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ORIGINAL PAPER

Low temperature carbonization of chicken manure to char and its effect on growth of *Oryza sativa* L. Koshihikari and *Brassica rapa* komatsuna

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Abstract Considering the demand for transforming poultry waste into eco-friendly manure, we carbonized chicken manure at 402, 449 and 528 °C and determined the physicochemical properties. We evaluated the effectiveness of the ensuing carbonized chicken manure (CCM) as a fertilizer using *Brassica rapa*, var. komatsuna and *Oryza sativa* L., var. japonica, cv. Koshihikari, in the upland and the paddy field soil, respectively. Herein, we carried out duplicate treatment of CCM (carbonized at 528 °C) either alone or in combination with nitrogen and measured the growth from three or more plants. The plots with the recommended chemical fertilizers containing nitrogen (N), phosphorus (P) and potassium (K) and with no fertilizers were used as controls for growth measurement. The vessel tests indicated that when applied alone, the CCM plot could not support the normal growth of both the plants. However, the CCM plot restored the plant growth with simultaneous application of nitrogen, and the growth in the CCM + N plot was comparable to that observed in the NPK plot. By estimating the growth in the NPK plots as 100%, the growth percentages of fresh weights of komatsuna were 12% in the CCM plot, 79% in the N plot and 99% in the CCM + N plot. Likewise, the plant heights of Koshihikari were 43% in the CCM plot, 77% in the N plot and 99% in the CCM + N plot. Our data suggest CCM supplementation to N fertilizers as a potential replacement of inorganic fertilizers like P and K for effective environmental management.

Keywords *Brassica rapa* v. komatsuna · *Oryza sativa* cv. Koshihikari · Char · Chicken manure · Carbonization at low temperature · Paddy field

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Introduction

According to a statistical study, about 1.2 billion chickens get fed in the EU (European Union), which is nearly four times larger than that in Japan. Annually, the manure from these chickens produces around 540 million kg of nitrogen (FAOSTAT 2002). Consequently, there is an increasing need to manage the waste biomasses and recycle them into useful environment-friendly byproducts using strategies like composting, biochemical conversion and carbonization (Jeffery et al. 2015; Sánchez-García et al. 2015; Singh et al. 2015). For effective management of enormous waste biomasses, carbonization technology is preferred. Unlike a slow processing technique like composting, carbonization quickly processes and efficiently reduces the odor from biomasses. Also, a technology for recycling needs to be energy saving, and the quality of the resulting products should be managed in an eco-friendly and cost-effective manner. Accordingly, Roberts et al. (2010) stated that carbonization could be an economically viable strategy for transforming waste biomass into value-added materials while suppressing energy costs and achieving a carbon offset. For energy saving and mitigating greenhouse gas emissions, carbonization should be performed as in Roberts et al. (2010), and the resulting char must be applied to land to remove the carbon from the atmosphere (Gaunt and Lehmann 2008; Singh et al. 2015; Kuppusamy et al. 2016).

Because chicken manure contains abundant quantities of nutrients such as nitrogen (N), phosphorous (P) and potassium (K), they have been used as fertilizers after anaerobic digestion, composting or combustion (Kelleher et al. 2002). Carbonization is known to effectively recycle chicken manure into carbonaceous materials with significantly reduced weight and volume. Also, the resulting char does not have any offensive odor and serves as a nutrient source for the plants (Tagoe et al. 2008, 2010; Celya et al. 2015). However, carbonization at 400 °C reduces the N content of the chicken manure, and hence there is a need to supplement the char produced from chicken manure with N before application to plants (Gaskin et al. 2008; Celya et al. 2015). Previous studies (Lehmann et al. 2003; Steiner et al. 2007; Asai et al. 2009) evaluated the fertilizing efficacy of carbonized woods for rice and suggested the cooperative function in the mixture of char from wood and chemical fertilizer. However, these studies overlooked the ability of the char to supply nutrition and emphasized the improvement in the physicochemical characteristics of the soil such as nutrient leaching or hydraulic conductivity.

In biomass recycling processes, it is important to be aware of the final energy balance used in the whole process of recycling. In contrast to the notion that heaping could save energy, this method in fact releases a significant amount of greenhouse gas and hence demands careful estimation of the circumstances and energy balance at the final stage. However, it is not easy to accumulate such exhaustive data, and various studies with appropriate controls need to be carried out before proposing an ultimate sustainable technology. In this study, we report the evaluation of the physicochemical properties of carbonized chicken manure (CCM). Furthermore, we demonstrate the fertilizing efficacy of CCM for agriculturally important plants including the leafy vegetable *Brassica rapa* komatsuna and rice *Oryza sativa* Koshihikari with evaluation studies in the upland soil and paddy field soil.

Materials and methods

Preparation of feedstock for carbonization

Chicken manure was collected from the cage and semi-dried to reduce the water content for 16 days in a composting reactor (C-65ET; Chubu Ecotec Co., Ltd, Aichi, Japan) before carbonization at 402–528 °C. The water content of the fresh chicken manure was 49–69%, but the chicken manure from one of the feedstocks that was semi-dried by composting for 16 days had about 20–32% water content.

Carbonization

The feedstock was carbonized at 402–528 °C in the inner cylinder of a furnace (SK-45 K, SK Teck, Tainai, Niigata, Japan) (Fig. 1) without oxygen for 1–2 h. For attaining stable data in the experiments using the char, it is important to reduce the water content of the feedstock to 0–1% (w/w) by heating. Based on our preliminary experiments, 1–2 h was sufficient to reach such level of the water content in all performances at three different temperatures. Thus, in the carbonization, heating was conducted for 1 h at around 528 °C, 1.5 h at around 449 °C and 2 h at around 402 °C. The resulting carbonized chicken manure (CCM) was used in the following experiments.

Analysis of the nutrient composition of carbonized chicken manure

The total N in the sample shown in Tables 1, 2 and 3 was quantified with the indophenol method (Bolleter et al. 1961) after Kjeldahl digestion. The total N, total C and the C/N ratio in Table 4 were analyzed with a C/N-Analyzer (MT-700, Yanaco Analytical Industries Ltd., Kyoto, Japan) calibrated with hippuric acid. The amount of nitrate nitrogen $\left(NO_3^-\right)$ and ammonium nitrogen $\left(NH_4^+\right)$ were determined according to Cataldo's colorimetric method (Cataldo et al. 1975) and the indophenol method (Bolleter et al. 1961), respectively. The total P in the sample was measured according to the vanadate-molybdate reagent method (Tandon et al. 1968) and total K, Ca and Mg were measured according to the flame photometry (Dagnall et al. 1971) using atomic absorption spectrometer (Z-6100, Hitachi, Tokyo, Japan) after dry ashing. The samples were diluted ten times the dry weight with distilled water to determine the pH and the electrical conductivity (EC), and the parameters were analyzed with a pH meter (HM-30R, DKK-TOA Corporation, Tokyo, Japan) and an EC meter (CM-50D, Takemura Denki Seisakusho, Tokyo, Japan),

Estimation of the mineralization of nitrogen (N) in CCM in paddy field and upland soils

The mineralization of N in CCM was evaluated in sandy soil (upland sandy soil) (Cultivated Soil Classification Committee 1995) encompassing 3.6% coarse sand (250–2000 µm in diameter), 44.2% fine sand (20–250 µm in diameter), 40.7% silt (2–20 µm in diameter) and 11.5% clay (<2 µm in diameter), and in calcinated red-yellow soil

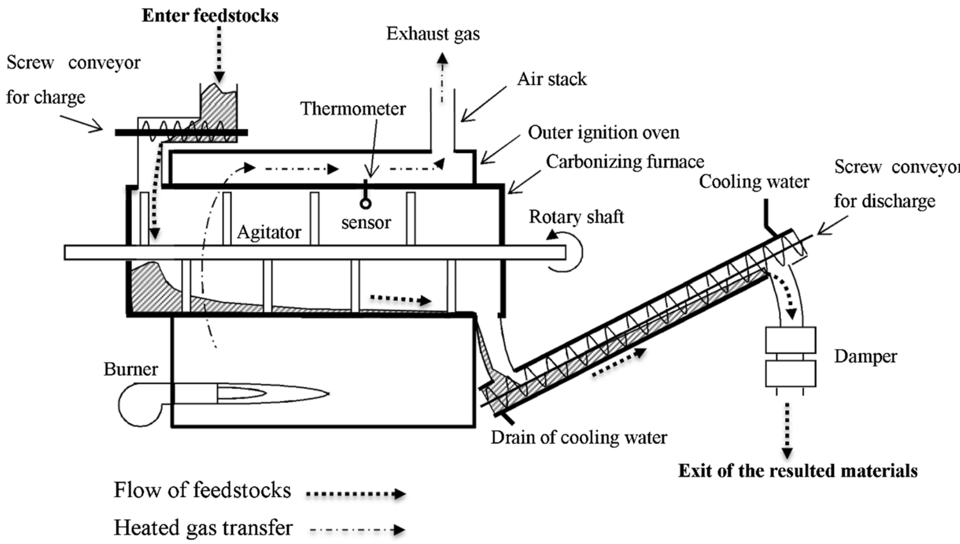

Fig. 1 The apparatus used for the carbonization of chicken manure. The feedstock was charged using the screw conveyor and carbonized in the carbonizing furnace enveloped with the outer ignition oven filled with hot air

Table 1 Combination of fertilizers used in the vessel test with *Brassica rapa*, komatsuna (●) and *Oryza sativa* Koshihikari (O)

Applied fertilizers (g)	Abbreviation of experimental plots							
	No-F[c]	N[c]	NP[c]	NK[c]	NPK[cd]	CCM[c]	CCM + N[c]	1/2CCM[c]
CCM[a]								
(N 0.1, P 0.2, K 0.4)[b]						●	●	●
(N 0.3, P 0.4, K 0.8)[b]						○	○	
AS[a]								
(N 0.5)[b]		●	●	●	●		●	
(N 1.0)[b]		○			○		○	
FCMP[a]								
(P 0.2)[b]			●		●			
(P 0.4)[b]					○			
PC[a]								
(K 0.4)[b]				●	●			
(K 0.8)[b]					○			

[a] *CCM* carbonized chicken manure, *AS* ammonium sulfate, *FCMP* fused calcium magnesium phosphate, *PC* potassium chloride

[b] The amounts of N, P and K applied per vessel are shown in g/vessel in parentheses

[c] *No-F* non-fertilizer, *N* ammonium sulfate alone, *NP* ammonium sulfate and fused calcium magnesium phosphate, *NK* ammonium sulfate and potassium chloride, *NPK* ammonium sulfate, fused calcium phosphate and potassium chloride, *CCM* CCM alone, *CCM + N* mixture of CCM and ammonium sulfate, *1/2CCM* half diluted CCM

[d] In the case of Koshihikari, NPK was from Nakajou-Koshihikari

(paddy field soil) (Soil survey staff 2010) with 90.6% coarse sand, 4.1% fine sand, 0.2% silt and 5.1% clay.

One hundred grams of each type of soil was mixed with 1 g of CCM containing 20 mg of N and the mixtures were placed in a test tube, 20 cm long and of diameter 3 cm. The test tube was incubated at 20, 25 or 30 °C for around 100 days.

In the case of upland soil, during the incubation, the test tube was covered loosely with plastic wrap to prevent the contamination with dust and occasionally water was refilled. The moisture of the soil corresponded to 60% of the maximum water-holding capacity (MWC).

In the case of the paddy soil, the test tube was filled with water and tightly capped without air bubbles. Every few days, the cap was occasionally opened to purge the gas. The tube was then refilled with water and capped tightly. The control experiment was done under the same procedure but without CCM.

NO_3^- and NH_4^+ were extracted from 10 g soil sample collected from more than three points in a test tube with

Table 2 Combination of fertilizers used in the paddy field growth tests using *O. sativa* Koshihikari

Applied fertilizers (g/m^2)	Abbreviation of experimental plots			
	CF[a]	CCM + CF	2CCM[d] + UR	2CCMP[e] + UR
CCM				
(N 1.0, P 1.4, K 1.7)[c]		●	●	●
CF[a]				
(N 3.6, P 3.1, K 4.5)[c]	●	●		
UR[b]				
(N 3.6)[c]			●	●

[a] *CF* chemical fertilizer of Nakajo-Koshihikari commercially available

[b] *UR* urea

[c] The concentration of each element is expressed as g/m^2 field

[d] *2CCM + UR* Mixture of twice higher amount of CCM and urea

[e] *2CCM* Twice higher amount of CCM pelletized into 5 mm diameter

Table 3 Several chemical features of CCM carbonized at around 528 °C

pH	Total *N* (gN/kg)	Total phosphorus (gP_2O_5/kg)	Citric acid-soluble phosphorus (gP_2O_5/kg)	Total potassium (gK_2O/kg)	Citric acid-soluble magnesium (gMgO/kg)	Total calcium (gCaO/kg)
10.5	21.4	93.7	81.8	86.7	23.3	97.2

Table 4 Effects of the carbonizing temperature on the contents of nitrogen, phosphorus, potassium and a few other parameters

Carbonizing temperature (°C)	N[a] (%w/w)	P	K	C/N	C	EC[b] (mS/cm)	pH[b]
(—)[c]	5.5 ± 0.7[d]a[e]	2.2 ± 0.1a	3.2 ± 0.0a	7.3 ± 0.8a	40.2	4.2	8.8
402 ± 6	4.0 ± 0.0b	3.4 ± 0.1b	3.8 ± 0.0b	7.5 ± 0.1a	30.0	3.0	9.8
449 ± 8	3.0 ± 0.1c	4.1 ± 0.2c	5.1 ± 0.1c	10.2 ± 0.2b	30.6	8.0	11.0
528 ± 24	2.5 ± 0.1c	3.8 ± 0.1bc	4.8 ± 0.2c	11.2 ± 0.2b	27.8	6.6	11.1

[a] The nitrogen content was determined with the C/N-analyzer

[b] These two values were evaluated once and no statistical analysis was performed

[c] The chicken manure without carbonization

[d] Values indicate the average ± standard deviation ($n = 3$)

[e] Different letters indicate a significant difference at $P < 0.05$ with Scheffe's multiple comparison test

10% KCl and the concentration was then determined. Weekly sampling was performed from different tubes during incubation, and the residual soil in the tubes was disposed. The cumulative amount of mineralized N from the CCM, termed Nc, was calculated using the following equation: $N_c = N_{s+c} - N_s$, where N_{s+c} and N_s are the quantities of mineralized N in the soil with CCM and the soil without CCM, respectively. The mineralized N is defined as the total amount of N in the form of NO_3^- and NH_4^+ in the upland soil, but in the paddy soil it was determined as the amount of N in the form of NH_4^+ since NO_3^- was not detected. Treatments were duplicated for each combination of temperatures (20, 25 or 30 °C) and soil types (upland or paddy field soil), and the sample prepared was determined as described above after each treatment.

The effect of CCM on the growth of *B. rapa* komatsuna and *O. sativa* Koshihikari

B. rapa komatsuna and *O. sativa* Koshihikari were used as test species to determine the effects of CCM on the growth of plant species. Rice is the most important crop in Niigata Prefecture, Japan. *B. rapa* komatsuna is one of the important typical *Brassica* vegetables in the upland soil in Japan. *B. rapa* komatsuna has also been recommended for use as the test plant for fertilizer registration. The CCM applied to both plants was prepared by carbonization at 528 °C.

Experiment with B. rapa komatsuna in the Wagner vessel test

B. rapa komatsuna was grown in a vessel (bottom diameter 13 cm, top diameter 16 cm, height 19 cm), filled with 3 kg of commercial alluvial paddy soil, (sandy loam) (Cultivated soil classification committee 1995) and supplemented with various combinations of four different types of fertilizers. The abbreviations and contents of the fertilizer used are shown in Table 1.

Five seeds per vessel were sown and, a week later, germinated plants having leaves fewer than three were removed. Two weeks later, plants with leaves less than five were discarded to leave behind equally grown plantlets (about three per vessel). The fresh weights of the plants were recorded at the end of the experiment, i.e., 40 days after sowing. Treatments were duplicated using two vessels for each combination of fertilizers, and the three plants were evaluated after each treatment.

Experiment with O. sativa Koshihikari

Wagner vessel test with O. sativa Koshihikari Rice plants were grown in a vessel (bottom diameter 13 cm, top diameter 16 cm, height 19 cm), filled with 5 kg of commercial granular red-yellow soil (calcinated soil) (Soil survey staff 2010) and supplemented with five combinations of fertilizers as shown in Table 2 for raising the seedlings. The abbreviations used in the test and concentration of elements are shown in Table 1. Four young rice seedlings were planted in each vessel on May 8. Plant growth was recorded every week until the maximum tillering stage was reached on September 19. Treatments were duplicated using two vessels in each plot, and all tillers produced from the four seedlings in the vessel were determined after each treatment.

Field test with O. sativa Koshihikari The rice paddy field (6 m × 6 m) located in Tainai City, Niigata Prefecture, composed of alluvial paddy soil (sandy loam soil), was supplemented with the CCM (2.4% N, 3.4% P, 4.1% K), urea (46% N) and/or chemical fertilizer (10% N, 20% P, 15% K) and was used for field experiments. Rice was grown in each plot for 4 months with several combinations of nutrients as shown in Table 2. The chemical fertilizer named Nakajyo-Koshihikari (Japan Agricultural Coop., Niigata, Japan), containing urea, P_2O_5 and K_2O as the respective source for N, P and K, was used in rice fields in this area of Tainai City where the field test was set. Likewise, we also used these systems in the field test.

The uniformly grown, young rice seedlings were transplanted into the field at a density of 20 plants/m^2, and the plant height and the number and length of stems were recorded every week over the whole period. The spikes were recorded at the major growth stages. Four months and 10 days after the transplantation, the plants were harvested. Parameters such as plant height, number of stems and spikes and the length of the stem and spike were recorded to estimate the quality of rice grains. In all plots, 3 g urea N/m^2 was applied right halfway during cultivation, according to the general method employed by the farmers living in the area where the experiments were performed. Treatments were duplicated in each plot, and whole plants harvested from an area of 3.3 m^2 in the paddy field were determined in each treatment.

Statistical analyses

Scheffe's multiple comparison tests and Student's *t* tests were adopted to investigate the effect of carbonizing temperatures on the physicochemical properties of CCM and the effect of feedstock moisture and carbonizing temperature on the yield of CCM and the amount of kerosene used. Statistical analyses were performed using computer-aided statistical software (Social Survey Research Information Co., Ltd., Tokyo, Japan).

Results

The effects of the carbonizing temperature on the nutrient composition of CCM

As shown in Table 4, the carbonizing temperature affected the amounts of N, P and K, and certain parameters in CCM. Besides, the N content of CCM decreased with the increase of the carbonizing temperature up to 528 °C. In contrast, the P and K contents in CCM increased with the carbonizing temperature up until 449 °C. Beyond this temperature, the amount of both elements decreased and reached a plateau between 449 and 528 °C. The C/N ratio in the CCM carbonized at 402, 449 and 528 °C were 7.5, 10.2 and 11.2, respectively. The C content in the same carbonizing temperatures were 30, 31 and 28, respectively (Table 4). The C/N ratio was increased up to 528 °C and seemed to have settled at approximately 11 at this temperature. CCM carbonized at ≥449 °C showed almost twofold larger EC value and higher pH than that of CCM at 402 °C and the feedstock (Table 4). The CCM carbonized at any temperature was shown to have lower N content and higher P and K contents compared to those of the feedstock (Table 4).

The amounts of Mg and Ca in the char carbonized at around 528 °C were also determined as 2.3 and 9.7% (w/w), respectively (Table 3).

Table 5 Energy consumption for the production of CCM carbonized at around 528 °C

Feedstock	Water content of feedstock (%)	Yield[a] (%)	Kerosene use[b] (L/kgCCM)
Fresh chicken manure[c]	49–69	23.7 ± 2.7[e]a[f]	1.26 ± 0.31a
Chicken manure	20–32	43.2 ± 3.5b	0.27 ± 0.05b

[a] Yield (%) = the amount of CCM produced (kg)/the amount of feedstock (kg)

[b] Kerosene use (L/kgCCM) = the total amount of kerosene used (L)/the amount of CCM produced (kg)

[c] Chicken manure freshly collected

[d] Chicken manure was composted for 16 days to reduce the water content. See "Materials and methods"

[e] Values indicate the average ± standard deviation. For the fresh chicken manure, $n = 7$, and for the chicken manure, $n = 16$

[f] Different letters indicate a significant difference at $p < 0.05$ with Student's t test

Amount of kerosene used for the production of CCM

The amount of the kerosene used for the CCM production at around 528 °C and yield of it from the feedstock were calculated using the formula indicated in Table 5 and briefly estimated. Fresh chicken manure containing around 49–69% water was changed to char with 24% yield efficiency. On the other hand, the composted chicken manure containing 20–32% moisture had 43% yield efficiency. To carry out the carbonization of the higher and lower moisture content manure, about 1.26 and 0.27 L kerosene, respectively got consumed for each kg of recovered CCM. Thus, the amount used for the semi-dried material was one-quarter less than that for fresh chicken manure.

Mineralization of nitrogen in CCM in paddy soil and upland soil

To assess the effects on the fertility of the soil on the addition of the fertilizer, mineralization of N in CCM in paddy field and upland soils was briefly estimated. The char carbonized at around 528 °C was employed in the following all tests with CCM. Mineralization of N in the mixture of upland soil was almost nil and seemed to be independent of the incubation temperatures (Fig. 2). On incubation in the paddy field soil for around 100 days at 30 °C, mineralization was observed at the rate of 5.1 mg/100 g soil (Fig. 2), and the amount of mineralized N corresponded to almost 25% of the total N in CCM.

The effects of CCM on the growth of *B. rapa* komatsuna in the vessel test

The effects of CCM on the fresh weight of komatsuna were evaluated in the vessel test (Table 6). The fresh weight (FW) of the plants grown in the NPK plot was 14.5 g. On the other hand, the FW value in the vessel treated with CCM alone (CCM plot) was 1.7 g, and that in the CCM plot was 1.3 g.

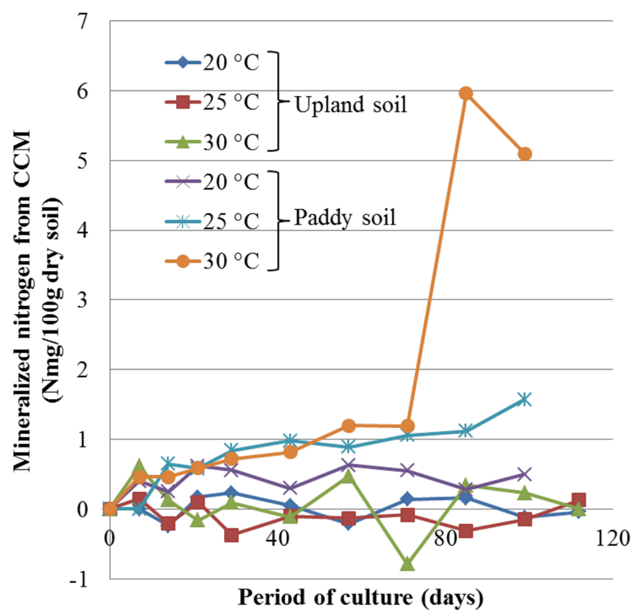

Fig. 2 The time course of the mineralization of nitrogen in CCM in rice paddy field soil and upland soils. Soils mixed with CCM were incubated at 20, 25 or 30 °C for 99–112 days, and every week the mineralization was determined. Each *line* shows the average ($n = 2$)

However, when the vessel in the CCM plot was supplemented with ammonium sulfate (AS), FW was remarkably restored to the same levels as those in the NPK plot, the highest among all plots. An equivalent as in NPK was observed even in the plot of 1/2CCM + N or CCM + N. In the plots of 1/2CCM + N and CCM + N, the weights of the komatsuna were 14.4 and 15.3 g, and were higher than 11.4 g in the N plot. In the plots of NP and NK, however, FWs of the komatsuna were 12.4 and 13.0 g, suggesting that addition of either P or K was insufficient to achieve the same effect as CCM.

The effects of CCM on the growth of *O. sativa* Koshihikari in the vessel test

CCM showed significant enhancement of the growth of *O. sativa* Koshihikari under the application of exogenous

Table 6 The effects of CCM on increase of the fresh weight

Experimental plots	Fresh weight (g/plant)
No-F[a]	1.3 ± 0.0[b]
N	11.4 ± 1.8
NP	12.4 ± 1.8
NK	13.0 ± 0.7
NPK	14.5 ± 4.4
CCM	1.7 ± 0.3
CCM + N	14.4 ± 1.2

The fresh weight was measured 41 days after the sowing

[a] For all abbreviation in the experimental plot, see "Materials and methods" and footnote for Table 1

[b] The value indicates the average ± standard deviation ($n = 2$)

nitrogen (Fig. 3). Consequently, the plant height in the CCM + N plot was restored to the same level as that in the NPK plot, and the increase of the height in the CCM + N plot was larger than that of N or CCM plots throughout the test period (Fig. 3a).

The number of rice stems in N, NF and CCM plots were almost nil over the whole test period (Fig. 3b). On the other hand, the numbers in the CCM + N plot notably increased at the same rate as that of the NPK plot.

The effects of CCM on the growth of *O. sativa* Koshihikari in the paddy field

The effect of CCM on the growth of rice plants was further assessed using a real paddy field. In this field test, a commercial chemical fertilizer named Nakajo-Koshihikari was used to confer rice with N, P and K. In this chemical fertilizer, the urea served as the N source instead of ammonium sulfate. As shown in Table 7, the plant height in 2CCM + UR was the same as that of the CF (=Nakajo-Koshihikari plot) or CCM + CF plots. This equivalent growth in the height was observed over the experimental period. The other parameters such as the number of stems and spikes, and length of stems and spikes were observed as a function of period, and the same change in the time course was detected, respectively, in the above-mentioned plots (Table 7).

The effects of CCM on the quality of rice grain were evaluated from the different parameters shown in Table 8. The various parameters in the plots of CF (=Nakajo-Koshihikari fertilizer plot), CCM, CCM + CF and 2CCM + urea (= twice higher CCM and urea plot), number of spikes/m^2, number of grains/head, number of total grains/m^2, yield of ripened grains, weight of thousands grains, and yield of grains/1000 m^2, respectively, were the same in all the plots used. The yield of the ripened grains in total grains was 90% in all plots and the yield of grains per 1000 m^2 was 641–675 kg and this was the same as that generally accomplished by farmers in the area (Table 8).

Discussion

The exponential increase in the poultry wastes worldwide necessitates sustainable waste management. For futuristic sustainable agriculture, it is important to minimize the energy consumption in the heating process through knowledge-based improvements. Herein, we briefly checked the energy consumption and confirmed the significant reduction in kerosene use with the feedstock having lower moisture content and/or lower temperature performance (Table 5). For making CCM, we should use feedstock containing much less amount of water that is

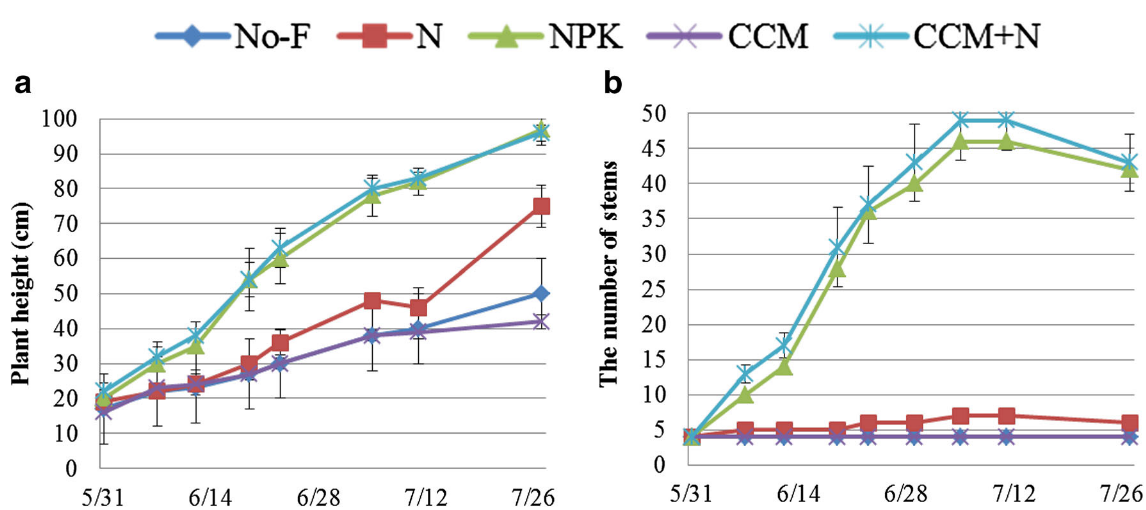

Fig. 3 The effects of CCM on rice plant height (**a**), the number of stems (**b**) in vessel tests. Each *line* shows the average, and *error bars* represent standard deviation ($n = 2$)

Table 7 The effects of CCM and exogenous chemical fertilizer, Nakajou-Koshihikari, and urea on the rice growth in the paddy field

Fertilizers exogenously added	Sampling days after transplanting into the paddy field						
	50 days (June 27th)		72 days (July 19th)		100 days (August 16th)		
	Plant height (cm)	No. of stems	Plant height (cm)	No. of stems	Length of stems (cm)	Length of spikes (mm)	No. of spikes
CF[a]	50 ± 2[b]	24 ± 6	70 ± 2	24 ± 5	86 ± 6	18.9 ± 0.4	22 ± 4
CCM + CF	49 ± 2	33 ± 4	69 ± 3	30 ± 3	86 ± 4	18.8 ± 0.5	26 ± 2
2CCM + UR	49 ± 3	25 ± 5	72 ± 2	26 ± 4	86 ± 4	18.8 ± 0.2	22 ± 3
2CCMP + UR	49 ± 1	27 ± 4	68 ± 3	26 ± 3	85 ± 4	18.5 ± 0.1	21 ± 2

[a] For the abbreviations of fertilizers added and the concentration, see Table 2

[b] The values indicate average ± standard deviation ($n = 2$)

Table 8 The effects of CCM and exogenous chemical fertilizer, Nakjou-Koshihikari, and urea on the yield and quality of the rice grown in a paddy field

Fertilizers exogenously added	Spikes (No/m^2)	Grains (No/head)	Total grains (No × 10^2/m^2)	Ripened grains (%)	Thousands grain weight (R)	Yield of grains (kg/1000 m^2)
CF[a]	445 ± 35[b]	69 ± 4	290 ± 14	90	21.7 ± 0.1	675 ± 28
CCM+CF	435 ± 38	74 ± 2	293 ± 12	89	21.5 ± 0.2	641 ± 21
2CCM + UR	435 ± 26	75 ± 7	281 ± 34	89	21.8 ± 0.2	646 ± 32
2CCMP + UR	419 ± 8	73 ± 1	277 ± 5	91	21.7 ± 0.0	645 ± 31

The rice was harvested 122 days after the transplant

[a] For abbreviations of fertilizers added and concentration, see the footnote in Table 2

[b] The values represent average ± standard deviation ($n = 2$)

reduced with appropriate methods such as solar drying or composting. We could completely diminish the odor emitted from the char in the 528 °C carbonization when semi-dried chicken manure was used as the feedstock (data not shown). Pre-drying of the feedstock may offer an energetically feasible method to degrade or volatilize the substances with odor.

Minimizing the heat energy is also important to save nutrients in feedstocks. In the carbonization of the poultry litter at 500 °C, the nitrogen content was reduced (Gaskin et al. 2008). The content of ammonium nitrogen was 2.8 g/kg in the fresh litter, but was decreased to 12 mg/kg in the leachate of poultry litter biochar (Maki et al. 2009). Therefore, the chars have been considered for use as soil conditioner rather than fertilizer (Steiner et al. 2007).

Nitrogen in organic materials began to volatilize at 200 °C and more than half of N was lost at 500 °C (Dubreuil and Moore 1982; Singh et al. 2015, Sánchez-García et al. 2015). P and K volatilize only at a temperature greater than 760 °C (Dubreuil and Moore 1982; Neary et al. 1999; Knicker 2007). This difference among N, P and K could explain the reason behind the lesser concentration of N and a higher concentration of P and K than that of feedstock, which we observed in CCM during carbonization (Tables 3, 4). In our study, the recovery of these elements was slightly better when compared to the value observed in the studies by Lehmann et al. (2003), Gaskin et al. (2008), (Table 3) and we attained 2.5–4.0% of N, 3.4–4.1% P, and 3.8–5.1% K at around 400–500 °C. Consequently, we engaged in using the resulted char from chicken manure as a fertilizer rather than as materials for soil amendment.

The rate of mineralization of N in farm soils is an important indicator to estimate the performance of CCM as a fertilizer. To this end, we selected two soils, the calcinated red-yellow soil (paddy field soil) and the sandy soil representing upland soil for evaluating the mineralization of N from CCM. In the paddy field soil, a significant but slow mineralization was observed at 30 °C (Fig. 2). However, almost no mineralized N from CCM was detected in upland soil at any adopted temperature (Fig. 2). The rates of reactions related to mineralization of organic nitrogen are affected by oxidation/reduction potential (ORP) of soils (Nakamura and Toride 2007). Hence, we suppose that the difference in the mineralization rate of nitrogen from CCM observed in the paddy field and upland soil could be related to ORP of these two soils.

Tewari et al. (2003) applied the fertilizer in a deep area of the field after the deep plow in the soybean cultivation and set the fertilizer in a much deeper area than that in the ordinary method. Tewari and colleagues intended to supply the slow-release fertilizer effectively for the growth of the plants. However, the ORP occurred by changing the depth of the set position thereby controlling the amount of N from CCM into soil.

We propose that maximum amount of N could be released from CCM through controlled ORP by changing either the water level in the paddy field or the depth of the position where the fertilizer is set. This idea will contribute well to reduce the total energy placed into the fields all over Japan and those in EU, especially in Italy where the rice plant is cultured in the paddy field. We also show that the growth of *O. sativa* Koshihikari and *B. rapa* komatsuna in the vessels could be recovered by only the addition of a simple single chemical fertilizer such as ammonium sulfate. The growth of the two plants in the plots where the N compensation occur by the only N source, i.e., ammonium sulfate, were identical as that in NPK plot with chemical fertilizer. Consequently, our study contributes well to advance the knowledge of CCM usage for practically simple waste management.

Rice qualities such as rate of mature grain recovery, weight of 1000 rice grains and the number of stems, spikes, etc., are shown in Tables 6 and 7. All these parameters in the 2CCM + urea plot were the same as that in the chemical fertilizer (Nakajo-Koshihikari) plot. This observation clearly showed that various ingredients including trace elements in the twice-concentrated CCM (2CCM) plot did not cause any significant negative effects to the rice growth and in fact had positive effect leading to complete growth.

For the field trial, we used the degraded paddy fields with sandy soil in which ferrous ion, manganese, potassium and various cations and even phosphate get eluviated and accumulated into soil bottoms. The cation exchange capacity of the soil in the whole area was determined to be about 10 cmol +/kg. Furthermore, the concentration of free iron oxide in the soil was around 0.2%, which was very low compared to the standard value of 1.5% recommended by the Japanese Ministry of Agriculture, Forestry and Fisheries for normal yield of rice grain (data not shown). In these degraded paddy fields, the application of a relatively higher amount of sulfur-containing fertilizer such as calcium superphosphate and a mixture of $Ca(H_2PO_4)/H_2O$ and $CaSO_4$, results in the generation of hydrogen sulfate, which often inhibits the uptake of nutrients in rice plants (Takijima et al. 1958; Takijima and Shiojima 1958). Therefore, application of urea has been recommended in this area. In these degraded paddy soils, the amount of K^+ is relatively lower than other cations (Takijima et al. 1958). Therefore, for rice culture in such paddy fields, not only the appropriate amounts of N, but also P and K are required to be applied exogenously. Otherwise, the expected tiller and yield of mature grains cannot be attained.

The same amount of rice grain yielded in both the plots of 2CCM + UR and CF (=chemical fertilizer plot) strongly suggested that in the 2CCM + UR plot, P and K from 2CCM were sufficient to assure the rice grain yield. Regarding the inhibition of nutrient uptake by compounds containing sulfur, 2CCM did not show such effects. Besides N, P and K, various nutrients such as Mg, Ca or trace elements should also be considered, but these nutrients were assumed to have no effect in the plot of 2CCM + urea. The trace elements, Mg and Ca could be from the paddy field and some of them from CCM. In our experiment, CCM contained Mg and Ca of about 23.3 and 97.2 g/kg (Table 3), respectively. In the degraded paddy soil, though a reverse in the concentration of Ca^{2+} and Mg^{2+} was observed, generally Ca^{2+} and Mg^{2+} are the most abundant ions among the cations. Hence, the lower concentration of these ions could not be associated with the normal growth of the rice plants in the paddy field.

Conclusions

Taken together, our system in which the chicken manure gets carbonized at around 528 °C can be a simple, cheap and eco-friendly method to produce char carrying a certain amount of N, P and K that is comparable to various previously studied methods. Since CCM worked as a useful organic fertilizer, we could substitute the chemical fertilizers supplying P and K with CCM to have no inhibitory effect in upland and paddy field soil. CCM usage could also offer the possibility to be practically favored as it could result in slow-release nitrogen fertilizer in paddy field soil.

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Compliance with ethical standards

Conflict of interest We declare that there are no conflicts of interest associated with this manuscript.

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