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ORIGINAL RESEARCH

Biochar production from poultry litter as management approach and effects on plant growth

S. Sikder[1] · J. C. Joardar[1]

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Abstract

Purpose A lots of poultry litter (PL) is being generated every day from poultry industries and improper management leads to different environmental problems. Production of biochar from PL is a new management strategy of PL which is a nutrient-rich organic amendment for improving soil nutritional status. The experiment was aimed for the production of poultry litter biochar (PLB) from fresh PL to assess the important properties of both PL and PLB, and to observe the effects on plant growth. It also appraised the change of soil properties after PL and PLB application.

Methods Poultry litter biochar was produced from fresh PL heated at 300 °C temperature for 10 min in muffle furnace. Poultry litter was applied into the soil at 2.5, 5.0, 7.5 and 10 t ha^{-1} and PLB was applied at 1, 2, 3 and 4 t ha^{-1} along with control. *Gima kalmi* (*Ipomoea aquatica*) was grown as test plant. To assess the potentiality and residual effect, the same plant was grown consecutively after harvesting first crop. Post-harvest soil analysis was also carried out after harvesting the first crop.

Results After pyrolysis pH, EC, organic carbon, available nitrogen, phosphorus, potassium, calcium, total phosphorus, potassium, calcium, magnesium, and iron were increased in PLB. A significant ($p < 0.001$) increase in plant growth and biomass production was observed and it was higher in PLB-treated soil than that of the PL-treated soil for both first and second crop.

Conclusion Poultry litter biochar might be a promising organic fertilizer with high nutrient composition than fresh PL. This also could be an ecofriendly management strategy for sustainable agriculture and long-term productivity.

Keywords Poultry litter · Biochar · Organic fertilizer · Pollution · Management

Introduction

Long-term sustainability of agriculture and attaining future food requirement have become burning issues and can be considered as a great challenge of the twenty-first century (Gruhn et al. 2000; Scholz et al. 2014). To fulfill the future food demand, the reckless application of inorganic fertilizer has steadily increased for intensive agriculture. Eventually, it leads to decline in the soil's physical, chemical and biological health (soil degradation, nutrient imbalance, soil acidity, etc.) resulting in poor crop yields (Widowati et al. 2012; Usman et al. 2015; Oshunsanya and Aliku 2016), whereas the use of organic fertilizer improves soil properties and plays an important role in long-term soil conservation by maintaining or restoring its fertility which ensures the sustainable agricultural production and also enhances the crop quality (Islami et al. 2011; Widowati et al. 2012; Adhami et al. 2014; Ali et al. 2017; Joardar and Rahman 2018). But rapid decomposition and mineralization result from using organic materials which leads to repeatedly high application doses and subsequently contributes to increasing global warming through carbon emission (Jenkinson et al. 1991; Lehmann et al. 2006, 2009; Sohi et al. 2009). Realizing the problem and to introduce a climate-smart agriculture, scientists are trying to use recalcitrant organic materials, such as 'biochar', a more resistant or stable carbon-rich organic material as a tool for improving soil fertility and productivity while also fighting the global challenge of climate change (Lehmann et al. 2006; Lehmann and Joseph 2009; Islami et al. 2011; Widowati et al. 2012; Scholz et al. 2014).

Global interest in the use of biochar in agriculture as an organic fertilizer, to improve the soil condition, has just inaugurated in the past few years (Verheijen et al. 2010; Bruun 2011; Nair et al. 2017). The application of biochar to agricultural soil is rapidly emerging day by day as a new

✉ J. C. Joardar
jcjoardar@yahoo.com

[1] Soil, Water and Environment Discipline, Khulna University, Khulna 9208, Bangladesh

management strategy as it gives greater resistance to microbial decay than other soil organic matter (SOM) and consequently provides nutrients for long time because of its stability with specific chemical structure (Baldock and Smernik 2002; Steiner et al. 2007; Cheng et al. 2008) and, therefore, indirectly contribute to enhance plant growth (Lehmann et al. 2003a; Steiner et al. 2007; Chan et al. 2008). Applying biochar into soil also helps in carbon (C) sequestration by stabilizing SOM which can contribute to reduction of greenhouse gas emission from soil (Lehmann et al. 2006; Steiner et al. 2007; Chan et al. 2007a; Lehmann and Joseph 2009; Nair et al. 2017). Though the decomposition rate of biochar is slow than the uncharred organic material but it is not strictly inert material, it takes a long time to decompose (Thies and Rillig 2009). Biochar can be originated from a diverse range of biomass materials including animal manures, agricultural wastes, rice husks, leaves, wood residues, weeds, etc. (Lehmann and Joseph 2009; Scholz et al. 2014) by thermal decomposition (pyrolysis) under no or limited supply of oxygen at relatively low to moderate temperatures (< 700 °C). The quality and nutrient status of biochar from feedstocks of animal origin such as poultry litter, cow manure, and sewage sludge are higher than biochar made from plants or crop residues (Shinogi 2004; Chan et al. 2007a, b, 2008; Gaskin et al. 2008; Covell et al. 2011).

Poultry litter itself is a valuable source of organic fertilizer for plant nutrients as it contains high content of essential macro and micronutrients (Warman 1986; Dikinya and Mufwanzala 2010). But improper management and over application of PL are responsible for ammonia volatilization, higher nitrogen mineralization, nutrients leaching, surface water contamination by excessive phosphorus and also damage of sensitive crops, etc. (Schilke-Gartley and Sims 1993; Chan et al. 2007c; Reddy et al. 2008; AWMFH 2013). Different environmental pollutions (emission of greenhouse gases, offensive odor, etc.) are also results from faulty droppings or mismanagement of PL (O'Neill and Phillips 1992; Abdullah-Al-Amin et al. 2009; Akanni and Benson 2014). Though there are different strategies to manage PL, the conversion of PL into PLB now can be considered as the most reliable, safe and effective strategy because of its stability and unique beneficial characteristics that will help to handle both soil and environmental pollution issues and will be an environment friendly management strategy of utilizing this organic resource in agriculture (Lehmann 2009; Lehmann and Joseph 2009; Draper and Tomlinson 2012; Scholz et al. 2014).

Poultry industry is located throughout the world and this sector has been growing at more than 5% per annum (FAO 2006). In Bangladesh, this rate is around 20% within the last two decades (Islam et al. 2014). The global production of poultry was estimated almost 22 billion in 2010 which is nearly three times more than that of in 1980 (MacLeod et al. 2013). A huge amount of PL is generated every day. On a dry weight basis, about 0.7 to 2.0 tons of litter per 1000 chickens per year have been reported (Bolan et al. 2010). In case of one chicken, approximately 8 to 11 lb of fresh manure is produced monthly (Foreman and Long 2013).

Most of the soils of Bangladesh contain less than 1.5% SOM and few soils contain even less than 1% SOM (FRG 2012). Moreover, the rate of SOM decomposition and mineralization in Bangladesh soils is usually very high because of temperate regime which is a basic problem in stability of SOM (Karim and Iqbal 2001). So, production of stable biochar from organic wastes and its use in soil can play a vital role to solve the current problem in agriculture and also can contribute to mitigate the raising greenhouse gas emission (Lehmann et al. 2006, 2009; Lehmann 2009; Sarkar et al. 2015).

Though PL itself has been used as organic fertilizer, there is limited research work for the production of PLB and its contribution in maintaining soil nutrients and effects on plant growth. The present research work was conducted for PL management by producing PLB from fresh PL, to determine the most important properties of both PL and PLB, to see the growth of *gima kalmi* under the application of PL and PLB in soil and also to evaluate the changes of soil properties after PL and PLB application.

Materials and methods

Study site

Pot experiment was carried out in the net house of Soil, Water and Environment Discipline, Khulna University, Bangladesh and all the analyses were performed in the laboratory of the Discipline.

Sample collection and preparation

Soil sample was collected from the surface of agricultural field behind the Khulna University campus (N22°45.122′/E89°31.456′). Collected soil sample was air dried, and visible roots and other debris were removed. The larger soil aggregates were broken gently using a wooden hammer, sieved through a 2.0-mm sieve and mixed thoroughly to prepare a composite soil sample (USDA 1951). The sieved soil was used for plant growth. A portion of the soil sample was further passed through 0.5-mm sieve for laboratory analyses.

Poultry litter was collected from a local poultry farm situated nearby the Khulna city. At the time of collection of bedding materials, feather, etc. were avoided as much as possible. Collected PL was sun dried for 3 days to remove extra moisture. Then, the dried PL was broken gently by a wooden hammer and sieved using a 0.5-mm sieve. The sieved PL was then preserved in plastic pot for further use.

Biochar production from poultry litter

Poultry litter biochar was produced through pyrolysis process using muffle furnace under limited oxygen condition (Baldock and Smernik 2002; Abbasi and Anwar 2015; Vijayanand et al. 2016). The pre-processed PL was taken into porcelain cup and kept into muffle furnace at 300 °C temperature for 10 min. So, in this experiment the PLB was produced by slow pyrolysis method (Brownsort 2009). Then, the char materials were grinded using mortar and pestle and sieved through 0.5-mm sieve.

Selection of experimental plant

In the present study, *gima kalmi* (*Ipomoea aquatica*) was selected as test plant to observe the effect of PL and PLB on plant growth. *Gima kalmi* is a high yielding and very popular leafy vegetable. It is cultivated everywhere in Bangladesh with or without irrigation facilities throughout the year. The main benefit is that when seeds are shown once in a year, yield can be obtained throughout the year as it has regrowth capacity from its shoot (Mondal et al. 2014).

Experiment set up

Twenty-seven earthen pots (2-L) were collected and filled up with 1.5 kg pre-processed soil. The surface area of the pot was 214 cm^2 and the height was 15 cm. There were four treatments for both PL and PLB along with control and three replications for each treatment. At the time of biochar production, moisture released from PL and burning at 300 °C temperature results in 60% weight reduction. The four PL treatment rates were 2.5, 5, 7.5 and 10 t ha^{-1} and by calculating the reduced weight of PL the four PLB treatment rates were 1, 2, 3 and 4 t ha^{-1}, respectively, which were equivalent to the rates of PL. Fifteen days prior to seed sowing PL and PLB were mixed in the soil according to treatments and watered well for proper mixing of the PL and PLB with soil. Ten seeds of *gima kalmi* were sown in each pot. Ten days after seed germination, thinning was done manually leaving five healthy plants in each pot and other plants were manually removed carefully by uprooting. Irrigation was done with similar amount of water for each pot very carefully according to the need of plant to avoid root rot.

Harvesting

Six weeks after seed germination, the plants were harvested from the individual pots by cutting the stems 1 cm above the ground. After harvest, the plant height was measured using measuring scale. After washing plant shoots and air dried, plant fresh weight was taken using electric balance. The plant samples were oven dried at 70 °C for 48 h and plant dry weight was weighed with the help of electric balance.

Post-harvest soil collection for laboratory analyses

After harvest, the soil samples were collected from each pot to observe the nutrient status of soil treated with PL and PLB.

Experiment to see the residual effect of PL and PLB

After harvesting, the pots were kept fallow for one month; then *gima kalmi* seeds were sown again in the same pot to observe the residual effects of PL and PLB on plant growth. All the cultural practices followed were similar to the first experiment.

Analysis of different parameters

pH, EC and all other nutrient elements were determined by following the procedures described in Imamul Huq and Alam (2005).

Statistical analysis

Data were analyzed statistically following ANOVA technique using Minitab 16.0 software. Significant variations and comparisons among data were analyzed through ANOVA (Fisher's test) and paired *t* test. Other calculations and graphs were prepared using Microsoft Excel 2010.

Results and discussion

Soil properties

The analytical result of some soil properties is represented in Table 1. The soil used in the experiment for plant growth is clay loam in texture, slightly acidic and very slightly saline (Soil survey manual 1993).

Properties of poultry litter and poultry litter biochar

The properties of PL and PLB are presented in Table 2. The pH values of PL and PLB were measured as 7.56 ± 0.13 and 9.05 ± 0.14, respectively, which shows 19.71% increase of pH value in PLB when PL was pyrolyzed at 300 °C. This result is in good agreement with the results of Chan et al. (2008); Cely et al. (2015); Gondek and Hersztek (2016) but opposite to Evans et al. (2017).

Table 1 Some properties of soil

Parameters		
pH		6.45 ± 0.03
EC (dS m^{-1})		3.80 ± 0.18
Organic carbon (OC, %)		0.82 ± 0.1
	Available	Total (%)
Nitrogen (N)	0.10 ± 0.01 (%)	0.25 ± 0.02
Phosphorus (P)	50.41 ± 6.93 (mg kg^{-1})	0.37 ± 0.02
Potassium (K)	0.19 ± 0.002 (%)	2.50 ± 0.3
Calcium (Ca)	0.17 ± 0.01 (%)	0.77 ± 0.25
Magnesium (Mg)	0.082 ± 0.01 (%)	0.32 ± 1.48
Sulfur (S)	332.76 ± 5.54 (mg kg^{-1})	0.18 ± 0.01
Iron (Fe)	364.91 ± 8.03 (mg kg^{-1})	1.78 ± 0.02

Data represent the average value ± the standard deviation (*n* = 3)

Table 2 Properties of poultry litter and poultry litter biochar

Parameters				
		PL		PLB
pH		7.56 ± 0.13		9.05 ± 0.14
EC (dS m^{-1})		4.44 ± 0.36		4.88 ± 0.27
OC (%)		26.76 ± 0.32		31.34 ± 1.14
	PL Available (%)	PLB	PL Total (%)	PLB
Nitrogen (N)	0.40 ± 0.03	0.56 ± 0.07	2.23 ± 0.14	2.04 ± 0.08
Phosphorus (P)	0.72 ± 0.05	1.15 ± 0.03	3.29 ± 0.07	4.68 ± 0.12
Potassium (K)	1.53 ± 0.12	2.01 ± 0.12	3.12 ± 0.7	4.30 ± 0.6
Calcium (Ca)	0.96 ± 0.06	1.25 ± 0.05	1.88 ± 0.25	2.1 ± 0.35
Magnesium (Mg)	0.43 ± 0.02	0.39 ± 0.03	0.71 ± 0.06	1.07 ± 0.12
Sulfur (S)	0.30 ± 0.02	0.27 ± 0.01	0.69 ± 0.07	0.63 ± 0.06
Iron (Fe)	0.017 ± 0.001	0.015 ± 0.001	0.28 ± 0.004	0.3 ± 0.01

Data represent the average value ± the standard deviation (*n* = 3)

PL poultry litter, *PLB* poultry litter biochar

The OC content of PLB was also increased by 17.12% than that of PL (Table 2). Enders et al. (2012) reported that with increasing temperature, the total OC content increased while total H and O decreased during pyrolysis. Similar results were also reported by others (Chan et al. 2008; Novak et al. 2009a; Cantrell et al. 2012). High OC content of PLB helps in increasing organic matter (OM) in soil. The incorporation of 31.34% OC of PLB is equal to 54.03% OM incorporation, which helps to increase SOM and improve soil fertility (Lehmann et al. 2006).

Available N content of PL and PLB were 0.40 ± 0.03 and 0.56 ± 0.07%, respectively. Results revealed that available N content was 40% higher in PLB than PL. Experiments conducted by Chan et al. (2008); Novak et al. (2009a) at 350 °C and Evans et al. (2017) at 400 °C temperature reported that the N content increased in PLB after pyrolysis, whereas the total N content of PLB (2.04 ± 0.08) % was a little bit lower than that of PL (2.23 ± 0.14) % that means after pyrolysis at 300 °C the total N content was slightly decreased in PLB (8.52%). In this experiment, the total N content of PLB was similar to the result of Chan et al. (2008), who reported 2% total N in PLB. During pyrolysis, with the increase in pyrolysis temperature volatilization of N increases with the changes in the chemical structure of N present in biochar, ammonia and other N containing volatile organic compounds emission, etc. resulting in decrease in the total N content in biochar (Sheth and Bagchi 2005; Chan and Xu 2009; Novak et al. 2009a). But Cantrell et al. (2012) reported a different statement that the total N content in the biochar increased initially with pyrolysis at 350 °C which may be related to recalcitrant N occurring in heterocyclic compounds (Kazi et al. 2011).

Both available and total P contents in PLB were higher than that of PL (Table 2) and were increased by 59.72% and 42.25%, respectively. This result indicates that the P content in PLB was increased after producing biochar from PL. This result was in accordance with the results of Singh et al. (2010) at 300 °C and 500 °C temperature; Cantrell et al. (2012); and Evans et al. (2017). But Cely et al. (2015) revealed a different result that P concentration decreases after producing biochar, as different factors such as type of organic material, pyrolysis conditions, etc. control the properties of biochar (Mukherjee et al. 2011) and P starts to volatilize at temperatures of about 770 °C (Knoepp et al. 2005).

The available and total content of both K and Ca in PLB were estimated higher than that of PL. The available K and Ca contents were increased by 31.37% and 30.20%, respectively, and in case of total K and Ca, the rates of increase were 37.82% and 11.70%, respectively, in case of PLB. Similar result was recorded at different pyrolysis temperature and revealed that pyrolysis temperature increased the K and Ca content in PLB than PL (Cantrell et al. 2012; Cely et al. 2015; Reiter and Middleton 2016; Evans et al. 2017). But Lima et al. (2015) found a negative result that Ca content was decreased after pyrolysis of PL at 250 °C temperature.

However, due to pyrolysis of PL to PLB, a decrease in available S, Fe and Mg content was observed. Lima et al. (2015) also observed that pyrolysis decreased the S and Mg content. On the other hand, Cantrell et al. (2012) found that S, Fe and Mg contents were increased in PLB after pyrolysis. In case of total Fe and Mg content, results were slightly higher in PLB than that of PL (Table 2). Evans et al. (2017) also estimated the similar results. But Reiter and Middleton (2016) revealed a different result for Mg. In case of total S, PLB contains low S than that of PL after pyrolysis (Table 2). This result was similar to Reiter and Middleton (2016) and in contrast to the findings of Evans et al. (2017) at 400 °C.

Effects of PL and PLB on plant (*gima kalmi*)

Visual observations

The visual growth of *gima kalmi* under PL- and PLB-treated soil is presented in Fig. 1. It was observed that the growth of plants was gradually increased with the increasing rate of both PL and PLB application. The average growth (height and biomass) of plants grown under PLB application was significantly higher than that of PL application and the maximum vegetative growth was observed at 4 t ha^{-1} PLB application.

Plant height (cm)

To compare plant growth among different treatments, measurement of plant height is one of the major components. The average plant height at different treatments of both PL and PLB is shown in Table 3. Plant height was increased with increasing rate of both PL and PLB application. For both the cases, plant height was significantly increased in all the treatments as compared to control (Table 3). Statistical analysis of the results also revealed that in case of PL application the plant height was significantly higher at 7.5 t ha^{-1} (23.37 ± 1.55 cm) and 10 t ha^{-1} (24.12 ± 1.22 cm) PL applications (Table 3). In case of PLB application, the plant height (26.15 ± 1.28 cm) was significantly ($p < 0.001$) higher at 4 t ha^{-1} PLB application. The height of the plants treated with PLB was significantly ($p = 0.024$) higher than that of PL. Similar findings were also reported by Bhattarai et al. (2015) on pea by 10 t ha^{-1} PLB application. In a pot experiment by application of 20 g kg^{-1} PLB on rice plant, Maru et al. (2015) also reported the increase in plant height than control.

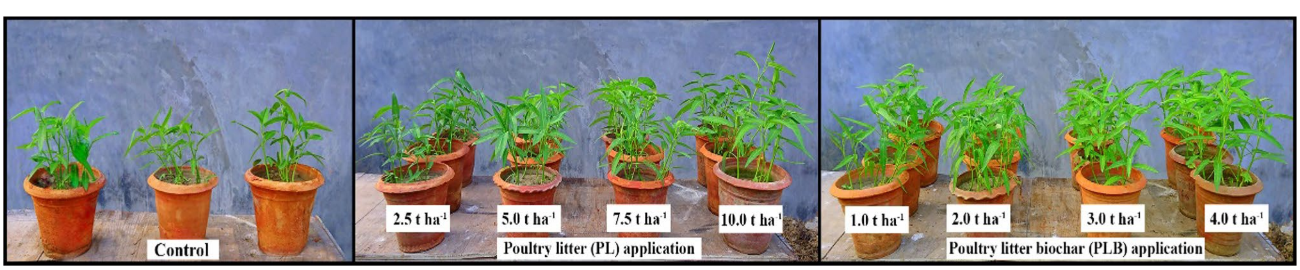

Fig. 1 Growth performance of *gima kalmi* treated with PL and PLB

Table 3 Response of PL and PLB application on plant height and biomass of *gima kalmi*

Source	Treatment	Height (cm)	Fresh weight (g)	Dry weight (g)
Control	0.0 t ha^{-1}	16.37 ± 1.14^{c}	13.22 ± 0.69^{c}	1.18 ± 0.17^{c}
Poultry litter (PL)	2.5 t ha^{-1}	19.43 ± 0.1^{b}	15.18 ± 1.93^{bc}	1.49 ± 0.08^{bc}
	5.0 t ha^{-1}	21.03 ± 1.02^{b}	17.73 ± 4.83^{abc}	1.75 ± 0.13^{b}
	7.5 t ha^{-1}	23.37 ± 1.55^{a}	18.9 ± 3.67^{ab}	2.07 ± 0.22^{a}
	10.0 t ha^{-1}	24.12 ± 1.22^{a}	22.18 ± 2.14^{a}	2.16 ± 0.16^{a}
Control	0.0 t ha^{-1}	$16.37 \pm 1.14^{d'}$	$13.22 \pm 0.69^{c'}$	$1.18 \pm 0.17^{d'}$
Poultry litter biochar (PLB)	1.0 t ha^{-1}	$20.23 \pm 0.21^{c'}$	$18.28 \pm 1.93^{b'}$	$1.73 \pm 0.16^{c'}$
	2.0 t ha^{-1}	$22.53 \pm 0.29^{b'}$	$18.79 \pm 1.85^{b'}$	$1.97 \pm 0.13^{b'c'}$
	3.0 t ha^{-1}	$23.92 \pm 1.51^{b'}$	$19.07 \pm 0.66^{b'}$	$2.14 \pm 0.22^{b'}$
	4.0 t ha^{-1}	$26.15 \pm 1.28^{a'}$	$24.91 \pm 0.47^{a'}$	$2.48 \pm 0.11^{a'}$

Data represent the average ± the standard deviation ($n = 3$); different letters indicate the significant differences

Plant biomass (g $plant^{-1}$)

Since *gima kalmi* is an edible leafy vegetable, the total plant weight (shoot *plus* leaves) is considered as plant biomass. Both fresh and dry weights of the plants were weighed. The changes in fresh weight (FW) and dry weight (DW) in grams (g) after applying different rates of PL and PLB are presented in Table 3. Both FW and DW of the plants were significantly ($p < 0.05$ for FW for PL, $p < 0.001$ for DW for PL, $p < 0.001$ for both FW and DW, for PLB application) increased with the application of both PL and PLB as compared to control. FW was significantly higher at 10 t ha^{-1} and 4 t ha^{-1} PL and PLB application, respectively. Both the FW and DW of the plants treated with PLB were higher than that of PL and it was significant ($p = 0.004$) only for DW but insignificant ($p = 0.104$) for FW. The present result was advocated by Gunes et al. (2014) on lettuce where 20 g kg^{-1} PL and 10 g kg^{-1} PLB were used and observed that the plant DW was increased in the PLB-treated soil. Our results were also in good agreement with Inal et al. (2015) on maize and bean plant (highest growth observed at 10 g kg^{-1} PLB application). Chan et al. (2008) also reported that the yield of *R. sativus* was increased with the application of PLB alone. On the other hand, Allen (2014) reported a negative result on PLB application on radish yield.

Post-harvest soil analysis

Results of post-harvest soil analysis are presented in Tables 4 and 5. It was found that soil pH, EC, OC, available N, P, K, Ca, Mg, S and Fe content were increased with the increasing rate of both PL and PLB application. The OC, N, P, K, Ca and Mg of PLB-treated soil were higher than those of PL-treated soil and the highest nutritional values were also estimated at the highest rate of PLB application (4 t ha^{-1}). The reason might be as biochar has a great ability to increase the capacity of soil to adsorb plant nutrients and decrease nutrient leaching (Liang et al. 2006; Lehmann et al. 2009; Laird et al. 2010; Steiner et al. 2010). On the other hand, S and Fe were observed higher in PL-treated soil than those of PLB-treated soil.

After harvest, there were no significant changes in the soil pH and EC treated with both PL and PLB. But an increasing effect of PLB on soil pH (Chan et al. 2008; Abbasi and Anwar 2015; Bhattarai et al. 2015) and soil EC (Chan et al. 2008) was reported in post-harvest soil

Table 4 Properties of post-harvest soil

Source	Treatment	pH	EC (dS m^{-1})	OC (%)
Control	0.0 t ha^{-1}	6.49 ± 0.03	3.80 ± 0.13	0.53 ± 0.18
Poultry litter (PL)	2.5 t ha^{-1}	6.49 ± 0.02	3.80 ± 0.13	0.53 ± 0.18
	5.0 t ha^{-1}	6.52 ± 0.02	3.80 ± 0.13	0.82 ± 0.20
	7.5 t ha^{-1}	6.52 ± 0.01	3.87 ± 0.07	0.89 ± 0.18
	10.0 t ha^{-1}	6.58 ± 0.01	3.93 ± 0.10	0.96 ± 0.20
Poultry litter biochar (PLB)	1.0 t ha^{-1}	6.51 ± 0.02	3.80 ± 0.07	0.60 ± 0.20
	2.0 t ha^{-1}	6.57 ± 0.04	3.80 ± 0.13	0.78 ± 0.10
	3.0 t ha^{-1}	6.63 ± 0.03	3.93 ± 0.06	0.96 ± 0.20
	4.0 t ha^{-1}	6.67 ± 0.02	3.93 ± 0.07	1.06 ± 0.18

Data represent the average ± the standard deviation ($n = 3$)

Table 5 Nutrient status of post-harvest soil

	Treatment	N (%)	P (mg kg^{-1})	K (%)	Ca (%)	Mg (%)	S (mg kg^{-1})	Fe (mg kg^{-1})
Control	0.0 t ha^{-1}	0.07 ± 0.002	37.0 ± 2.1	0.14 ± .002	0.11 ± 0.03	0.07 ± 0.01	312.0 ± 4.6	329.3 ± 5.9
Poultry litter (PL)	2.5 t ha^{-1}	0.07 ± 0.01	39.0 ± 4.3	0.14 ± 0.01	0.13 ± 0.02	0.07 ± 0.02	313.8 ± 4.6	333.3 ± 5.4
	5.0 t ha^{-1}	0.08 ± 0.01	40.2 ± 3.7	0.17 ± 0.01	0.15 ± 0.01	0.08 ± 0.01	322.4 ± 6.1	340.1 ± 2.8
	7.5 t ha^{-1}	0.08 ± 0.01	42.7 ± 1.4	0.19 ± 0.01	0.17 ± 0.01	0.08 ± 0.01	332.2 ± 2.6	341.4 ± 3.6
	10.0 t ha^{-1}	0.09 ± 0.01	47.6 ± 2.4	0.21 ± 0.004	0.22 ± 0.03	0.09 ± 0.01	336.2 ± 4.6	346.8 ± 2.8
Poultry litter biochar (PBL)	1.0 t ha^{-1}	0.07 ± 0.002	37.8 ± 3.1	0.13 ± 0.01	0.13 ± 0.02	0.07 ± 0.01	313.8 ± 6.2	332.0 ± 6.2
	2.0 t ha^{-1}	0.08 ± 0.004	42.7 ± 2.5	0.18 ± 0.01	0.15 ± 0.01	0.08 ± 0.01	321.8 ± 1.7	336.0 ± 3.4
	3.0 t ha^{-1}	0.09 ± 0.01	46.3 ± 2.1	0.19 ± .004	0.19 ± 0.02	0.09 ± 0.01	327.6 ± 4.6	340.1 ± 5.4
	4.0 t ha^{-1}	0.09 ± 0.002	52.4 ± 1.2	0.23 ± 0.002	0.22 ± 0.003	0.10 ± 0.004	332.2 ± 4.3	341.4 ± 2.7

Data represent the average ± the standard deviation ($n = 3$)

analysis. Increased soil OC content was observed in higher rate of PL and PLB application as compared with initial soil OC content. Soil OC was higher in PLB-treated soils compared to PL which was also observed by Widowati et al. (2011); Abbasi and Anwar (2015); Bhattarai et al. (2015). The result indicated that biochar might be resistant to decomposition and also revealed the C storage capacity of PLB in soil (Lehman et al. 2003a; Chan et al. 2008; Lehmann and Joseph 2009). Available soil N, P and K contents showed no significant differences from its initial values though there was an increasing tendency of the elements in PLB-treated soil than that of PL-treated soil at higher rate of application. Similar results were also reported by Chan et al. (2008); Bhattarai et al. (2015); and Inal et al. (2015). The results of soil Ca and Mg content were higher after application of PLB than that of PL which were similar to the results of Chan et al. (2008) and Novak et al. (2009a). Sulfur and Fe were estimated lower in PLB-treated soil. The reasons were due to the reduction of bioavailability and water insoluble nature of S after pyrolysis. During pyrolysis under highly reducing conditions, the forms of S change, resulting in the disappearance of inorganic sulphate (Knudsen et al. 2004; Chan and Xu 2009). Novak et al. (2009b) also stated that soil bioavailability of S decreased after biochar application. Inal et al. (2015) and Maru et al. (2015) reported the similar results in case of Fe.

Residual effects of PL and PLB on plant growth

Biochar is generally popular for its distinctive properties (stability, nutrient supplier for longer period of time, carbon storage capacity, etc.). To observe the residual effects of PL and PLB on plant growth, the same plant (*gima kalmi*) was grown in the same pot after a one-month fallow period and the observations are given below.

Visual observations

The growth of *gima kalmi* was increased with the increasing rate of both PL and PLB application. But the growth was higher in case of PLB application than that of PL. The maximum growth was observed at 4 t ha^{-1} PLB application. The leaves were greener in color of the plants treated with PLB than that of PL-treated plants (Fig. 2). Moreover, the color of leaves in the PL-treated plants was yellowish and then turned curly in nature, which represents a sign of nutrient deficiency syndrome, especially of nitrogen (Fig. 2). Nitrogen deficiency results in a pale yellowish green colored (chlorosis) leaves, especially in the older leaves (Brady and Weil 2002). Chlorosis, restricted plant growth, etc. were

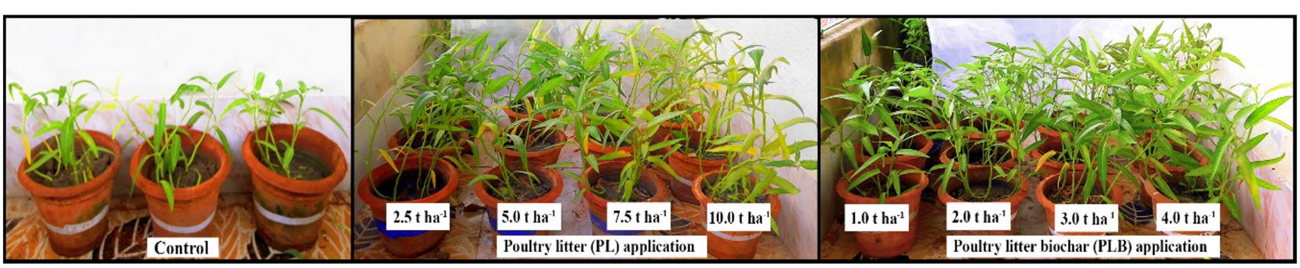

Fig. 2 Visual observation of *gima kalmi* as second crop grown in previously PL- and PLB-treated soil

observed due to N deficiency (Silas et al. 2012). So, in this experiment the PL-treated plants suffered from nitrogen deficiency. On the other hand, plant N deficiency syndrome was not prominent under PLB-treated soil. So, PLB might has the ability to absorb nutrients and release available N slowly, decrease of N loss by inhibiting NO_3^-–N transformation from NH_4^+–N and lowering nitrogen leaching (Chan et al. 2008; Masulili et al. 2010; Widowati et al. 2011, 2012).

Plant height (cm)

The average plant height among different treatments of PL and PLB is shown in Table 6. In both the cases, plant height was increased significantly with increasing rate of application. It was observed that the plant height was significantly higher for all the treatments as compared to control plants (Table 6). Statistical analysis of the results also revealed that in case of PL application the plant height (29.82 ± 0.93 cm) was significantly ($p < 0.001$) higher at 10 t ha^{-1} PL application (Table 6), whereas in PLB application, the plant height (30.67 ± 0.36 cm) was significantly ($p < 0.001$) higher at 4 t ha^{-1} PLB application. The height of the plants treated with PLB was higher than that of PL but it was not significant ($p = 0.231$).

Plant biomass (g $plant^{-1}$)

It was observed that both plant FW and DW were significantly increased with the increasing rate of PL and PLB application as compared to control. Both FW and DW were significantly higher at 10 t ha^{-1} PL and 4 t ha^{-1} PLB applications, respectively. The FW and DW of the plants treated with PLB was significantly ($p = 0.005$ for FW, $p = 0.004$ for DW) higher than that of PL. Similar result was also observed by Widowati et al. (2012) and reported that the height and yield of second season maize were higher than that of first season maize under PLB application.

Comparison between first and second crop treated with PL and PLB

Plant height of second crop was significantly ($p = 0.021$) higher than that of the first crop when it was treated with PL but it was not significant ($p = 0.074$) in case of PLB application (Tables 3, 6). Plant FW and DW of second crop were higher than that of the first crop in both the cases of PL and PLB. Plant FW of second crop was significantly higher ($p = 0.038$ for PL and $p = 0.015$ for PLB) than that of first crop (Tables 3, 6). Plant DW of second crop was higher than that of first crop but it was not statistically significant ($p = 0.692$ for PL and $p = 0.428$ for PLB) (Tables 3, 6). Widowati et al. (2012) reported that the height and yield of second season maize were higher than that of first season maize under PLB application.

Though the nutrient content of biochar and its effects on plant growth is an area of different opinion and controversy, numerous experiments have proven that the application of biochar helps in improving soil conditions and plant growth (Asai et al. 2009; Wisnubroto et al. 2017). In the present experiment, the most important nutrients responsible for plant growth were increased in PLB than the PL feedstock after pyrolysis. Higher yield by applying PLB might be due to its higher nutrients content. Since organic fertilizers are slow release nutrient sources, so the growth of second crop was found to be increased in both cases of PL and PLB application than that of first crop. The higher growth of the second crop under PLB-treated soil than that of PL-treated soil revealed that biochar was a stable organic amendment, resistant to microbial decomposition and with great ability to absorb and store plant nutrients than PL. This helped to decrease nutrient loss through leaching and volatilization and supplied potential nutrients slowly over time and, therefore, contributed to enhanced soil fertility and improved plant growth (Lehmann et al. 2003a, b; Steiner et al. 2007; Cheng et al. 2008; Lehmann and Joseph 2009). The growth of *gima kalmi* was promoted

Table 6 Residual effects of PL and PLB on plant height, and biomass of *gima kalmi*

Source	Treatment	Height (cm)	Fresh weight (g)	Dry weight (g)
Control	0.0 t ha^{-1}	12.13 ± 0.80^{d}	8.54 ± 1.42^{d}	0.69 ± 0.06^{e}
Poultry litter (PL)	2.5 t ha^{-1}	23.12 ± 1.13^{c}	19.75 ± 1.06^{c}	1.73 ± 0.09^{d}
	5.0 t ha^{-1}	24.46 ± 1.32^{c}	21.97 ± 1.59^{bc}	1.92 ± 0.14^{c}
	7.5 t ha^{-1}	27.30 ± 1.43^{b}	24.37 ± 1.59^{ab}	2.13 ± 0.14^{b}
	10.0 t ha^{-1}	29.82 ± 0.93^{a}	26.63 ± 0.75^{a}	2.23 ± 0.07^{a}
Control	0.0 t ha^{-1}	$12.13 \pm 0.80^{e'}$	$8.54 \pm 1.42^{c'}$	$0.69 \pm 0.06^{e'}$
Poultry litter biochar (PLB)	1.0 t ha^{-1}	$22.71 \pm 1.19^{d'}$	$21.06 \pm 1.95^{b'}$	$1.84 \pm 0.17^{d'}$
	2.0 t ha^{-1}	$24.78 \pm 0.76^{c'}$	$24.49 \pm 2.48^{b'}$	$2.14 \pm 0.22^{c'}$
	3.0 t ha^{-1}	$27.64 \pm 0.74^{b'}$	$27.93 \pm 1.36^{a'}$	$2.44 \pm 0.12^{b'}$
	4.0 t ha^{-1}	$30.67 \pm 0.36^{a'}$	$30.98 \pm 2.02^{a'}$	$2.74 \pm 0.15^{a'}$

Data represent the average ± the standard deviation ($n = 3$)

after application of PLB than application of PL in soil is clearly noticed in the present experiment. Considering all the facts PLB could be a great source of stable nutrients-rich organic amendment for plant growth.

Conclusion

Poultry litter biochar was produced from fresh PL as one of the PL management strategies and an experiment was conducted to observe the growth performance of plant treated with both PL and PLB. Thermal conversion of PL to PLB resulted in an increase of the essential nutrient content in PLB than that of PL. When PL was pyrolyzed, pH, EC and OC were increased and most of the available nutrient elements like N, P, K, Ca were increased in PLB and in case of total nutrients P, K, Ca, Mg, Fe were increased. Experimental results and visual observations revealed that plant growth (*gima kalmi*) was increased significantly ($p < 0.001$) with the increasing rate of application of PLB than that of application of PL in both cases of first and second crop. Plant height, FW and DW were higher in PLB-treated soil than that of plant grown under PL-treated soil in both cases. The highest growth of plants was observed under the highest application rate (4 t ha^{-1}) of PLB in both first and second crop over control and other treatment rates. On the other hand, nutrient deficiency syndrome (especially N) was observed in second crop under PL-treated soil because the post-harvest soil analysis (soil was collected after the harvest of first crop) indicated that the nutrient status was lower in PL-treated soil than that of PLB-treated soil.

Though the growth of *gima kalmi* was also increased by PL application as it is a very good source of essential nutrients, but the growth rate of plants, especially second crop, revealed that the nutrients of PLB were more stable and had the ability to decompose slowly which results in reduction of nutrient loss and supplied available nutrients for long time and helped to improve soil fertility and plant productivity. So, from the experimental results, it is clear that PLB undoubtedly can be evaluated as a promising organic fertilizer with high nutrient content and has considerable influence on plant growth than that of fresh PL for sustainable agriculture. At the same time, making PLB from PL could be an environment friendly management strategy of PL.

Compliance with ethical standards

Conflict of interest The authors would like to declare that there is no conflict of interest with this research.

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