International Journal of Plant & Soil Science

Volume 36, Issue 5, Page 152-163, 2024; Article no.IJPSS.114621
ISSN: 2320-7035

Biochar-fortified Sil-KAB: Environment Friendly Briquette Technology to Improve Growth, Yield and Economics of Paddy

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2024/v36i54512

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114621

Original Research Article

Received: 11/01/2024
Accepted: 15/03/2024
Published: 20/03/2024

ABSTRACT

Paddy is one of the most important staple foods in the world. The area under paddy cultivation is 43.79 million hectares and the production is 116.43 million tons in 2018-19. It is an important staple food consumed by 65 percent of the country's population. However, paddy cultivation is also associated with an unbalanced use of fertilizers.
A balanced use of fertilizers is essential to increase the productivity of the harvest. Broadcast application of fertilizers during the *Kharif* season (In India, *Kharif* season is popularly considered to start in June and end in October.) leads to losses due to the dissolution of fertilizers in water and

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leaching from the field with the flooded water, thereby increasing the fertilizer requirement. Improper application of fertilizers leads to pollution of water bodies and is not environment friendly. Applying fertilizers through deep placement reduces the loss of fertilizers and is environmentally friendly. The field trial was conducted in Bhor during the *Kharif* season of 2022 to study the effect of biochar fortified Sil-KAB briquettes on growth, yield, economics and reduction of methane emissions from the paddy field. The biochar fortified Sil-KAB briquettes have the potential to improve the efficiency of fertilizer use. The experiment was conducted with two treatments consisting of a conventional fertilizer application and biochar fortified Sil-KAB briquettes. The experiment was replicated with 14 farmers in two villages of Bhor, Pune.

The results of the trial showed that the application of biochar fortified Sil-KAB briquettes significantly increased the height of the paddy at tillering, panicle initiation and at the harvest stage. Significantly highest number of tillering hill^{-1}, number of productive tillering hill^{-1}, panicle length, number of filled grains panicle^{-1}, number of total grains panicle^{-1}, percentage of grain filling, grain yield, straw yield and net return of paddy were observed in biochar fortified Sil-KAB briquettes treatment. The application of biochar fortified Sil-KAB briquettes significantly reduced methane emissions from the paddy field. The application of biochar fortified Sil-KAB briquettes significantly improves the growth, yield and profitability of paddy in the *Kharif* season.

Keywords: Paddy; biochar fortified Sil-KAB briquettes; growth; fertilizer application; yield; methane emission; economics.

1. INTRODUCTION

Paddy is one of the most important staple foods in the world. Paddy is grown in diverse agro-ecologies ranging from irrigated uplands to rain-fed lowlands and flood-prone paddy ecosystems. India is second only to China in terms of paddy acreage and production [1,2]. Paddy production in India stood at 116.42 million tons on an area of 43.79 million hectares, accounting for about 35.33 per cent of the foodgrain area and 40.86 per cent of the total foodgrain production in the country in 2018-19. It is an important staple food consumed by 65 percent of the country's population. It contributes around 10 percent to agricultural GDP and its production generates 3.5 billion man-days of employment [3,4].

Unbalanced application of fertilizers leads to deterioration of soil health, reduction in crop quality and loss of crop yields, which has become a problem. Unbalanced use of inorganic fertilizers has a direct impact on the food and nutrition security of farming families. Therefore, a balanced use of fertilizers plays an important role in crop production and in minimizing environmental damage.

Total fertilizer consumption of India in the year 2021-22 is 29796.3 thousand tons [5]. Rice is the major crop which are consuming 37% of the total fertilizers consumed in India among various crops [6]. Nitrogen runoff loss ranged from 6 to 70% of applied nitrogen, depending on the form, rate, and method of nitrogen application as well as water management. In rainfed lowland rice fields with 25 cm of ponding water, runoff loss of nitrogen up to 78% of applied nitrogen has been seen in case of surface broadcasting of urea [7]. Runoff losses of nitrogen and other nutrients contaminates the water bodies. Contamination of water bodies with fertilizers poses severe environmental threats. Excessive nutrients like nitrogen and phosphorus from fertilizers lead to harmful algal blooms, depleting oxygen levels in water and causing aquatic dead zones. This disrupts ecosystems, harming fish and other aquatic life. Furthermore, these contaminants can enter drinking water sources, posing health risks to humans. The impact extends beyond immediate aquatic damage, affecting biodiversity, water quality, and human well-being.

Heavy and unbalanced use of chemical fertilizers leads to multiple nutrient deficiencies and lower organic matter content in the soil. About 8 million hectares of paddy soils are deficient in zinc and 15 million hectares of paddy soils are acidic, which is associated with iron and aluminium toxicity, depletion of bases (calcium, potassium and magnesium), phosphorus fixation and probably deficiency of boron and silicon. On the other hand, organic sources are not sufficient to meet the nutrient requirements of high-yielding varieties [8]. Unbalanced fertilization leads to a decline in productivity and fertilizer use efficiency in paddy. Emissions from the synthetic nitrogen fertilizer supply chain amounted to 1.13 Gt CO_2

equivalent in 2018, representing 10.6 per cent of agricultural emissions and 2.1 percent of global greenhouse gas emissions [9]. Bhor faces similar challenges such as heavy rainfall, constant flooding of paddy fields with rainwater and more than 95 percent of farmers apply fertilizers by broadcasting, which reduces the efficiency of fertilizer use and increases the application rate. This also has an impact on plant growth and productivity.

In paddy cultivation, farmers focus on the application of nitrogen, phosphorus and potassium. Several studies have shown that there is a clear and almost constant need for nitrogen, phosphorous and potassium to produce high-yielding crop varieties [10]. Silicon plays an important role in both biotic and abiotic stress and helps to increase productivity. Silicon is also an element that acts like potassium and does not harm plants when over-accumulated [11]. The benefits of biochar are well known. The addition of biochar reduces the bulk density of the soil, improves water holding capacity and promotes the growth of beneficial microorganisms. The application of biochar increases pH, cation exchange capacity, availability of essential elements and reduces the concentration of heavy metals [12].

The study was carried out in Bhor. In Bhor, fertilizers for crops are usually applied by broadcasting. A large proportion of farmers apply urea in excessive quantities compared to other nutrients. The application method usually leads to fertilizer losses due to volatilization, denitrification, surface runoff, leaching losses of nitrogen and fixation of phosphorus in the soil [13]. The reduced efficiency of fertilizer use through application increases fertilizer demand and leads to water pollution, greenhouse gas emissions and other negative environmental impacts.

Paddy cultivation in the region is practiced by flooding the paddy fields, leaving the soil under water. The flooding practice leads to methane emissions from the paddy fields. It has been found that balanced and systematic application of nutrients such as nitrogen, silicon, potassium and sulphur have the potential to reduce methane emissions in paddy cultivation [14,15]. Therefore, proper management of these nutrients in the paddy field can improve the efficiency of fertilizer use and suppress methane emissions [16].

Deep placement of fertilizers reduces loss through volatilization. In addition, deep placement of fertilizer is environmentally friendly and does not affect the normal fertility of the soil [17]. Applying urea 10 cm deep and 5 cm away from rice roots led to a notable decrease in nitrogen fertilizer loss. This technique exhibited a reduction in fertilizer losses ranging from 56.3% to 81.9% compared to the conventional method of urea surface broadcasting [18]. The application of conventional fertilizers by deep placement is beneficial but is very difficult in paddy cultivation. In solving this problem, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli has developed the fertilizer briquette technology and recommended it for paddy cultivation. Several studies have demonstrated the benefits of fertilizer briquettes for paddy cultivation under flooded or submerged conditions. The benefits of biochar are well known. A new formulation has been developed to combine biochar with fertilizer briquettes. The effect of biochar fortified Sil-KAB briquettes on the growth and yield of paddy was assessed in this research study.

2. MATERIALS AND METHODS

2.1 Study Location

The target sites for the study were the Bhor blocks of Pune district (Maharashtra, India). The study site in Bhor block lies at latitudes 18° 9'38.23"N to 18°10'22.90"N and longitudes 73°46'30.04"E to 73°49'35.30"E. The major rivers flowing in the Bhor block are Nira, Velvandi and Gunjavani, which flow from west to east, and Shivaganga from north to south. The two largest dams in the block are Bhatghar on the Velvandi river and Nira Devghar on the Nira. The average annual rainfall in the Bhor block is 900 mm. Most of the Bhor block is covered by Deccan basalt, and thick alluvial soil spreads along the banks of the Nira and Velvandi rivers. The region is also of historical importance as it was the main link between the Deccan Plateau and the west coast. The soil is deep, with moderately well-drained clay soils. The main crops grown in the Bhor block are paddy, sorghum and ragi. Minor crops include groundnut, pigeon pea and sugarcane [19].

Fig. 1. Location map of study area

2.2 Study Details

Paddy crop of *Indrayani* variety was used as a test crop. The conventional cultivation method of submerged cultivation was used in the *Kharif* season of 2022. In India, *Kharif* season is popularly considered to start in June and end in October. The spacing between the plants was maintained at 15 x 20 cm. The field trial was designed as a paired T-test and was replicated with 14 farmers. The trial was conducted with two treatments consisting of conventional fertilizers and biochar fortified Sil-KAB briquettes. One biochar fortified Sil-KAB briquettes were incorporated 7 to 8 cm deep into the soil between four paddy hills as recommended by Dr. Balasaheb Sawant Konkan Krishi Vidhyapeeth, Dapoli. The briquettes were produced at the Sustainable Agriculture Revolution Producer Company Ltd. in Dapoli under the supervision of Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. The specifications of biochar fortified Sil-KAB briquettes are as follows:- Form: solid, Shape: flattish oval, Thickness: 4.14 cm, Weight: 2.6 gm, Average length: 3.0 cm and Nutrient content: N - 33.8 per cent, P - 13.8 per cent, K - 5.8 per cent, Si - 0.44 per cent and Biochar 0.8-1.0 per cent.

Height of paddy was measured during tillering, panicle initiation and at harvest stage of paddy. Number of productive tillers hill^{-1}, unproductive tillers hill^{-1}, total tillers hill^{-1}, length of panicle, numbers of filled grains panical^{-1}, number of unfilled grains panical^{-1} and total grains panical^{-1} was measured at the harvest stage of paddy. Grain filling per cent became calculated as the quantity of filled grains panicle^{-1} multiplied by a factor of 100 over the total number of grains panicle^{-1} [20]. At the harvest stage, grain yield and straw yield were recorded in a 1 x 1 m^{2} area (Kg m^{2}) and it was converted into quintals per hectare. The Harvest index was calculated in line with Yoshida [21]. Harvest index (%) = Grain yield / (Grain yield + Straw yield) × 100. The gas samples were collected using static closed chamber method [22].

2.3 Statistical Analysis

The statistical analysis of experimental data was done by paired T-test given by Panse and Sukhatme [23]. Star was used to show the flag's level of significance. If a p-value is less than 0.05, it is flagged with one star (*). If a p-value is less than 0.01, it is flagged with two stars (**). If a p-value is less than 0.001, it is flagged with three stars (***). This research trial was conducted at farmers field therefore, data was tested at 5 per cent (0.05) flag level of significance.

3. RESULTS AND DISCUSSION

Plant height: Table 1 demonstrates that the application of biochar fortified Sil-KAB briquettes when applied through deep placement, resulted in significantly greater paddy height (72.36, 94.00, and 99.07 cm) compared to the application of conventional fertilizers through broadcasting (59.52, 80.98, and 88.62 cm) during the tillering, panicle initiation, and harvest stages of paddy.

This deep placement technique ensures that a majority of the nitrogen remains in the soil as ammonium, a less mobile form than nitrates, thereby providing a sustained supply of nitrogen to paddy plants and promoting their vegetative growth. Consequently, deep placement minimizes the risk of nitrogen leaching, volatilization, nitrification, and denitrification, thus enhancing its availability and uptake by crops. As a result, the plants in the deep placement plots exhibit increased height compared to those in plots where urea was applied using conventional methods, which are associated with stunted growth [24].

Table. 1. Effect of Biochar fortified Sil-KAB briquettes on the height of paddy

Stage	**Plant height (cm) at tillering stage**	
Treatment	Conventional fertilizers	Biochar Fortified Sil-KAB
Mean	59.52	72.36
Variance	76.30	50.93
No. of observations	14	14
T test value	4.26*	
Standard error	3.01	
Stage	**Plant height (cm) at panicle initiation**	
Mean	80.98	94.00
Variance	111.63	51.32
No. of observations	14	14
T test value	3.82*	
Standard error	3.41	
Stage	**Plant height (cm) at harvest**	
Mean	88.62	99.07
Variance	88.82	41.17
No. of observations	14	14
T test value	3.43*	
Standard error	3.05	

Table 2. Effect of Biochar fortified Sil-KAB briquettes on number of productive tillers hill^{-1}, number of unproductive tillers hill^{-1}, total number of tillers hill^{-1} and panicle length of paddy

Parameter	**No. of productive tillers hill^{-1}**		**No. of unproductive tillers hill^{-1}**	
Treatment	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**
Mean	12.50	14.79	3.79	4.29
Variance	4.58	4.34	2.18	2.53
No. of observations	14	14	14	14
T test value	2.86*		0.86	
Standard error	0.80		0.58	
Parameter	**Total No. of tillers hill^{-1}**		**Panicle length (cm)**	
Mean	16.29	19.07	18.33	20.83
Variance	2.68	3.46	2.77	1.57
No. of observations	14	14	14	14
T test value	4.21*		4.49*	
Standard error	0.66		0.56	

Number of productive tillers hill^{-1}: In plots treated with biochar fortified Sil-KAB briquette, the number of productive tillers hill^{-1} recorded in Table 2 was significantly higher (14.79). Conversely, the plots that adopted the conventional method of fertilizer application had the lowest number of productive tillers hill^{-1} (12.50). The use of fertilizer in briquette form ensured a balanced supply of nutrients to the crop throughout its growth period. This steady and slow availability of nitrogen during both the early and later growth phases, along with the presence of phosphorus and potassium in the root zone, may have contributed to the maximum number of productive tillers hill^{-1}.

Number of unproductive tillers hill^{-1}: Table 2, displays that the application of biochar fortified Sil-KAB briquettes resulted in an increase in the number of unproductive tillers hill^{-1} from 3.79 to 4.29. However, this increase was not significantly different from the conventional fertilizers.

Total numbers of tillers hill^{-1}: The total number of tillers hill^{-1} at the harvest stage varied between 16.29 to 19.07 due to the application of different nutrient sources in various treatments. The biochar fortified Sil-KAB briquette showed a significantly higher total number of tillers hill^{-1} compared to conventional fertilizers. This is likely due to the conventional method of fertilizer application, which increases nitrogen solubility and leaching losses from the field, reducing nitrogen availability during the tillering stage. In contrast, nitrogen application through biochar fortified Sil-KAB briquettes results in a slow and steady supply of nitrogen throughout the growing season, ensuring nutrient availability throughout the crop cycle of paddy. The sustained availability of nitrogen is possibly responsible for biomass development and the highest tillering in biochar fortified Sil-KAB briquette. Chanchareonsook et al. [25] reported that the application of NPK fertilizer in combination with silicon increased the total number of tillers in paddy.

Panicle length: The mean comparison at a 5 per cent significance level on panicle length between the two treatments is presented in Table 2. According to the results, the plots where biochar fortified Sil-KAB briquette was applied recorded a significantly higher panicle length (20.83 cm) compared to the plots receiving fertilizers through conventional methods (18.33 cm). It is assumed that nitrogen, being an essential constituent of amino acids, nucleic acids, nucleotides, and chlorophyll, plays a crucial role in cell division and tissue differentiation. This, in turn, contributes to the development of new cells, tissues, and plant organs. Yoshida [26] suggested that the increased panicle length observed may be attributed to enhanced cell division and tissue differentiation during the flowering stage.

Number of filled grains panicle^{-1}: In terms of the number of filled grains panicle^{-1}, Table 3 indicates that the application of biochar fortified Sil-KAB briquette resulted in a significantly higher number of filled grains panicle^{-1} (121.36) compared to the treatment with conventional fertilizers, which had the lowest number of filled grains panicle^{-1} (112.43). Jawahar et al. [27] reported that silicon fertilizer promotes the assimilation of carbohydrates in panicles, leading to an increased number of filled grains.

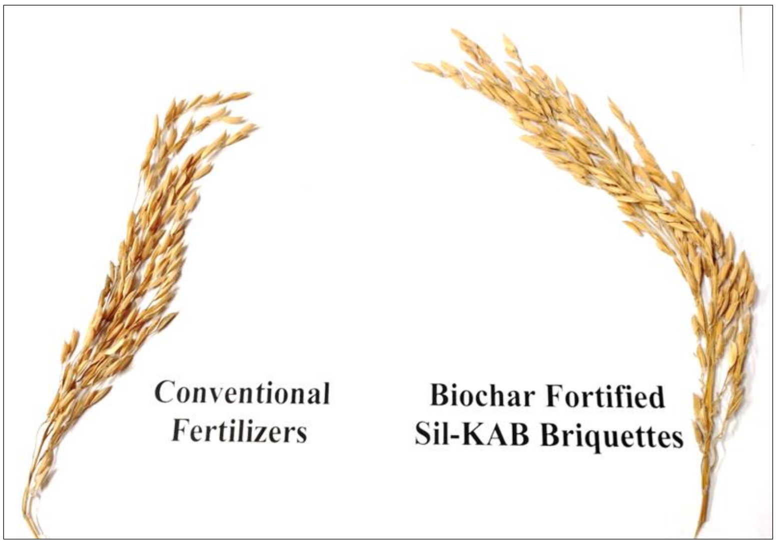

Fig. 2. Panicle length

Table 3. Effect of Biochar fortified Sil-KAB briquettes on number of filled grains panicle^{-1}, number of unfilled grains panicle^{-1}, number of total grains panicle^{-1} and percent grain filling of paddy

Parameters	**No. of filled grains panicle^{-1}**		**No. of unfilled grains panicle^{-1}**	
Treatment	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**
Mean	112.43	121.36	18.93	17.29
Variance	44.73	41.79	6.53	14.99
No. of observations	14	14	14	14
T test value	3.59*		1.33	
Standard error	2.49		1.24	
Parameters	**No. of total grains panicle^{-1}**		**Percent grain filling**	
Mean	131.36	138.64	85.59	87.56
Variance	51.02	47.17	3.12	6.79
No. of observations	14	14	14	14
T test value	2.75*		2.34*	
Standard error	2.65		0.84	

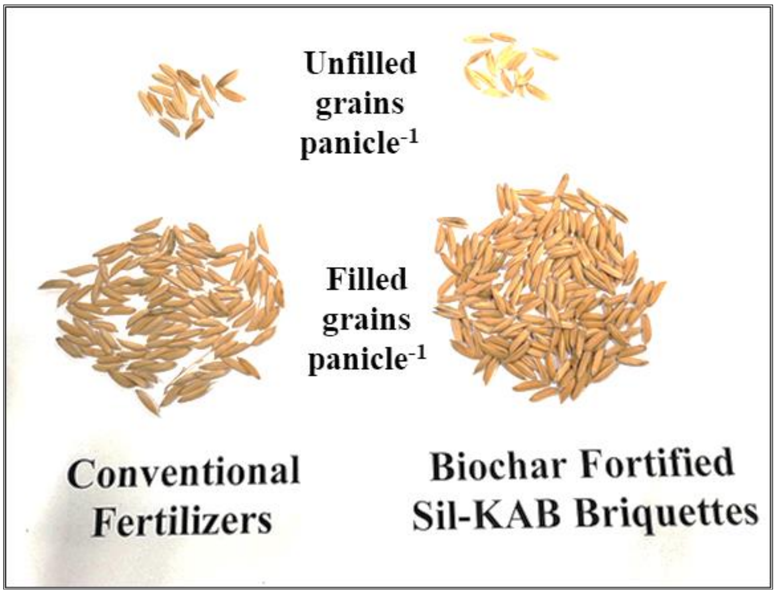

Fig. 3. Number of Filled and Unfilled grains panicle^{-1}

Number of unfilled grains panicle^{-1}: Table 3 presents glimpses of the data regarding the number of unfilled grains panicle^{-1} in paddy. The range of this number was observed to be from 17.29 to 18.93, and there was no significant difference between the two treatments. However, it is worth noting that the treatment involving conventional fertilizers had the highest number of unfilled grains panicle^{-1} compared to the treatment involving biochar fortified Sil-KAB briquettes.

Number of total grains panicle^{-1}: Furthermore, the application of biochar fortified Sil-KAB briquettes resulted in a remarkable variation in the number of total grains panicle^{-1} (Table 3). The results indicated that the treatment involving biochar fortified Sil-KAB briquettes had the highest number of total grains panicle^{-1} (138.64), which was statistically identical to the treatment involving conventional fertilizers (131.36). This could be attributed to the higher nitrogen content, which led to an increase in chlorophyll concentration in the leaves, thereby enhancing the photosynthetic rate and providing an abundance of photosynthates during grain filling. Additionally, the deep placement of these briquettes minimized nutrient losses through leaching and runoff, resulting in better retention and release of nutrients.

Grain filling percentage: In terms of grain filling percentage, the data showed that it ranged from 85.59 to 87.55 (Table 3). The treatment involving biochar fortified Sil-KAB briquettes had the highest grain filling percentage (87.55), which was statistically identical to the treatment involving conventional fertilizers. This could be attributed to the higher number of filled grains panicle^{-1} and the lower number of unfilled grains panicle^{-1} in the same treatment.

Yield of paddy: Table 4, data demonstrates that the application of biochar fortified Sil-KAB briquettes had a significant impact on the grain yield, straw yield, and harvest index of paddy. The grain yield of paddy ranged from 46.35 to 62.45 q ha^{-1}, with the highest yield observed in the treatment of biochar fortified Sil-KAB briquettes due to a consistent and uninterrupted supply of nutrients throughout all growth stages of the crop. The results also showed that the fields where biochar fortified Sil-KAB briquettes were applied had a significantly higher straw yield of paddy (87.73 q ha^{-1}) compared to conventional fertilizers (68.50 q ha^{-1}). The same trend was observed in the harvest index of paddy, which ranged from 40.36 to 41.60 per cent. These findings indicate that the use of inorganic sources of nutrients through broadcasting cannot maintain a consistent flow of nutrients in the soil for optimal growth and crop yield. Therefore, it is necessary to use organic and chemical fertilizers through briquette formulations with silicon to enhance crop productivity. Bagal [28] reported an increase in crop yield with improved fertilizer management through briquettes compared to the traditional method of broadcasting fertilizers in paddy crops.

Table 4. Effect of Biochar fortified Sil-KAB briquettes on yield and harvest index of paddy

Parameter	**Grain yield (q ha^{-1})**	
Treatment	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**
Mean	46.35	62.45
Variance	12.08	11.71
No. of observations	14	14
T test value	12.35*	
Standard error	1.30	
Parameter	**Straw yield (q ha^{-1})**	
Mean	68.50	87.73
Variance	25.95	28.87
No. of observations	14	14
T test value	9.71*	
Standard error	1.98	
Parameter	**Harvest index (%)**	
Mean	40.36	41.60
Variance	1.62	0.98
No. of observations	14	14
T test value	2.86*	
Standard error	0.43	

Methane flux: Variation in methane flux was observed at different growth stages of paddy, including the seedling stage (1.88 to 3.78 mg m^{-2} hr^{-1}), tillering stage (15.88 to 17.42 mg m^{-2} hr^{-1}), panicle initiation stage (20.31 to 21.38 mg m^{-2} hr^{-1}) and grain filling stage (4.69 to 5.03 mg m^{-2} hr^{-1}). The methane flux values for each stage are presented in Table 5. The application of biochar fortified Sil-KAB briquettes resulted in significantly lower methane flux compared to conventional fertilizers at the seedling stage (1.88 mg m^{-2} hr^{-1}), tillering stage (15.88 mg m^{-2} hr^{-1}), panicle initiation stage (20.31 mg m^{-2} hr^{-1}) as compared with conventional fertilizers. However, at the grain filling stage, the same treatment did not show a significant effect on methane flux, although it still exhibited the lowest values. The findings of the study suggest that the reduction in methane flux can be attributed to the application of biochar fortified Sil-KAB briquettes, which contain silicon. Silicon enhances the root biomass and its oxygen carrying capacity, leading to improved activity of methanotrophic bacteria and methane oxidation [29]. Additionally, the silicate fertilizer present in the briquettes increases the concentration of ferrous ions in the soil, acting as an electron acceptor and reducing methanogenic activity, which may contribute to the reduction in methane emissions [30]. Notably, a remarkable difference in methane flux was observed at the seedling stage immediately after the application of fertilizers and briquettes in the respective treatment plots.

Cumulative methane emission and methane emission reduction: Table 6 presents the data on cumulative methane emission and methane emission reduction, which varied at different growth stages of paddy due to the application of conventional fertilizers and biochar fortified Sil-KAB briquettes. The methane emissions observed in various plots ranged from 9.02 to 18.15 Kg ha^{-1} at seedling stage, 95.29 to 104.52 Kg ha^{-1} at tillering stage, 121.86 to 128.27 Kg ha^{-1} at panicle initiation stage, and 33.77 to 36.21 Kg ha^{-1} at grain filling stage. Deep placement of biochar fortified Sil-KAB briquettes resulted in significantly lower cumulative methane emission at seedling, tillering, and panicle initiation stages compared to the application of conventional fertilizers through broadcasting. However, no significant difference was observed at the grain filling stage.

The experimental plots of paddy at Bhor location exhibited a range of total cumulative methane emissions from 259.93 to 287.15 Kg ha^{-1}. The treatments that utilized biochar fortified Sil-KAB briquettes for fertilizer application recorded the significantly lowest total cumulative methane emission of 259.93 Kg ha^{-1}, while the conventional practices resulted in the highest methane emission (287.16 Kg ha^{-1}) from paddy field. The application of biochar fortified Sil-KAB briquettes led to a reduction of 27.22 kg ha^{-1} methane emission compared to conventional fertilizers. Additionally, the use of biochar fortified Sil-KAB briquettes resulted in higher grain and straw yield due to the effective conversion of soil organic carbon/nutrients into biomass and grain [31]. The slow release of nutrients in biochar fortified Sil-KAB briquettes led to better nutrient use efficiency and lesser methane emissions. The plot receiving conventional fertilizer through broadcasting exhibited an increment in methane emission, which may be attributed to the use of excessive urea. Hydrolysis of the urea results in release of NH4+ irons, which are responsible for methane emission [14]. The application of biochar fortified Sil-KAB briquettes was found to be effective in mitigating methane emissions, as suggested by Setyanto et al. [32] and Rath et al. [33].

Table 5. Effect of Biochar fortified Sil-KAB briquettes on stage wise methane flux (mg m^{-2} hr^{-1}) from paddy field

Stage	**Seedling**		**Tillering**	
Treatment	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**
Mean	3.78	1.88	17.42	15.88
Variance	0.78	0.30	0.90	0.74
No. of observations	14	14	14	14
T test value	6.87*		4.49*	
Standard error	0.28		0.34	
Stage	**Panicle Initiation**		**Grain filling**	
Mean	21.38	20.31	5.03	4.69
Variance	1.35	1.22	0.86	0.64
No. of observations	14	14	14	14
T test value	2.49*		1.04	
Standard error	0.43		0.33	

Table 6. Effect of Biochar fortified Sil-KAB briquettes on stage wise cumulative methane emission and methane emission reduction (Kg ha^{-1})

Stage	**Seedling (0-20 DAT)**		**Tillering (20-45 DAT)**	
Treatment	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**	**Conventional fertilizers**	**Biochar Fortified Sil-KAB**
Mean	18.15	9.02	104.52	95.29
Variance	7.54	6.80	32.40	26.79
No. of observations	14	14	14	14
T test value	9.02*		4.49*	
Standard error	**1.01**		**2.06**	
Stage	**Panicle Initiation (45-70 DAT)**		**Grain filling (70-100 DAT)**	
Mean	128.27	121.86	36.21	33.77
Variance	48.70	43.90	44.54	33.18
No. of observations	14	14	14	14
T test value	2.49*		1.04	
Standard error	2.57		2.36	
Parameter	**Total methane emission**		**Methane emission reduction**	
Mean	287.15	259.93	27.22	
Variance	216.69	220.73	The abbreviation used DAT means Days After Transplanting	
No. of observations	14	14		
T test value	4.87*			
Standard error	5.59			

Table 7. Effect of Biochar fortified Sil-KAB briquettes on cost of cultivation of paddy

Treatment	**Cost of cultivation (Rs. ha^{-1})**	**Gross return (Rs. ha^{-1})**	**Net return (Rs. ha^{-1})**	**Cost: Benefit Ratio**
Conventional fertilizers	60,100	1,02,014	41,914	1.70
Biochar Fortified Sil-KAB	67,600	1,37,412	69,812	2.03

Cost of cultivation of paddy: Table 7 presents the data on the cost of cultivation, gross returns, net returns, and Cost-Benefit ratio, which are influenced by different treatment combinations. In treatments using biochar fortified Sil-KAB briquettes, the cost of cultivation is higher at Rs. 67,600/- ha^{-1} compared to conventional fertilizer application practices at Rs. 60,100/- ha^{-1}. However, the increased cost of cultivation is offset by the higher yields and returns achieved through the application of biochar fortified Sil-KAB briquettes. The treatment with biochar fortified Sil-KAB briquettes resulted in higher gross returns at Rs. 1,37,412/- ha^{-1}, net returns at Rs. 69,812/- ha^{-1}, and Cost-Benefit ratio at 2.03 compared to conventional fertilizer application. The results indicate that the application of biochar fortified Sil-KAB briquettes incurred an additional cost of Rs. 7,500/- compared to conventional fertilizers, but farmers received an additional gross return of Rs. 35,398/- from the same treatment. Excluding all cultivation costs, farmers received an additional net return of Rs. 27,898/- ha^{-1}. from biochar fortified Sil-KAB briquettes compared to conventional fertilizers.

4. CONCLUSION

The investigation indicates that the application biochar fortified Sil-KAB briquettes leads to increased growth and yield of paddy, higher net returns, and a reduction in methane emissions compared to traditional fertilizer application methods during the *Kharif* season.

ACKNOWLEDGEMENT

Team BAIF is grateful to Tata Motors Limited for showing faith and providing financial support for implementing various innovative activities on the ground. The support is instrumental and has helped in identifying new ways of supplying fertilizer to the rice-cultivating farmers in the form of Biochar Fortified Sil-KAB Briquette. This innovation has helped farmers increase their revenue from the same agricultural land by adopting sustainable agricultural practices by increasing fertilizer use efficiency and reducing methane emissions. There is a long way to go, but initial support is always special as it is a strong belief that some innovation can be thought of and established through such initiatives.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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