* and other species (Garg and Gupta, 2009).

Though both composts and vermicomposts are being promoted as nutrient sources, they are still inferior in nutrition when compared to inorganic fertilizers. For example, urea has 46% Nitrogen, compound fertilizer like 3:2:3 (35 %) has 42.8 % Phosphorus and 28% Potassium whilst homemade compost was reported to have as low as 0.5% Nitrogen, 0.27% Phosphorus and 0.81% Potassium (Tilley 2020). This has led researchers to use various materials for amendment such as fly ash, rock phosphate and biochar as well as other methods like phosphorus solubilising bacteria to increase nutrient content. A study by Zheng et al. (2020) reported that rock phosphate amendment increased the contents of total Phosphorus and available Phosphorus, and reduced the loss of nitrogen during sewage sludge composting.

According to Lukashe et al. (2019) the inoculation of fly ash – cow dung – waste paper vermicompost with phosphate solubilising bacteria accelerated the biodegradation resulting in an improved vermicompost with low C/N ratio and high Olsen phosphorus. A study that used modified fly ash as an amendment to remediate heavy metal contamination from the soil reported that the mixture of fly ash and chicken manure reduced the concentrations of cadmium, copper and lead by 49.0%; 53.5% and 67.8 % respectively. They also observed an increase in organic matter and available NPK (Hu et al. 2020).

In another study, the incorporation of biochar made from corn cobs and wood improved soil quality as it provided higher soil organic matter of and macronutrients during the production of maize (Kizito et al. 2019). Biochar as an amendment is quite interesting as it is rich in recalcitrant forms of carbon and contains elevated nutrient concentrations (Katakula et al. 2020). The use of biochar has potential to reduce the bioavailability of trace elements, increase organic matter content of composting feedstock, enhance the level of humification and increases nutrient retention during vermicomposting (Were et al. 2019). Amendment of biochar in soil enhances plant nutrient availability, microbial activities, organic matter, water holding capacity and crop production; while lessening the fertilizer requirements, greenhouse gas productions and nutrient leaching (Wang et al, 2020).

Research has shown that amendment of 10% (w/w) plant biochar into kitchen waste – sewage sludge vermicompost increased the reproduction rate of earthworms (*Eisenia fetida*) by up to 53.9 % (Khan et al. 2019). In the same study, biochar amendments increased the concentration of macronutrients, total Nitrogen (15.8–31.0%), total phosphorus (8.6 –9.9%), total potassium (2.8–17.3%), calcium (4.1–9.9%) and magnesium (0.8–12.2%). Makini et al, (2020) reported that amending soils with goat manure-based vermicompost enhances soil chemical properties. Among the different application rates used, the highest rate of 30 t ha^{-1} goat manure-based vermicompost showed higher soil pH (8.00), total Nitrogen (0.606%), available Phosphorus (21.933 ppm) and exchangeable K (0.456).

Much of the research that has used biochar as an amendment has mainly used material of terrestrial origin with no research having used marine biomass. In a recent study, Katakula et al. (2020) identified that biochar derived from seaweed species such as *Laminaria pallida* and *Glacilariopsis funicularis* pyrolysed at a temperature of 400 degrees Celsius can generate nutrient rich and carbon rich biochar. Marine biomass derived biochar can be an important source of amendment for organic fertilizers in hyper arid countries such as Namibia. However, there is limited research that looked at marine biomass and converted them into biochar to be used as an amendment into vermicompost. Therefore, the objective of this study was to evaluate the seaweed biochar incorporation into food waste-goat manure vermicompost for enhanced vermidegradation (C/N, pH, EC) and essential plant nutrient release (Olsen P, Ca, Na, Mg, and K).

Materials And Methods

Source of materials used in the study

The experiment was conducted at the Sam Nujoma Campus of the University of Namibia, located in Henties Bay, Erongo Region of Namibia. The optimum ratio of food waste and goat manure mixture of 50% food waste and 50% goat manure was used based on the results of Katakula et al. (2021). The seaweed biochar used in this study was identified from Katakula et al. (2020) and this was derived from *G. funicularis* which was pyrolysed at a temperature of 400 degrees C for 1 hr. Plastic buckets of 20 L capacity were used as vermi-reactors for the process of vermicomposting, and holes were drilled at the bottom and on the lid for gaseous exchange and leachate drainage (Mupambwa 2015). The earthworms were obtained from the local wormery at the University of Namibia- Sam Nujoma Campus, where the species *Eisenia fetida* was kept feeding on mainly vegetable food waste and goat manure.

Treatments, experimental design and setup

Seaweed biochar (SB) was incorporated into the optimised food waste -goat manure mixture (FWGM) at 5 different levels on a dry w/w basis and this gave 5 treatment combinations which are: Control (FWGM only); 2% SB + FWGM; 4% SB + FWGM; 6% SB + FWGM; 8% SB + FWGM. The experiment was laid in a completely randomized design with 3 replications. The mixtures from the different treatments were allowed to pre compost for 2 weeks to moisten the materials and to get rid of volatile toxic gases (Mupambwa and Mnkeni 2016). After the 2-week pre-composting, earthworms (*E. fetida*) were introduced into each vermireactor at a stocking density of 25 g of worms per kg of compost following recommendations of Mupambwa and Mnkeni (2016). A total of 3 kg (dry mass basis) food waste and goat manure mixture was used for the experiment and this was kept at a moisture content of 70-80% under shade at room temperature. Sampling was done for each treatment at 0; 4; 8; 10; weeks. The collected compost samples were air dried and ground using a mechanical grinder (POLYMIX PX-MFC 90 D made in Switzerland by KINEMATICA AG) to analyse for the selected parameters as described below.

Electrical conductivity and pH

Electrical conductivity (EC) and pH were measured in water at a ratio of 1:10 (w/v) as described by AgriLASA (2004). Briefly, a 5g of the compost was mixed with 50 mL of deionized water and shaken with a horizontally reciprocating shaker at 120 rpm for 30 minutes and then pH and EC were measured using a calibrated multi - meter (Lovibond Water Testing, Senso Direct 150).

Olsen extractable P

The Olsen method was used to determine extractable phosphorus because it has been shown to be effective for acidic materials (Schoenau and Halloran 2006). A solution of 0.5M sodium hydrogen carbonate adjusted to a pH of 8.5 using 1M of Sodium hydroxide was used for extraction. Briefly, a 2.5g of the vermicompost was shaken in 50 mL of the extracting solution for 30 minutes at 120 rpm and then filtered with Whatman Number 2 filter paper. The extracts were then analyzed for P using the Ascorbic acid method as described by Kuo (1996).

Total C and N

Total C and N were determined using the dry combustion method employing a LECO CHN628 auto analyser (LECO Corporation, USA).

Extractable cations (Ca, Mg, Na, and K)

The cations were extracted using the ammonium acetate method as described by (AgriLASA 2004). Solution of1 Mol ammonium acetate adjusted to pH 7 was used to extract the cations. To prepare this, an amount of 57 mL of glacial acetic acid was diluted with de-ionised water to a volume of 500 mL. An amount of 69 mL concentrated ammonia solution was then added to the diluted solution of acetic acid. The solution was mixed well and diluted to about 900 mL with deionised water and then pH was adjusted to 7 using either acetic acid or ammonia solution. A 5 g of compost was placed in 100 mL extraction bottle and 50 mL of ammonium acetate solution was added into the extraction bottle and the mixture was shaken horizontally on a reciprocating shaker at 180 rpm for 30 minutes. The extracts were filtered using Whatman Number 2 filter paper and the cation concentrations in the solution were determined using a calibrated Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES – iCAP 6000 SERIES).

Humification parameters

The humic and fulvic acid fractions in the composts were extracted using a method described by Sanchez-Monedero et al, (1996). A 0.1 mol L^{-1} NaOH solution was used at an extraction ratio of 2:40 (w/v), and shaken for 4 hours with a reciprocal shaker. The extracts were then centrifuged at 4000 rpm for 15 min. After centrifugation, the supernatant was divided into two fractions, with one half stored for analysis of total extractable C fraction (*C*tEX). The other half was acidified to pH 2 by adding drops of concentrated H_2SO_4, to form a precipitate representing the humic acid fractions (HA) whilst the liquid part represented the fulvic acid fraction. The acidified extracts were allowed to coagulate for 24 hours at 4 °C and further centrifuged at 4000 rpm to separate the humic and fulvic fractions. The non-precipitated part of the centrifuged samples was then further analysed for fulvic acid carbon (CFA). The C concentrations in the supernatants were determined using the dichromate oxidation method, with the concentration of the humic acid (CHA) fraction being calculated as the difference between C_{tEX} and *C*FA. The humification ratio (HR, equation 1), humification index (HI, equation 2), percentage of humic acids (Pha, equation 3), and polymerization index (PI, equation 4) which are indices used for the evaluation of humification level in the vermicompost were then calculated as indicated in the equations.

$$HR = \frac{C_{tEX}}{C} \times 100 \quad \text{(Eqn. 1)}$$

$$HI = \frac{C_{HA}}{C} \times 100 \quad \text{(Eqn. 2)}$$

$$Pha = \frac{C_{HA}}{C_{tEX}} \times 100 \quad \text{(Eqn. 3)}$$

$$PI = \frac{C_{HA}}{C_{FA}} \times 100 \quad \text{(Eqn. 4)}$$

Statistical analysis

The data were analysed using repeated measures of analysis of variance (ANOVAR). Where sphericity assumptions could not be met, the Greenhouse-Geisser correction of *P* was used. For the humification parameters, a one-way analysis of variance (ANOVA) was done for the data collected at week 10. Mean separations were conducted using the Fishers protected least significant at $P < 0.05$ when analysis of variance indicated a significant *P*-value. All data were analyzed using JMP version 14.0.0 Statistical software (SAS Institute, Inc., Cary, North Carolina, USA, 2010), whilst all the graphs were plotted using Microsoft Excel (2007).

Results

Effects of seaweed biochar incorporation during vermicomposting on compost maturity

pH and Electrical conductivity (EC)

A significant difference ($P < 0.05$) was observed between treatments on changes in pH across the 10 weeks of vermicomposting (Table 1). Generally, pH was alkaline throughout the vermicomposting process with pH actually increasing from the initial values across all treatments (Figure 1). After 10 weeks of vermicomposting, the control treatment which had no biochar incorporated into it had the highest pH of 9.06 whilst the lowest pH was 8.72 observed in the 8% biochar treatment. It was interesting to observe that the final pH values at 10 weeks showed a strong link to the level of biochar incorporation as it followed the order 0% > 2%; 6% > 4% > 8% biochar. After 10 weeks of vermicomposting, the pH values observed were 9.06; 8.83; 8.79; 8.82; and 8.72 for the treatments 0%, 2%, 4%, 6% and 8% treatments, respectively.

Throughout the 10 weeks of vermicomposting, EC showed an almost linear increase for all treatments, with a significant difference ($P < 0.05$) being observed between treatments and time as indicated in Table 1 and Figure 2. Similar to the observations of pH, the higher the biochar incorporation rate, the higher the EC and also the higher the incorporation rate the higher the rate of change (Figure 2). Across all treatments between 0 and 10 weeks, EC increased by 28%; 42.2%; 42.3%; 54% and 67% for the 0%, 2%, 4%,6% and 8% treatments, respectively. After the 10 weeks of vermicomposting the final EC values were 6 mS/cm; 9.2 mS/cm; 10.9 mS/cm; 12. 4 mS/cm and 16.5 mS/cm for 0%; 2%; 4%; 6%; and 8% treatments, respectively.

C/N ratio

Across the different treatments, there were significant differences ($P < 0.05$) observed on changes in C/N ratio, across the 10 weeks of vermicomposting (Table 1). Generally, across all the treatments the C/N decreased from an average C/N of 34:1 at week 0 to a final average of 15:1 at week 10 (Figure 3). After the 10 weeks of vermicomposting, relative to the starting values, the C/N ratio decreased by 97%; 116%; 155%; 128% and 134% for the 4%; 6%; 2%; 8% and control treatments, respectively, as indicated by the significant difference on time indicated in Table 1. At the end of the vermicomposting, the final C/N ratios were 14.4; 14.9; 16.7; 15.1 and 14.4 for the treatments 0%; 2%; 4%; 6% and 8%. There were no significant interactions ($P > 0.05$) between treatments and time (Table 1).

Table 1 Repeated measures ANOVA for changes in the selected parameters during vermicomposting of a goat manure food waste mixture amended with seaweed (G. funicularis) biochar.

Parameter	Treatment		Time (Weeks)		Treatments × Time	
	F	*P*	*F*	*P*	*F*	*P*
C/N ratio	0.67	< 0.0001	373.85	< 0.0001	1.84	ns
pH	29.45	< 0.0001	520.45	< 0.0001	8.79	< 0.0001
EC (mS/cm)	129.4	< 0.0001	397.59	< 0.0001	22.06	< 0.0001
Olsen P (g/kg)	11.12	< 0.0024	11.48	0.0010	1.42	ns
Ca (g/kg)	1.06	ns	110.14	< 0.0001	14.15	< 0.0001
K (g/kg)	887.06	< 0.0001	42.62	< 0.0001	67.71	< 0.0001
Mg (g/kg)	3.80	0.0511	46.79	< 0.0001	3.49	0.0167
Na (g/kg)	863.63	< .0001	92.58	< 0.0001	34.24	< 0.0001

ns = not significant at $P > 0.05$

Humification parameters

For all the four humification indices measured which are humification ratio (HR), humification index (HI), percentage of humic acids (Pha), and polymerisation index (PI) there were no significant differences ($P >$ 0.05) between all the treatments after 10 weeks of vermicomposting. The highest humification ratio was observed in the control treatment with a humification ratio of 16.1 whilst the lowest was the 4% treatment with the HR of 13.8. The HR values followed the order 0% > 8% > 2% > 6% > 4% with final values of 16.1; 16.0; 15.6; 15.3 and 13.8, for biochar treatments, respectively (Figure 4 A). For humification index, the control treatment had the highest value of 2.8 whilst the lowest was with the 4% treatment with a HI of 2.3. The final HI after 10 weeks of vermicomposting followed the order of 4% < 6% < 2% < 8% < Control (Figure 4 B).

Similarly, the control treatment also resulted in the highest value of percentage humic acids of 17.8 whilst the 6% treatment had the lowest Pha of 16.5. The Pha followed the order of 6% < 4% < 8% < 2% < control with 16.5; 16.7; 16.9; 17. 1 and 17. 8 respectively (Figure 4 C). For polymerization index, the highest value was observed at the control treatment with the PI of 21.6 whilst the lowest was 19.9 at 6% biochar treatment. The PI followed the order of 6% < 4% <8% < 2% < control with 19.9; 20.1; 20.4; 20.6 and 21.6 (Figure 4 D).

Effects of seaweed biochar incorporation during vermicomposting on nutritional content

Olsen extractable phosphorus

There were significant differences ($P < 0.05$) observed between treatments on changes in Olsen phosphorus as shown in the repeated measures ANOVA Table 5.1. The 8% treatment gave the highest final concentration of Olsen extractable phosphorus of 0.40 g per kg whilst the 2% treatment had the lowest final concentration of 0.30 g per kg of compost at ten weeks. It was interesting to observe that the changes in Olsen P during vermicomposting could be modelled using a second order polynomial equations with very high R^2 values (Figure 5). For all the treatments, the peak Olsen phosphorus was observed between week 6 and week 8 of vermicomposting and after 8 weeks, almost all the treatments started showing a decrease in Olsen P concentration. After 10 weeks of vermicomposting the final percentage change in Olsen P was 19%; 14.2%; 7.3%; 4.1% and 3.0% for 8%; 6%; 0%; 4%; and 2% treatments, respectively (Figure 5).

For the control treatment, the peak concentration of Olsen P was observed at week 4 with a concentration of 0.37 g/kg which was a 7.3% increase in Olsen P compared to the initial concentration. The peak concentration for 2% biochar treatment for Olsen P was observed at week 4 with a concentration of 0.38 g/kg with a 3.0 % increase. For the 4% treatment the peak concentration of Olsen P was observed at week 8 with a concentration of 0.40 g/kg with a 4.1 % increase in Olsen concentration. The peak concentration of 6% treatment was observed at week 4 with the Olsen concentration of 0.41 g/kg with a 14.2 % increase in Olsen P. For the 8% treatment the peak Olsen concentration was 0.42 g/kg observed at week 8 with 19% increase in Olsen P relative to the starting values (Figure 5).

Extractable cations (Ca, Mg, Na and K)

There were significant differences ($P < 0.05$) observed between treatments for Mg, K, and Na except for Ca as shown in repeated measures ANOVA (Table 1). For all treatments except for the control, the concentration of calcium increased from week 0 until week 8 and thereafter significantly decreased to concentrations that were below the original concentrations. However, the control treatment showed an almost constant concentration of calcium across the 10 weeks of vermicomposting. After ten weeks of vermicomposting the final concentration of calcium was observed to be high in the control followed by 2%; 4%; 8% and 6% treatment with the final concentration of 18.9 g/kg; 16.2 g/kg; 15.7 g/kg; 15.5 g/kg and 15.3 g/kg (Figure 6 A). It was observed that the final concentration of calcium for all treatments was lower than that of the treatment without biochar.

Similar to the changes in electrical conductivity, the higher the concentration of biochar incorporation rate the higher the concentration of potassium. For all treatments the concentration was almost consistent across the 10 weeks of vermicomposting, whilst it increased only for the 8% biochar concentration (Figure 6 B). The final concentration of potassium followed the order 8% >; 6% >; 4% >; 2% > 0% with the final concentration of 27.4 g/kg; 15.8 g/kg; 15.0 g/kg; 14.1 g/kg and 6.4 g/kg after 10 weeks of vermicomposting. For all treatments the concentration of magnesium increased until week 8 and thereafter decreased (Figure 6 C). The final concentration of magnesium followed the order 0% >; 2% >; 4% >; 8% >; 6% with the final concentration of 0.59 g/kg; 0.58 g/kg; 0.58 g/kg; 0.55 g/kg and 0.52 g/kg at 10 weeks (Figure 6 C). Generally, sodium showed a small decrease for most of the treatments across the 10 weeks of vermicomposting. After 10 weeks, the higher the biochar incorporation rate the higher the concentration of sodium. The final concentration of sodium followed the order 8% > 6% > 4% > 2% > 0% with the final concentration of 5.44 g/kg; 3.45 g/kg; 3.29 g/kg; 3.2 g/kg and 2.2 g/kg at 10 weeks (Figure 6 D).

Discussion

Influence of seaweed biochar incorporation on vermidegradation

According to results in the study, the alkalinity of the pH is probably from the materials used which are goat manure and food waste which had a pH of 9 and not due to the application rate of biochar. The increase in pH across all treatments could be attributed to the release of ammonia and calcium as suggested by Karwal and Kaushik (2020) and this has been attributed to earthworm’s activity. Furthermore, the pH increase has also been reported to be attributed to the increase in ash formation and mineralization of organic nitrogen as a result of microbial activities (Jain et al. 2018). The alkaline vermicompost may present an opportunity to use it as an amendment for acidic soils though there is no clear link between the level inclusion of biochar and the changes in pH. Though the pH was alkaline it was still within the region where most of the macro-nutrients needed by the plants will still be bio available as recommended by Simms and Mahato (2020). In our study, it was clear that the higher EC observed is attributed to the level of biochar incorporation. The increase in EC is attributed to the high levels of cations mainly calcium and potassium that are present in the biochar hence the higher the biochar level the higher the EC. Higher EC reflects the presence of more soluble salts, metabolites like ammonium and inorganic ions that are produced by earthworm’s activities during vermicomposting (Lukashe et al. 2019). It will be critical to monitor the changes in electrical conductivity when seaweed biochar amended vermicompost is incorporated into the soil as the EC value of beyond 4 mS/m has been reported to result in soil salinity (Sarfaraz et al. 2020).

The incorporation of biochar did not influence the trend of change in C/N ratio as all the treatments followed the same trend. C/N ratio is the key indicator of biodegradation during the vermicomposting process (Karwal and Kaushik 2020) and C/N of less than 20 has been reported to represent mature compost though a C/N ratio of below 15 represent a much more stable compost (Bernal et al. 2009). In our study it was observed that the treatments that had biochar incorporated at 6 to 8% resulted in much more stable compost though even the control resulted in mature compost with a C/N ratio of below 20. The decrease in C/N ratio may be due to the accumulation of nitrogenous compounds, the release of CO_2 by earthworm metabolism and enzyme-microbe induced decomposition of organic matter (Bhat et al. 2015; Karwal and Kaushik 2020; Alidadi et al 2016; Zhi-wei 2019). This was also observed in a study by Ravindran and Mnkeni (2016) who reported that C/N ratio decreases may be due to a higher loss of carbon accompanied by an increase in nitrogen during vermicomposting of waste paper and chicken manure. In the study the decrease in C/N may have been a result from the rapid breakdown of organic matter for microbial metabolism. When you incorporate biochar into compost you may get faster maturity relative to the control without biochar. Inclusion of biochar does not result in reduced decomposition but rather enhanced decomposition as observed in the study.

The humification parameters showed a different trend with the control having the highest humification parameters though they were not significantly different from the other treatments. As observed in our study, incorporation of biochar does not result in reduced humification parameters. Mature compost has been indicated to have a humification ratio of > 7 which was achieved in all treatments in our study (Bernal et al. 2009). However, according to (Bernal et al. 2009) the humification index, polymerisation index and percentage of humic acids were all below the recommended levels for mature compost. This may be because the humification takes place later after the initial decomposition during vermicomposting; therefore, it might be interesting to do this vermicomposting over a longer period to see if humification can be improved. It's interesting that the C/N ratio indicated mature compost unlike the humification parameters. There is still need to evaluate other parameters other than humification parameters that are critical in the evaluation of compost maturity (Li et al. 2015)

Influence of seaweed biochar incorporation on nutrient transformations

An incorporation rate of biochar of between 6 and 8% resulted in the highest Olsen extractable P after 10 weeks of vermicomposting. The peak concentration of Olsen P was observed between week 6 and 8 which unfortunately was when the compost was not yet matured. The decline in Olsen P may be due to leaching of the nutrients in the leachate. The higher the biochar the higher the concentrations of Olsen P observed. The higher concentrations in vermicomposts may be due to various earthworm activities during vermicomposting with the enzymes that help the release of phosphorus from feedstock (Sharma and Garg 2020). According to the food and Agricultural Organisation of the United Nations (FAO 2001), the potassium content in organic fertilizer should not be less than 1.5% while the concentration of calcium and other essential micro nutrients should be in the range from 0.01% - 0.05%. In this study the concentration of potassium was above 1.5% which means incorporation of biochar may enhance the concentration of potassium in composts. Zhang et al. (2016) found that the concentration of Na ions was lower in the composted mixture amended with biochar as compared to mixture without biochar addition. However, in this study that was not the case and this might be attributed to the origin of the material that was used to prepare the biochar which is from the marine environment were salinity is higher. It will be important to monitor the changes in soil physical properties when this seaweed biochar amended vermicompost is used as soil amendment. The increase in exchangeable calcium and magnesium be ascribed to the higher content of these nutrients in the materials used (Madiwe et al. 2020). In the study, that was not the case; the increase in Calcium and magnesium could be attributed to the effect of organic acids produced during the process of decomposition which enhances the solubility of Calcium and Magnesium. The incorporation level of biochar increased the potassium concentration and this may be due to the biochar used which had high amounts of potassium from the first experiment.

Conclusion

The study observed that biochar incorporation does not really influence the biodegradation process. However, higher inclusion levels of the seaweed biochar in vermicomposts might result in elevated EC. In terms of nutrients, the seaweed biochar resulted in significantly higher Olsen extractable P levels as compared to the control. An optimized level of 6 to 8 % biochar incorporation ratio can be recommended in terms of nutrition and decomposition during vermicomposting of food waste-goat manure mixture. During vermicomposting, the peak concentration of elements such as P was observed before the vermicompost indicated maturity based on C/N ratio and humification parameter. It will be interesting to evaluate the changes in soil parameters and plant growth when vermicompost with seaweed biochar incorporated between 6 to 8% is used.

Declarations

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Competing interests

The authors declare no competing interests

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Figures

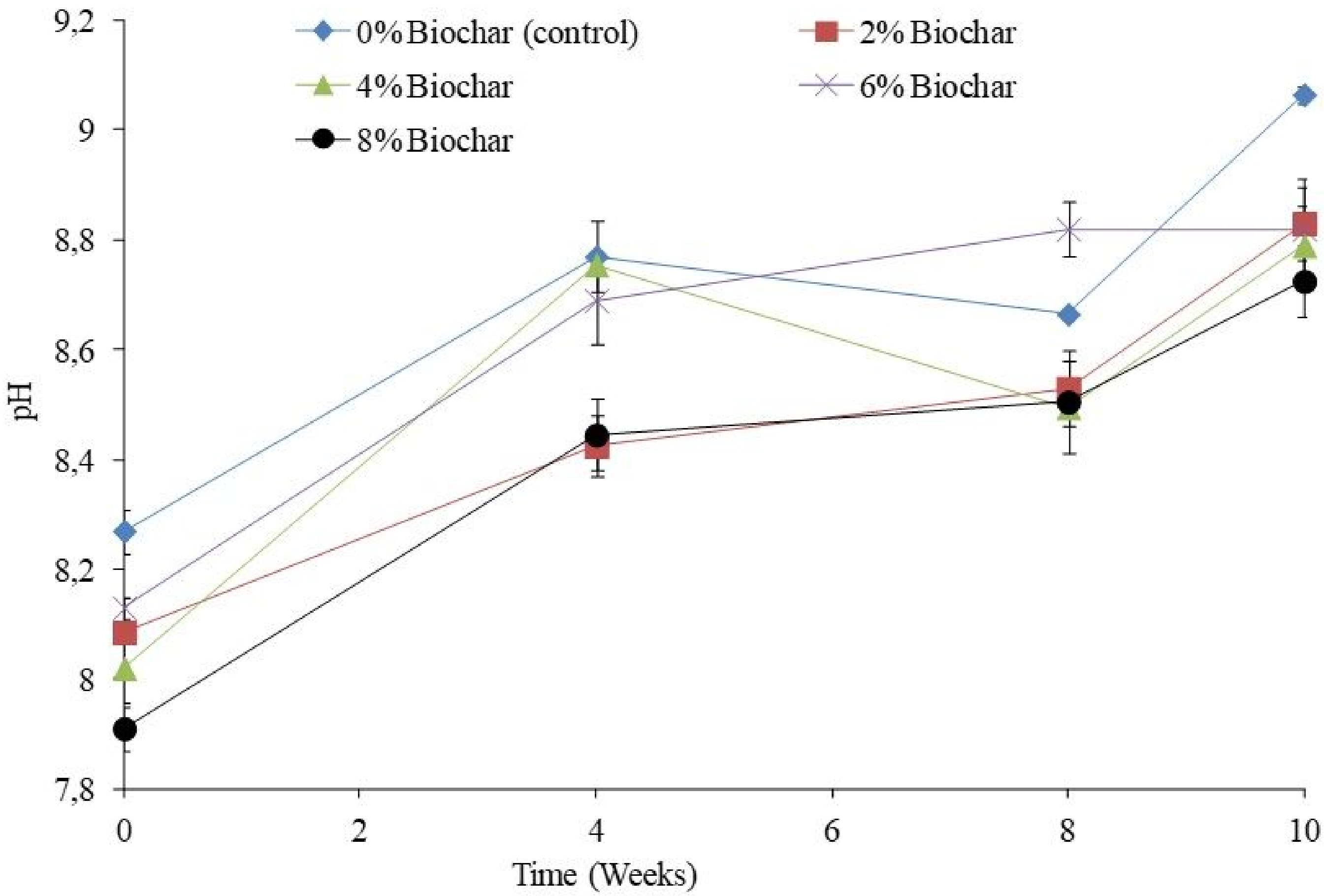

Figure 1

Changes in pH during vermicomposting of goat manure - food waste mixture amended with seaweed (G. funicularis) biochar. Error bars indicate standard deviation

Figure 2

Changes in Electrical conductivity during vermicomposting of goat manure - food waste mixture amended with seaweed (G. funicularis) biochar. Error bars indicate standard deviation.

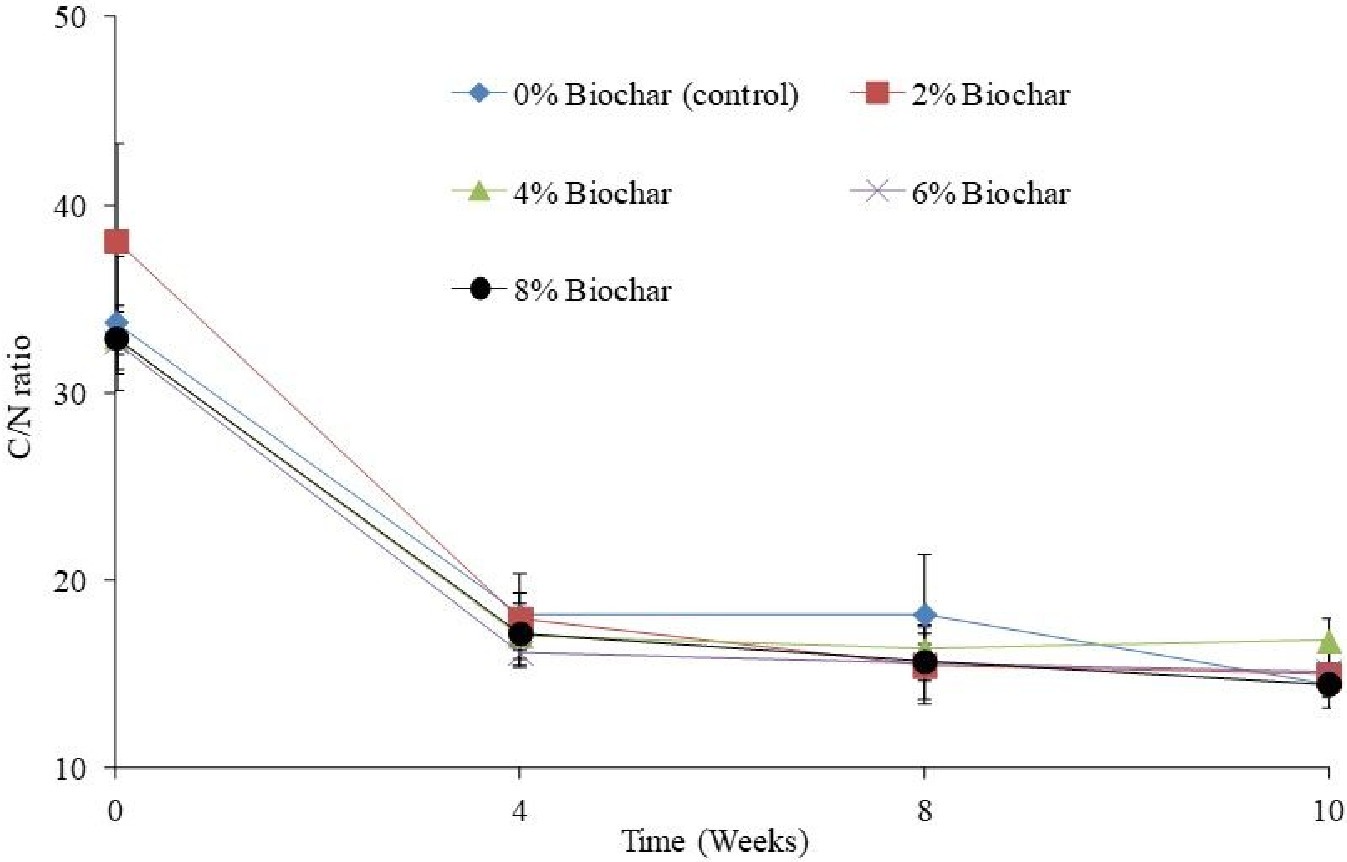

Figure 3

Changes in Carbon to Nitrogen ratio (C/N) during vermicomposting of a goat manure food waste mixture amended with seaweed (G. funicularis) biochar into. Error bars indicate standard deviation.

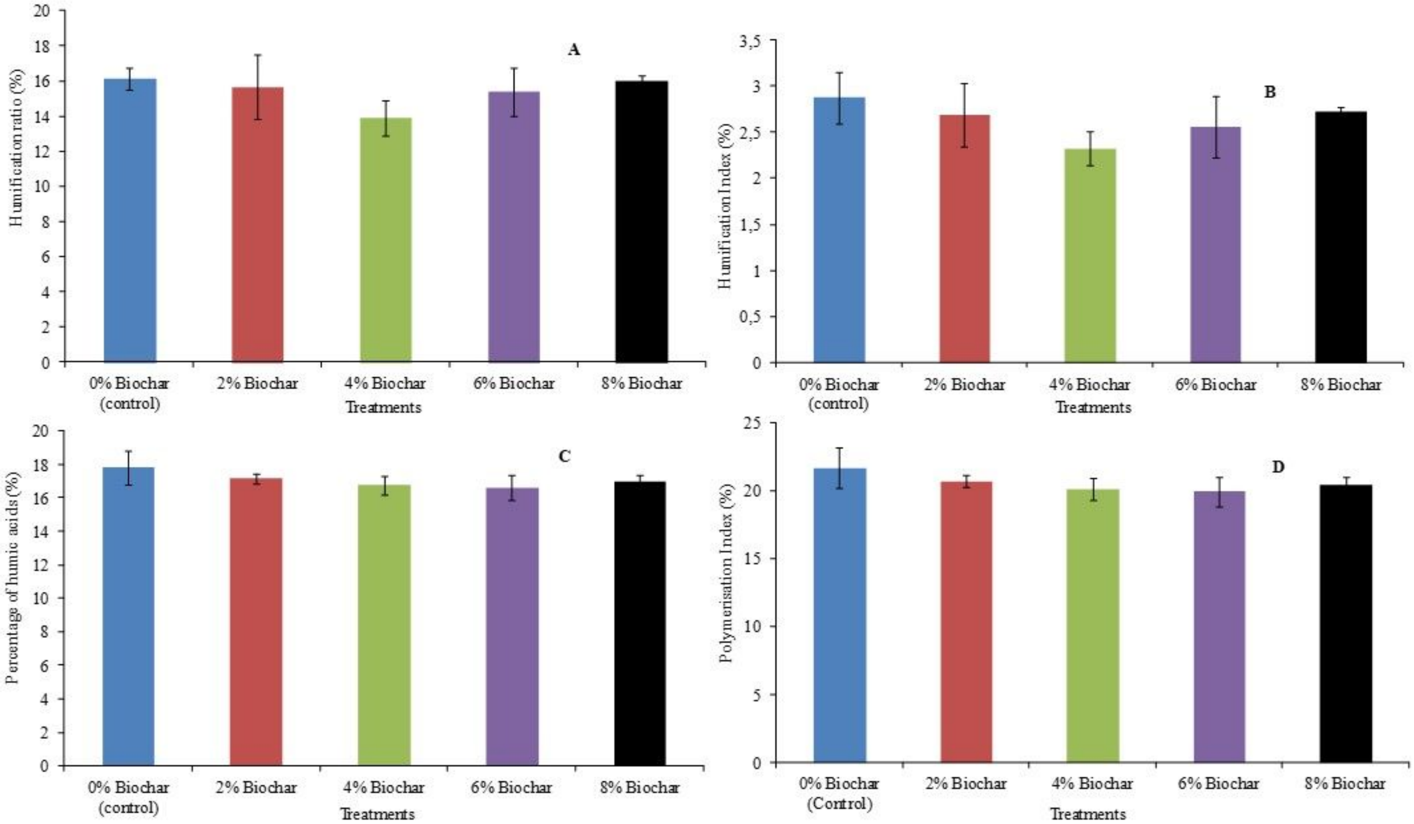

Figure 4

Final humification parameters after 10 weeks of vermicomposting of a goat manure food waste mixture amended with seaweed (G. funicularis) biochar. A (Humification ratio); B (Humification index); C (Percentage of humic acids) and D- (Polymerisation Index).

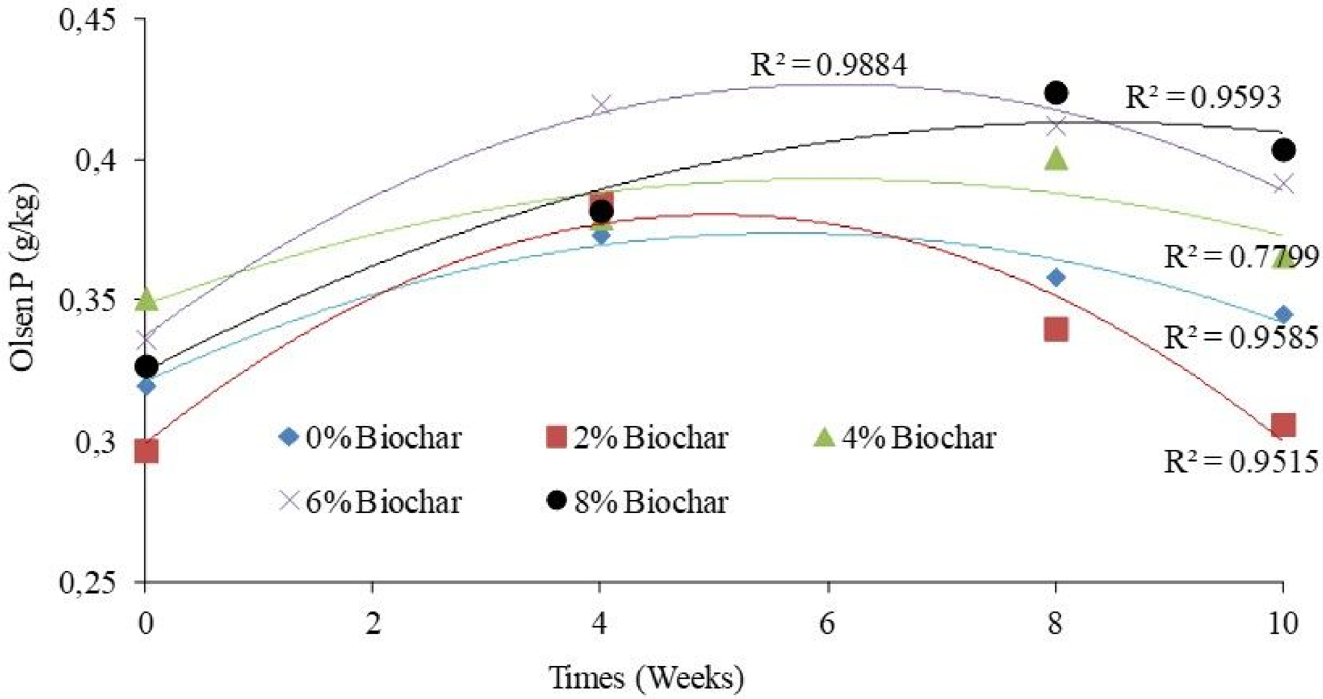

Figure 5

Second order polynomial line graphs showing the trends of changes in Olsen P after ten weeks of vermicomposting of a goat manure food waste mixture incorporated with seaweed (*G. funicularis*) biochar.

Figure 6

Changes in extractable A (Ca); B (K); C (Mg) and D (Na) after 10 weeks of vermicomposting of a goat manure food waste mixture amended with seaweed (G. funicularis) biochar. Error bars indicate standard deviation.