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Effects of Placement and Application Rates of Briquette Compost on Soil, Plant Nitrogen Content and Yield of Red Brown Rice in the Swampland of South Sumatra

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ABSTRACT

Briquette compost (BC) was made from water mimosa (*Neptunia prostrate* Lam.) which grows in the swampland rice fields. Factorial Randomised Block Design (FRBD) was used with the placement of BC as the first factor and BC dosage as the second factor. The placement of compost was one BC at 1 dosage for 1 plant clump with the BC being placed inside soil and rice seedling planted above it (BC_1) and the second placement was one BC applied at the middle of four plant clumps, so 4 dosages were combined into one BC because this was for 4 clumps as (BC_2). The second factor was application of BC at rates of 0, 10, 20 and 30 ton ha^{-1} for both treatments. Regression analysis showed that placement and dose of BC significantly correlated with absorbed N, tillers, productive tillers and rice yield. Placement of BC under plant roots gave better results than placement of BC in the middle of four plant clumps. The best combination was between BC_1 and a dosage of 20 ton ha^{-1} which produced a rice yield of 1,014 g m^{-2} (or 10.14 ton ha^{-1}). This yield was 175% higher compared with the control plot (586.73 g m^{-2} or 5.867 ton ha^{-1}). The higher rice yield in BC1 compared to BC_2 was due to plants being better able to absorb nutrients from BC straight away compared to BC_2 where the plant roots needed a longer time to elongate and reach the BC placed in the middle of the four plant clumps. Meanwhile, nitrogen could have been lost before the roots reached the location where the BC was placed. Our study suggests that it is better to form the compost into a BC and insert it into the soil under a plant clump for direct absorption by the roots.

Keyword: Briquette compost, nitrogen, dosage, rice, swampland.

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INTRODUCTION

As there is no proper irrigation system in paddy fields of the swamplands in South Sumatra, Indonesia, rice fields depend on rain and flooding from rivers, but this means the water level cannot be controlled. The swampland paddy fields flood during the moonson (from November to April) and are dry during summer (from May to October). Farmers grow rice by following the depth of water in the paddy field; they start to plant rice when the water level is about 10 cm above ground. If compost needs to be applied, it has to be buried, otherwise it would be floating on the water. Incorporation of compost in the form of crumbs into the soil is also difficult because of the water depth. That is why the compost needs to be in the form of a briquette which can ben inserted directly into the soil.

This briquette compost (BC) was made of water mimosa, *Neptunia prostrate* Lam, a dominant weed that grows in swampland paddy fields during flooding. This weed compost contained high nitrogen (4%), P (1675 mg kg^{-1}), and K (5.6%) while the C/N was 8.32. The process of making compost briquette has been patented by Bernas *et al.* (2018). Bernas *et al.* (2017) had applied this briquette compost for rice growing on the raft as a floating system by inserting the BC into the soil and planting the rice crops above it. BC application of 20 ton ha^{-1} increased the rice yield from 1.58 ton ha^{-1} (without compost) to 4.55 ton ha^{-1} with compost. The higher yield in the BC treated plot was caused by the better contact between plant roots and the compost which caused the roots to grow vigorously inside the BC thus increasing their absorption of water and nutrients. As the BC was high in nitrogen (Bernas *et al.* 2015), inserting it into the soil decreased N loss. Compost application could decrease net global warming potential by 25% (especially in releasing CH_4 and N_2O) in rice cultivation as reported by Seung *et al*. (2018). When compost is applied as BC and inserted into the soil, global warming could be reduced even more due to less oxidation of compost inside the soil than if compost was on the soil surface. The purposes of this research were to determine the best combination of placement and dose of BC into the swampland soils planted with rice and the effect of its placement and dose combinations on nitrogen content, growth and yield of rice.

MATERIALS AND METHODS

This research was carried out on a paddy field at a swampland in Keramasan District, Palembang City, South Sumatra, Indonesia. This experiment was done on 18 plots with each plot being 2 m x 2 m in size with the distance between plant clumps being 20 cm x 25 cm. Soil used in this research was a potential Acid Sulphate soil with a pH of 4.46 and a pyrite depth >80 cm, N content of 0.25%, C-organic content of 2.61%, and clay content of 64.33%. However, the pH of water could be about 6.0 during flooding due to dilution and flushing (Bernas *et al.* 2015).

The experiment treatments were as follows: In treatment 1, BC application at one dose, where BC was inserted into the soil and rice seedling was planted above BC as (BC_1). In treatment 2, one BC applied at the middle of four plant clumps, so 4 dosages were combined into one BC because this was for 4 clumps as (BC_2). The BC doses were 0 g (D_1), 28 g (D_2), 56 g (D_3), 74 g (D_4) in weight per crop which was equivalent to 0 (control), 10, 20 and 30 ton ha^{-1}, respectively.

This experiment was conducted as a Factorial Randomised Block Design, BC placement as the first factor and compost dosage as the second factor. If there was any significant difference between treatments, then they were analysed using LSD procedure (SAS University Edition 2.8 9.4 M6, USA).

Data were collected on soil and plant N contents (Kjeldahl Method), plant height, tiller, productive tiller, filled spikelet and rice yield. Rice yield was taken from 36 rice clumps from 1 m x 1 m fields.

RESULTS AND DISCUSSION

Effects of BC Placement and Dosage on Soil and Plant N Content and Plant Absorbed N

Based on the ANOVA results, BC placement and dosage did not have a significant effect on soil and plant N content, but affected significantly the N absorbed by the crops. However, N dosage had the effect of increasing N in soil and plant up to application of 20 ton ha^{-1} but decreased when dose was increased to 30 ton ha^{-1} when one BC was placed either under one plant clump (BC_1) or under four plant clumps (BC_2) (Figures 1, 2 and 3).

According to Ngo and Cavagnaro (2018), the impact of compost on soil N content is less consistent because of the highly dynamic nature of N cycling which is affected by soil/water content and this research was carried out in a flooded paddy field. Soil and plant N content tended to decrease at a dose of 30 ton BC ha^{-1} both in BC_1 and BC_2. This could be attributed to the high amount of N in BC (4%). Further, as the soil used in this research contained medium C-organic and total N, the application of 30 ton BC ha^{-1} might have created excessive N. But in the case of BC_2 treatment, the higher dose of compost resulted in higher N content in soil and plants (Figures 1 and 2). This was caused by lost N in the compost in the form of ammonia that leached or evaporated before plant roots absorbed it, as the plant roots needed time to reach the BC in the centre of the four plants. According to Zhenping *et al.* (1991), under waterlogged conditions, N could convert to ammonia and ammonia loss is higher under waterlogged than in aerobic conditions. Xiaowei *et al*. (2016) reported that this is similar to the use of mineral fertilisers such as nitrogen that is applied once as basal fertiliser into 10 cm deep holes, positioned at 5 cm from the roots. He observed a 19.9% decrease in N compared with broadcast application which saw a decrease of 62.6%. In the case of BC_1, roots could absorb N in the compost straight away because the BC was just under the crop. These plants grew well and produced more shoots as well as absorbed more nitrogen (Figure 3) compared to BC_2. In the case of BC_2, the placement of BC in the middle of four plant clumps led to more N loss than in BC_1, perhaps due to stamping during weeding and measuring of plant growth causing some BC_2 to be exposed to the soil surface.

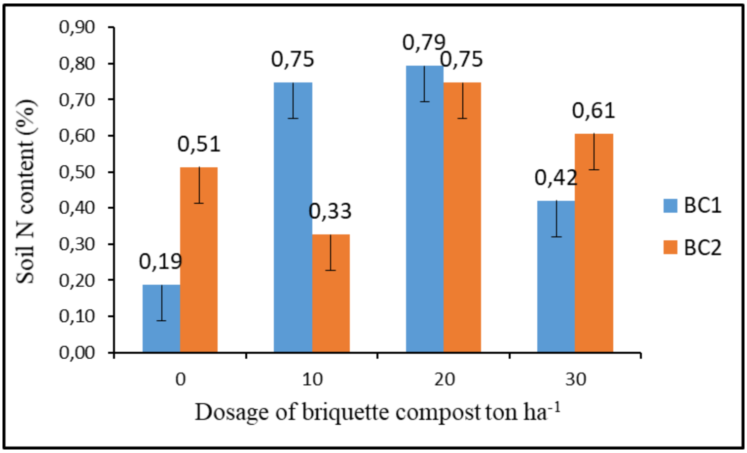

Figure 1. Soil N content at heading stage. The values are the means of three replicates and vertical lines are standard errors.

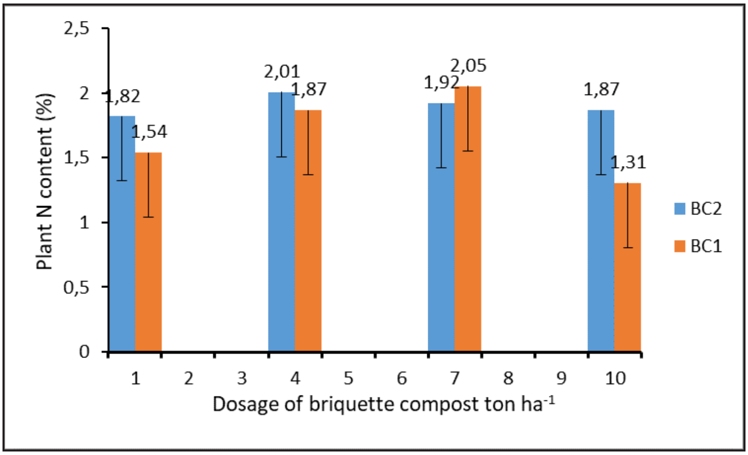

Figure 2. Plant N content at heading stage. Values are the means of three replicates and vertical lines are standard errors.

Note: BC_1 is the placement of 1 BC under under one plant clump and BC_2 is the placement of 1 BC under and middle of four plant clumps.

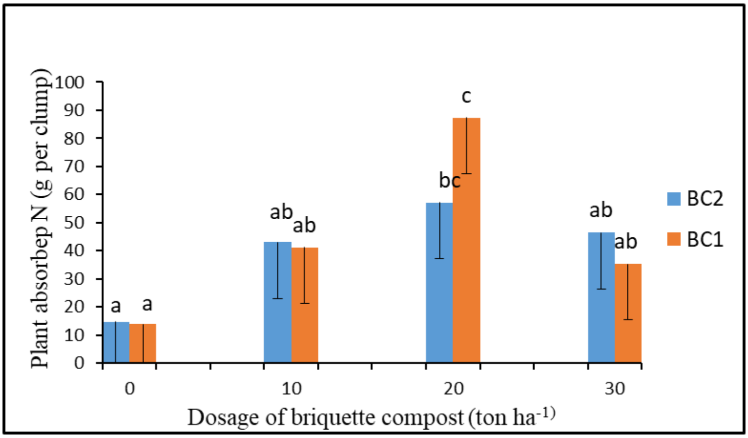

Figure 3. Absorbed N at heading stage. Values are the means of three replicates and vertical lines are standard errors. Notations differed significantly between treatments, where LSD ($p<0.05$) = 36.46

Note: BC_1 is the placement of 1 BC under one plant clump; BC2 is the placement of 1 BC under and middle of four plant clumps.

Effect of Placement and Dosage of BC on Plant Height, Tiller and Rice Yield

Our results showed that placement and dosage of BC influenced significantly plant height from 21 to 35 days after transplanting (Table 1). Plant height was also recorded before 21 days after transplanting but the results did not show any significant difference between treatments. Plant height was highest in BC_1 treatment of 30 ton ha^{-1} at 43.75 cm followed by 43.34 cm at 10 ton ha^{-1} and 42,69 cm at 20 ton ha^{-1}) but there was no significant difference between these three combination treatments. However, there was a significant difference with control and BC_2 treatment. Plant height appears to have responded quickly to the treatment of BC placement than to dosage of compost, with BC_1 being better than BC_2. This could be attributed to roots absorbing nutrients faster in BC_1 than in BC_2, and being able to grow vigorously as the BC was high in available N, P, and K and low C/N (8.33) (Bernas *et al*. 2018). Meanwhile, in BC_2 treatment the plant roots had to grow longer and needed more time to reach the BC.

Results showed that placement and dosage of BC influenced significantly rice tillers, starting from 21 to 56 days after transplanting (Table 2). Rice tillers were also recorded before 21 days after transplanting but showed no significant difference between treatments. From 21 to 28 days after tranplanting, BC_1 treatment at 20 and 30 ton ha^{-1} rates significantly differed from control but not in the case of BC_2 treatment. Further, 35 days after tranplanting, the rice tillers started to increase significantly in the BC_2 treatment at rates of 30 ton ha^{-1} (26.7 clump^{-1}) but were not significantly different from BC_1 rates of 10, 20, and 30 ton ha^{-1} at 28.8, 35, and 30.17 clump^{-1} respectively. It appears that rice tillers responded more quickly to BC placement than to dosage with BC_1 being better than BC_2. The highest rice tiller was recorded in the BC_1 treatment of 20 ton ha^{-1} at a height of 43.53 cm followed by 30 ton ha^{-1} and BC_2 at 35.13 clump^{-1}. Though, there was no significant difference between these two combination treatments, there was a significant difference between these two treatments and other treatments. Thus, inserting the compost into the soil close to the plant roots was found to be a better option because it could increase plant N content and absorb N as reported by Liu *et al*. (2016). They found that when N organic fertiliser was inserted into the soil at 20 cm depth and close to the root at about 5 cm, plant N content increased up to 0.95%. Similar results were found by Nurrahma and Melati (2013) with the application of 5 ton ha^{-1} compost combined with 15 ton ha^{-1} chicken manure which resulted in a 0.95% increase in plant N content. Garib *et al*. (2008) also reported that compost placed under the plant was better at increasing N absorption and plant shoots .

Placement of BC and dosage resulted in maximum tillers, productive tillers and significant yields. Our study showed that all combination treatments differed significantly with control (Table 3). The highest maximum tiller was achieved by a combination of BC$_1$ and a rate of 20 ton ha^{-1} with 44 tillers clump^{-1} compared to control of 20 tillers clump^{-1}. BC$_1$ treatment at a rate of 30 ton ha^{-1} decreased tillers sigificantly (29 tillers clump^{-1}) compared to the rate of 20 ton ha^{-1} which saw an increase in tillers (44 tillers clump^{-1}). The application of BC$_2$ at a rate of 30 ton ha^{-1} significantly increased tillers (35 tillers clump^{-1}) compared to other rates and control. However, it must be noted that the application of BC$_1$ recorded higher maximum tillers than BC$_2$.

TABLE 1

Effect of placement and dosage of briquette compost on plant height

Treatments	Plant height (cm)				
	Days after transplanting				
	21st	28th	35th	42nd	49th
BC_1D_1	34.34 ± 1.63 a	43.32 ± 1.51 a	48.75 ± 1.32 a	50.87 ± 3.09	53.86 ± 0.90
BC_1D_2	43.34 ± 2.08 b	54.08 ± 2.86 b	58.97 ± 6.12 c	62.91 ± 9.63	65.93 ± 12.03
BC_1D_3	42.69 ± 2.96 b	51.43 ± 1.37 b	54.98 ± 2.01 bc	60.70 ± 4.25	67.04 ± 1.95
BC_1D_4	43.75 ± 1.36 b	52.18 ± 1.78 b	58.20 ± 1.69 bc	61.25 ± 2.09	61.04 ± 5.38
BC_2D_1	36.96 ± 6.12 a	44.24 ± 6.31 a	48.36 ± 7.95 a	53.76 ± 8.17	53.76 ± 9.16
BC_2D_2	36.10 ± 1.29 a	45.08 ± 0.29 a	50.02 ± 1.32 a	54.37 ± 0.94	54.37 ± 2.14
BC_2D_3	35.87 ± 2.39 a	45.56 ± 2.55 a	52.88 ± 1.91 abc	57.32 ± 1.3	57.32 ± 2.85
BC_2D_4	35.47 ± 1.27 a	45.55 ± 3.37 a	51.57 ± 4.01 ab	59.20 ± 4.4	59.20 ± 1.25
$LSD_{0.05}$	5.04	5.40	7.09	ns	ns

Note: Different letters in a similar column indicate statistically significant different values among treatments in LSD ($p<0.05$); ns = not significant.

BC$_1$: placement of 1 BC under one plant clump; BC$_2$: placement of 1 BC under and middle of four plant clumps

BC doses were 0 g (D$_1$), 28 g (D$_2$), 56 g (D$_3$),and 74 g (D$_4$)

Combination of BC placement and dosage gave significant effects on plant height and tillers starting from the 21st day after transplanting (Tables 1 and 2). However, application of BC_1 had significantly different results from BC_2 and control. Plant height and tiller were higher compared to control and BC_2. In BC_1 treatment, the plant roots grew inside the compost, absorbed nutrients straight away and grew vigorously; plant height and rice tiller therefore increased significantly. But in the case of BC_2 treatment, the plant roots needed time to reach the BC placed in the middle of four plant clumps. So plant height and tillers grew and developed slowly compared to BC_1 treatment. On the 35th day following transplanting BC_2 treatment began to have a similar effect as in the application of BC_1; presumably by this time plant roots were long enough to reach BC and create more contact between roots and BC and plants were able to absorb nutrients. It appears that plant roots need up to 35 days to grow in clay before reaching BC which was at a distance of about 16 cm (Phytagoras equation calculation) from the crop. The slow growth of the roots could be caused by high clay content in this soil. There was a difference of about 14 days before the plant roots could grow long enough to reach the compost in the middle in BC_2 treatment. Yoshida *et al.* (1982) reported that rice plant roots could grow to a length of 105 cm at the time of flowering, with the length of root growth dependent on variety of rice. That is why it is important to place the fertilser close to the roots, as reported by Drew (1975) in Wild (1988). According to Wild (1988), when part of the roots are exposed to a high concentration of nitrate, it causes initiation and vigorous in situ extension of primary and secondary lateral roots within the exposed zone. Placement of BC was found to be more important than dosage, because there was direct contact between roots and BC resulting in better and immediate absorption of nutrients from BC. The roots did not need to grow longer as in the case of BC2 treatment. Though roots can grow up to 95 cm in length (Yoshida *et al.* 1982), they do not grow straight and therefore take some time to reach the BC which was only 16 cm away from the roots.

The best plant height of 54.98 cm and highest amount of rice tillers of 43.57 clump^{-1} were achieved by BC_1 at a rate of 20 ton ha^{-1} BC. On the other hand, BC_2 treatment at 20 ton ha^{-1} BC recorded a plant height of 52.88 cm and rice tillers of 24.60 clump^{-1}. Thus placement of BC under a plant clump was better than in the middle of four plant clumps.

Correlating BC with dosage showed similar pattern effects on productive tillers and maximum tillers (Table 3) where placement and dosage of BC had a significant effect on productive tillers. The treatment of BC_1 at a rate of 20 ton ha^{-1} produced the highest productive tillers (22 tillers clump^{-1}) and was significantly different from other treatments and control (12 tillers clump^{-1}). The highest productive tillers (22 clump^{-1}) and rice yield (10.3 ton ha^{-1}) were reached by the treatment of BC_1 at a rate of 20 ton ha^{-1} and this differed significantly compared to other treatments. These results are rather similar to a study done by Zhou *et al.* (2017) where the rice plant produced 33 productive tillers and 10.18 ton ha^{-1} rice grain at a compost dosage of 439,2 g per clump and plus NPK fertilizer. This was

TABLE 2
Effect of placement and dosage of briquette compost on rice tiller

Treatments	Tillers per rice clump					
	Days after transplanting					
	21st	28th	35th	42nd	49th	56th
BC_1D_1	4.93 ± 2.10 ab	9.67 ± 2.84 a	16.07 ± 3.53 a	19.53 ± 2.66 a	19.80 ± 5.29 ab	20.00 ± 4.20 a
BC_1D_2	7.26 ± 0.61 abc	17.80 ± 3.02 bc	28.80 ± 8.74 cd	30.33 ± 12.19 abc	26.20 ± 8.27 abcd	26.67 ± 9.00 abc
BC_1D_3	7.53 ± 0.61 bc	23.80 ± 3.30 **c**	35.00 ± 5.70 **d**	43.27 ± 8.69 **d**	43.53 ± 4.41 **e**	35.27 ± 11.32 **c**
BC_1D_4	8.06 ± 1.63 **c**	24.87 ± 6.18 c	30.27 ± 7.00 cd	34.27 ± 6.49 cd	28.93 ± 6.55 bcd	29.20 ± 4.70 bc
BC_2D_1	5.93 ± 2.40 abc	11.13 ± 4.11 ab	16.53 ± 4.50 ab	20.60 ± 4.70 ab	19.27 ± 3.11 a	19.67 ± 2.69 a
BC_2D_2	6.06 ± 1.22 abc	16.00 ± 2.43 ab	25.13 ± 2.76 abc	32.07 ± 4.03 bcd	29.27 ± 4.35 cd	29.93 ± 4.62 bc
BC_2D_3	4.80 ± 1.83 a	12.00 ± 6.09 ab	18.73 ± 3.31 ab	24.60 ± 3.89 abc	23.47 ± 3.56 abc	22.67 ± 4.59 ab
BC_2D_4	5.06 ± 1.90 ab	15.53 ± 3.14 ab	26.07 ± 5.30 bcd	32.40 ± 4.89 bcd	35.13 ± 5.69 de	34.00 ± 7.64 bc
$LSD_{0.05}$	2.71	7.08	9.93	12.09	9.19	11.87

Note: Different letters in a similar column indicate statistically significant different values among treatment in LSD ($p<0.05$).
BC_1: placement of 1 BC under one plant clump; BC_2: placement of 1 BC under and middle of four plant clumps
BC doses were 0 g (D_1), 28 g (D_2), 56 g (D_3),and 74 g (D_4)

TABLE 3
Combination effects of placement and dosage of briquette compost on productive rice tillers and yield

Dosage of BC (ton ha^{-1})	Maximum tillers per rice clump	
	1 briquette (1 dosage) for 1 plant clump (BC_1)	1 briquette (4 dosages) for 4 plant clumps (BC_2)
0 (D_1)	20 ± 5.29a	20 ± 0.00a
10 (D_2)	27 ± 9.00b	30 ± 0.16b
20 (D_3)	44 ± 4.41d	23 ± 0.30a
30 (D_4)	29 ± 4.70b	35 ± 0.35c
$LSD_{0.05}$	4.83	
Dosage of BC (ton ha^{-1})	Productive tiller per clump	
	1 briquette (1 dosage) for 1 plant clump (BC_1)	1 briquette (4 dosages) for 4 plant clumps (BC_2)
0 (D_1)	12 ± 1.25 a	13 ± 0.52ab
10 (D_2)	17 ± 2.69bc	17 ± 2.58bc

Note: Different letters in a similar column and row indicate statistically significant different values among treatments in LSD ($p<0.05$).
BC_1: placement of 1 BC under one plant clump; BC_2 : placement of 1 BC under and middle of four plant clumps
BC doses were 0 g (D_1), 28 g (D_2), 56 g (D_3),and 74 g (D_4)

much higher compared to the study of Hasanuzzaman *et al*. (2010) which used green manure at 15 ton ha^{-1} which resulted in only 5.6 productive tillers and 2.32 ton ha^{-1} rice grain. This briquette compost was better than green manure because BC was made of legume and was high in N, P and K and had a low C/N (8.32). Nutrients were therefore readily available for plants (Bernas *et al.* 2015).

The placement of BC and dosage had a significantly different effect on dried rice grain (Table 3). The highest was reached by the treatment of BC$_1$ at a rate of 20 ton ha^{-1} (1030.81 g m^{-2} or equal to 10.3081 ton ha^{-1}) and this dried rice was not significantly different from other BC$_1$ rates (10 and 30 ton ha^{-1}) but significantly different from control (586.73 g m^{-2} or 5.867 ton ha^{-1}). Thus a combination of BC$_1$ and a rate of 20 ton ha^{-1} produced about 175% higher than control (0 compost). On the other hand, the application of BC$_2$ at 10, 20 and 30 ton rates did not result in any significantly different yields. This means the BC$_1$ treatment was better than BC$_2$ treatment. BC made of water mimosa was even better than poultry manure as reported by Hidayatullah (2016). In her study, poultry manure applied at a rate equal to 120 N resulted in 9.3 ton ha^{-1} rice grain. This was caused by a large amount of plant nutrients being supplied by poultry manure at a low CN ratio (12.0). This also indicates that BC characteristics are similar to poultry manure as the CN ratio of BC was 8.32 with a 4% N content. This high N content was due to compost being made of water legume plants as reported by Bernas *et al*. (2018). Organic matter incorporated into the soil could increase the ability of plants to absorb water through roots proliferation (Curtis and Claassen 2005), as shown by the vigorous growth of roots inside BC (Appendix 1). BC as compost was able to stimulate plant growth, root development and nutrient uptake (Walker and Bernal 2008) thus increasing rice yield.

Relationship between BC Placement and Dosage and Rice Growth and Yield

In the case of BC$_1$ treatment, the regression analysis showed that BC dosage significantly correlated with productive tillers ($r^2 = 0.54^*$; p=0.03) and rice dry weight ($r^2 = 0.71^*$; p=0.03). But BC$_2$ treatment showed a very significant correlation only between rate of BC and rice dry weight ($r^2 = 0.70^{**}$; p=0.01). In BC$_1$ treatment, the different rates showed a curve with the optimum application being reached at 20 ton ha^{-1} on BC$_1$. Any further increase in rate would result in lower rice tillers and dry rice yield. On the other hand, the different rates of BC$_2$ treatment showed a linear correlation. This means the optimum rate was not reached yet. So when BC was applied in the middle of four plant clumps (BC$_2$), it would need a higher rate than in BC$_1$ treatment. Thus BC$_1$ treatment allowed the roots to grow inside BC vigorously and absorb the nutrients straight away without the need to grow longer compared to he BC$_2$ treatment (see Appendix 1).

A rate of 30 ton ha^{-1} in BC$_1$ treatment showed a decrease in rice dry weight, which might be due to excessive N, as BC contains 4% N. Dong *et al*. (2011) found that excessive N decreased grain yield. Another study by Zhu *et al*. (2017) found that excessive nitrogen application reduced rice yield; they suggest that a suitable rate would be 270 kg ha^{-1}. Thus, it is suggested that compost be applied just around the rice roots, especially under flooded conditions where the efficiency of N is low due to NH_{3+} volatilisation (Bouwman *et al*. 2002).

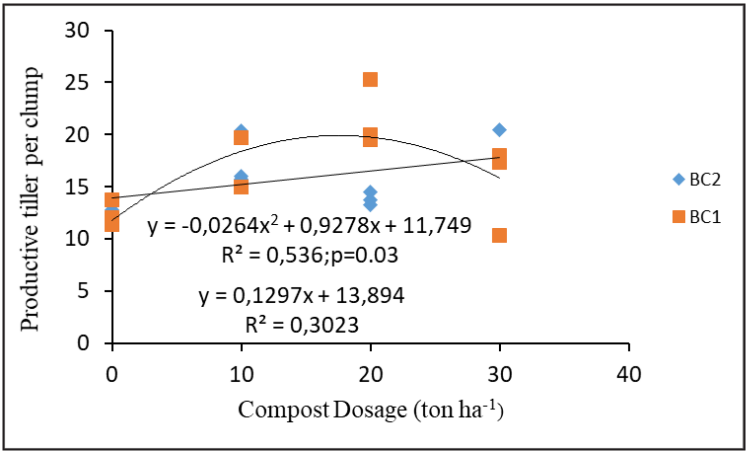

Figure 4. Relationship between different BC rates and productive tillers

Note: BC_1 : placement of 1 BC under one plant clump; BC_2 : placement of 1 BC under and middle of four plant clumps

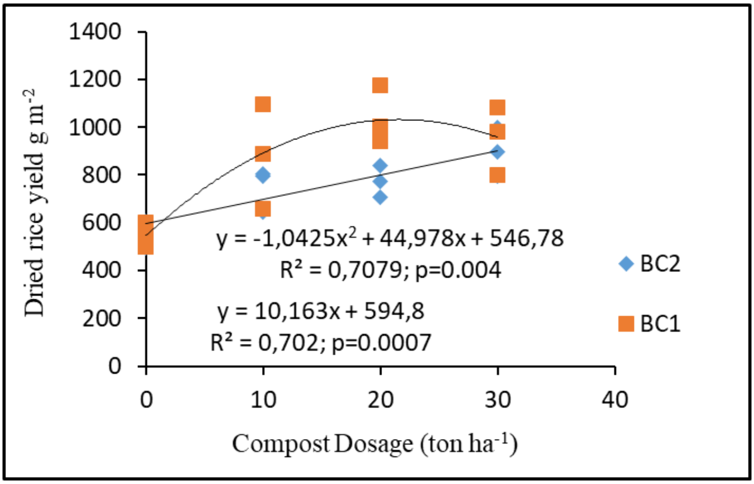

Figure 5. Relationship between different BC rates and rice dried weight dosages

Note: BC_1 : placement of 1 BC under one plant clump; BC_2 : placement of 1 BC under and middle of four plant clumps

CONCLUSSION

Placement of BC under the rice plant clumps (BC_1) gave better results than placement of BC in the under and middle of four rice plant clumps (BC_2). The optimum value was achieved by application of 20 ton ha^{-1} for BC_1 with a yield of 1,014 g m^{-2} or 10.14 ton ha^{-1}. This high rice yield in BC_1 might be due to roots being able to absorb nutrients and water from BC straight away resulting in stimulation of root development and plant growth at an early stage. In BC_2 treatment, crop roots needed more time and greater length to reach BC in the middle of four plant clumps and utilise the nutrients in the compost; also several nutrients in the compost might be lost before the roots could reach it. So it is better to apply briquette compost by inserted into the soil and rice seedling was planted obove it.

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Appendix 1. Development of rice plant after BC_1 and BC_2 treatments (Figure A, B, C and D).

	
A. Rice roots after BC_1 treatment: 1 BC under 1 plant clump	B. Rice roots after BC_2 treatment: 1 BC under & middle of 4 plant clumps
	
C. Rice crop under BC_1 treatment with 20 ton ha^{-1}	D. Rice crop under BC_2 treatment with 20 ton ha^{-1}