Variations in crop productivity, microbial biomass and greenhouse gas fluxes as influenced by soil temperature elevation incorporated with indigenous organic amendments

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ABSTRACT

Field experiments were conducted from February 2018 to May 2018 and October 2018 to January 2019 to evaluate the potentials of elevated soil temperature on crop production, microbial biomass carbon (MBC), and CO_2 and CH_4 emissions along with the imposition of organic amendments, viz. rice straw compost (RSC), mustard meal (MM), and tricho-compost (TC). Soil temperature elevation of 3°C from the field temperature of 23–25°C was considered and RSC at the rates of 0, 4, and 8 t ha^{-1}, MM at the rates of 0, 3, and 6 t ha^{-1}, and TC at the rates of 0, 2.5, and 5 t ha^{-1} were applied. The carried-over effects of the aforesaid treatments were examined. The highest grain yields of 8.86 t ha^{-1} for BRRI dhan 29, 8.25 t ha^{-1} for BRRI dhan 74, and 6.97 t ha^{-1} for BR 3 rice varieties were recorded under 3°C of temperature rise along with RSC followed by MM and TC, while TC exerted the pronounced effect on the subsequent bottle gourd (BARI Lau–1: *Lagenaria siceraria*) production (10 fruits/plant). The amounts of MBC in the soils were maximum at 60 days after transplantation of rice, compared to other growth stages of rice under soil temperature rise of 3°C with TC at 2.5 t ha^{-1} in the first trial, while MBC contents were increased with the advent of time in succeeding soil, irrespective of the treatments which might be due to the flourishment of *Trichoderma* spp. even under stressful conditions. The elevated temperature notably increased CO_2 emission (from 500 to 1,800 mg m^{-2} h^{-1}) but lessened CH_4 emission (from 985 to 687 mg m^{-2} h^{-1}). The CH_4 emission was greatly influenced by MBC compared to CO_2. Among the used amendments, mustard meal exerted the highest absorption capacity of the analyzed gases in soil by conserving 20–30% soil moisture which thereby ameliorated microbial abundance. Furthermore, the practices of the mustard meal and tricho-compost in the field markedly increased crop production, improved soil health, and lessened CH_4 emission.

Keywords: Elevated soil temperature, crop production, microbial biomass carbon, greenhouse gas emission, tricho-compost, mustard meal

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INTRODUCTION

The earth has experienced its fourth consecutive hottest year in 2019 since the record has been kept (IPCC, 2018). The expected climate change includes the rise in the global average surface air temperature by 2.8–7.8°C at the end of the 21st century. If this occurrence continues steadily, the earth will face warming of 2°C between 2030 and 2050 (IPCC, 2014). This high atmospheric temperature trend may wretchedly act upon soil temperature. Sizable increases in atmospheric temperature associate with the surface soil temperature implying the dominant effects of climate warming on surface soil temperature, reporting the sharp soil warming in the surface of 0.57°C per decade (Fang *et al.,* 2019).

Soil temperature varies seasonally and daily which may result in changes in radiant energy and energy changes taking place through the soil surface. Measurements of the nutrient availability may indicate a soil's capacity to support crop growth, conversely, it may identify threshold values for environmental hazard assessment (Dalal and Moloney, 2000). Climate change alters the relative abundance and function of soil communities because soil community members differ in their physiology, temperature sensitivity, and growth rates (Whitaker *et al.,* 2014). Soil microbial biomass, a living component of soil organic matter, is considered as the most labile carbon pool in soils and a sensitive indicator of changes in soil temperature with links to soil nutrient and energy dynamics (Saha and Mandal, 2009). Seasonal changes in soil temperature and available residues have a strong influence on soil microbial biomass and its activity.

Rice (*Oryza sativa* L.), a globally important cereal, accounts for 20% of the calorie intake of 3.5 billion people (FAO, 2019). Rice cultivation especially Boro rice completely depends on irrigation water. Generally, 3,000 to 5,000 L of water is needed to produce 1 kg of rice (Bouman *et al.,* 2002). Limited water availability in the future coupled with climate change effects may reduce the capacity of farmers to irrigate their fields, which may result in an increased incidence of rice water stress. In addition, the soil temperature rise has already exerted deleterious effects on other crops. Among them, the effects on bottle gourd (*Lagenaria siceraria*) are most prominent. The bottle gourd is planted for the production of seeds that can be used for eating as a snack food or the production of salad oil. The seeds of bottle gourd are a good source of edible protein and oil (Ibrahim and El-Kader, 2015). Up-to-date evidence suggests that the mineral nutrition status of rice plants markedly affects their ability to adapt to adverse environmental conditions. Furthermore, the supply of adequate nutrition to plants by the usage of organic amendments might be an efficacious strategy to alleviate environmental stress especially soil temperature rise. But the usage of organic amendments on wetland rice incorporated with changing climatic conditions has pronounced effects on greenhouse gas emissions (Kim *et al*., 2013). Globally rice cultivation contributes 1.5% of total anthropogenic greenhouse gas (GHG) emissions, while in Bangladesh it contributes 32% of agricultural GHG emissions (FAO, 2015). Methane, a significant atmospheric trace-gas, is more than 20 times as potent a GHG as carbon dioxide on a molecule-for-molecule basis (Badr *et al*., 1991). Henceforth, the abatement of methane emission from rice fields will be a challenging issue after applying organic amendments in rice fields for the improvement of soil health and rice production. There has been insufficient information on the dynamics of soil microbial biomass carbon in subtropical rice fields which are attributed to misunderstanding the relationship among soil microbial biomass carbon, crop production, and gas dynamics. Considering the stated facts, the study was performed till carry-over effects to find out environmentally sound ways for minimizing the caustic influences of elevated soil temperature on crop production and microbial biomass content as influenced by the organic amendments for the justification of their sustainability and to introduce fruitful ways of reducing the emission of methane (CH_4) and carbon dioxide (CO_2) gases from rice soil under changing climatic conditions.

MATERIALS AND METHODS

Study Area

An experimental site was selected based on soil properties. The site was located at Chandipur, Keraniganj (23°40'N, 90°18'E), Dhaka, Bangladesh. The studied soil belongs to the Tejgaon soil series. Physico-chemical properties of the soil are presented in Table 1. According to these properties, the present amendments were selected to conduct the experiments.

Table 1 Selected properties of initial soil (1–15 cm) of the experiment

Soil properties	Values
Soil series	Tejgaon
General soil type	Non-calcareous dark grey and grey floodplain soils
Textural class	Clay loam
Soil reaction	5.95 ± 0.11
Electrical conductivity (μS cm^{-1})	56.91 ± 0.26
Organic carbon (%)	0.41 ± 0.05
Organic matter (%)	0.71 ± 0.06
Cation exchange capacity (cmol kg^{-1})	24.00 ± 0.30
Total nitrogen (mg kg^{-1})	95.96 ± 0.07
Available nitrogen (mmol kg^{-1})	1.07 ± 0.13
Available phosphorus (mmol kg^{-1})	0.39 ± 0.02
Available sulfur (mmol kg^{-1})	0.41 ± 0.09

Experimental Design

The experiment was laid out in a split-plot design with three replications, where two of the main plots were assigned for ambient field temperature of 23–25°C and elevated soil temperature of 26–28°C, respectively. In each of the main plots, different dosages of the selected organic amendments, three rice varieties, and subsequent bottle gourd crops were used and grown to the subplots as per treatment. Each main plot consists of seven subplots (2 m × 2 m). Rice varieties such as BR 3, BRRI dhan 29, and BRRI dhan 74 were selected as test crops for the first trial of the experiment (from February 2018 to May 2018), and bottle gourd variety such as BARI Lau–1 (*Lagenaria siceraria*) was selected for the second trial of the experiment (from October 2018 to January 2019). A drain (25 cm) was placed between the main plots to apply hot water and control the irrigation water supply. Forty-two days old rice seedlings were transplanted in each subplot at the rate of two seedlings per hill. Each subplot consisted of 6 rows of rice seedlings. The hill to hill and row to row distances were 20 and 25 cm, respectively. The residual effects of the treatments which were applied during the first trial of the experiment were evaluated for the subsequent crop (bottle gourd) during the second trial without the application of organic amendments. In the subsequent cropping season, the seeds of the BARI Lau–1 variety were sown in the distinct subplots as per treatment at the rate of 30 kg ha^{-1}. After germination, 2 seedlings were kept in each subplot by uprooting the remaining seedlings. These crop varieties were chosen by considering their lifespans, fertilizer requirements, and susceptibility to soil temperature rise. The denotation of the treatments and their combination used for the experiments are presented in Table 2.

Table 2 Denotation and combination of treatments applied in the field experiment

Treatment		Arrangement of the treatments	
Code	Denotation	Organic amendment (t ha^{-1})	Soil temperature (°C)
T_1	Control ($RSC_0MM_0TC_0TE_{23–25}ML_{100}$)	Control soil	23–25
T_2	$RSC_4TE_{23–25}ML_{100}$	Rice straw compost at 4	23–25
T_3	$RSC_8TE_{23–25}ML_{100}$	Rice straw compost at 8	23–25
T_4	$MM_3TE_{23–25}ML_{100}$	Mustard meal at 3	23–25
T_5	$MM_6TE_{23–25}ML_{100}$	Mustard meal at 6	23–25
T_6	$TC_{2.5}TE_{23–25}ML_{100}$	Tricho-compost at 2.5	23–25
T_7	$TC_5TE_{23–25}ML_{100}$	Tricho-compost at 5	23–25
T_8	$RSC_0MM_0TC_0TE_{26–28}$	Control soil	26–28
T_9	$RSC_4TE_{26–28}$	Rice straw compost at 4	26–28
T_{10}	$RSC_8TE_{26–28}$	Rice straw compost at 8	26–28
T_{11}	$MM_3TE_{26–28}$	Mustard meal at 3	26–28
T_{12}	$MM_6TE_{26–28}$	Mustard meal at 6	26–28
T_{13}	$TC_{2.5}TE_{26–28}$	Tricho-compost at 2.5	26–28
T_{14}	$TC_5TE_{26–28}$	Tricho-compost at 5	26–28

Elevated Soil Temperature Treatment

The soil temperature was raised by 3°C i.e., 26–28°C from the daily field temperature of 23–25°C in the experimental plots by applying hot water for 5 hours a day on the furrows between the hills of rice plants about 30 days after transplantation of seedlings. The electric kettle was used to make water hot up to 70°C. This practice of hot water application was conducted three consecutive days a week and continued during the whole vegetative stage of the rice plants i.e., from 30 to 70 days of rice growth. The residual effects of these treatments were also evaluated in the same ways as followed for the first trial.

Different Organic Amendments

Three different indigenous organic amendments, viz. rice straw compost (RSC) at the rates of 0, 4, and 8 t ha$^{–1}$, mustard meal (MM) at the rates of 0, 3, and 6 t ha$^{–1}$, and tricho-compost (TC) at the rates of 0, 2.5, and 5 t ha$^{–1}$ were applied to the experimental plots before two weeks of seedling transplantation. The studied field was prepared by the ploughing and cross ploughing methods. The carry-over effects of RSC, MM, and TC were also screened out on succeeding soil during the second trial of the experiment. The composition and nutrient contents of the amendments used are presented in Table 3.

Table 3 Ingredients and nutrient contents of organic amendments used in the experiment

Organic amendments	Rice straw compost	Mustard meal	Tricho-compost
Ingredients	Decomposed straw of rice	By-product of mustard oil seed crop	Mixture of spore suspension of *Trichoderma harzianum* and processed raw materials*
Organic matter (%)	54.00 ± 0.30	51.30 ± 0.25	69.10 ± 0.31
Nitrogen (%)	1.05 ± 0.03	5.20 ± 0.12	2.42 ± 0.07
Phosphorus (%)	0.19 ± 0.01	0.11 ± 0.02	0.25 ± 0.03
Potassium (%)	0.48 ± 0.08	1.79 ± 0.19	1.71 ± 1.15
Sulfur (%)	0.18 ± 0.03	1.06 ± 0.11	0.71 ± 0.08

Note: * Processed raw materials are composed of cow dung, poultry refuse, water hyacinth, vegetable waste, sawdust, maize bran, and molasses

Gas Sampling

Emitted gases from the studied soil were collected by using specially designed plastic containers of 5 L volume (Mahmud *et al.*, 2014; Piash *et al.,* 2018). Each container received a special modification treatment for collecting the emitted gases which received 2.5 kg of air-dried soils and selected dosages of RSC, MM, and TC. These containers were made completely airtight and thus had no leaks in them during air sampling. The upper hole of the container was used for both applications of hot water to control the desired soil temperature. All containers were kept open except during gas sampling. The upper hole of the container was sealed with a rubber stopper that facilitated the one-way entry of a syringe needle for air sampling. A thermometer was inserted into the soil to monitor soil temperature in the container. Air samples from the container were collected through a 100 mL airtight syringe that was adjusted with a 3-way bulb and suitable needles were adjusted into the bulbs by which the gas samples were collected from the container. Gas samplings were carried out at 9 a.m., 12 p.m., and 4 p.m. to get the average of CO_2 and CH_4 emission rates. Emissions of CO_2 and CH_4 were analyzed every 15 days of interval. The CO_2 and CH_4 concentrations in the collected air samples were measured by a portable 800–5 $O_2/CO_2/CH_4$ METER which is manufactured by Columbus Instruments. Air samples collected in 100 mL airtight syringes were then injected into the machine through its tube. The machine gave the results on a percentage basis.

Determination of CO_2 and CH_4 Emission

Since the occupied gas in the container was 2,500 cm^3 and air sampling was performed by 100 mL of airtight syringes, then the volume occupied by CO_2/CH_4 in the container was calculated by using an equation: (%gas × 2,500)/100. According to the gas law: $V_1T_1 = V_2T_2$, where V_1 is the volume of $CO_2/CH_4/CO$ released from 1 ha soil, T_1 is the temperature of the observation day (temperature ranged from 26–35°C), V_2 is the volume of gas at standard temperature and pressure, and T_2 is the standard temperature (293 K). Thus, the equivalent CO_2/CH_4 release from 1 ha soil (in mg m^{-2} h^{-1}) was calculated by an equation as follows: (volume of gas × 2,000,000)/amount of soil.

Data Collection

At the ripening stage, the rice and bottle gourd plants from each subplot were harvested, measured, and thus collected the agronomic data of each crop variety. In the case of soil sampling, both initial and post-harvest soils were collected. Soil samples were collected from each subplot at the active root zone (0–15 cm depth) with the help of a core sampler. Post-harvest soils were collected during the first and second trials of the experiments. Then, the samples were dried, sieved, and prepared for analysis.

Soil and Compost Analyses

Particle size distribution of the soil was determined by Hydrometer method (Piper, 1966), soil pH by glass electrode pH meter (Jackson, 1973), electrical conductivity (EC) by USSL method (USSL, 1954), and cation exchange capacity (CEC) by CH_3COONH_4 extraction method (Jackson, 1973). Organic matter content was determined by the wet oxidation method (Walkley and Black, 1934) and total nitrogen (N) was determined by the Micro-Kjeldahl method (Jackson, 1973). Microbial biomass carbon (MBC) was determined by chloroform fumigation-incubation and fumigation-extraction methods (Jenkinson and Powlson, 1976; Brookes *et al*., 1985; Harris *et al*., 1997). For the determination of available N content, a 10% NaCl extraction method (Jackson, 1973) was used. For available phosphorus (P), Bray No. 1 extraction method (Bray and Kurtz, 1945) was applied. For available sulfur (S), the $BaCl_2$ turbidity method (Page *et al.,* 1982) was used. The sample of the selected organic amendments was digested using nitric acid-perchloric acid (2:1) extract as described by Jackson (1973). The total P content of the organic amendments was determined by the colorimetric method (Jackson, 1973). Other nutrients of rice straw compost, mustard meal, and tricho-compost were analyzed by the following methods that were discussed earlier.

Statistical Analyses of Data

Statistical analyses of the data were performed through using computer-based statistical programs Minitab–19 and IBM® SPSS® Statistics 20. Significant effects of treatments were determined by analysis of variance (ANOVA). Tukey's range test was used for mean comparisons of the treatments at a 5% level of significance. Descriptive statistics (mean and standard deviation) were used to analyze the related parameters such as rice production, bottle gourd production, and soil organic carbon contents. In addition, the correlation coefficient of MBC with crop yields, soil properties, and gas concentrations was calculated, and the significance level of the correlation coefficient estimates was determined by IBM® SPSS® Statistics 20.

RESULTS AND DISCUSSION

Yield of Rice and Bottle Gourd Crops

Grain yield increased maximum with the medium rates of RSC, MM, and TC in combination with soil temperature rise of 26–28°C from the field temperature of 23–25°C. The maximum grain yield was recorded as 6.97 t ha^{-1} for BR 3 by $TC_{2.5}TE_{26–28}$ (T_{13}) treatment, 8.86 t ha^{-1} for BRRI dhan 29 by $RSC_4TE_{26–28}$ (T_9) treatment, 8.25 t ha^{-1} for BRRI dhan 74 by $MM_3TE_{26–28}$ (T_{11}) treatment and the minimum yield (3.42 t ha^{-1}) was noted in BRRI dhan 74 by T_8 treatment, where soil temperature was raised to 26–28°C without the application of any selected organic amendments (Table 4). Grain yield of rice was found to be increased most by the RSC at 4 t ha^{-1} followed by MM at 3 t ha^{-1} and TC at 2.5 t ha^{-1} along with elevated soil temperature of 3°C rather than their highest rates viz. 8, 6, and 5 t ha^{-1}, respectively. The effects of the treatments could be arranged in the order of: $T_2 > T_6 > T_{10} > T_4 \geq T_{14} > T_5 > T_{12} > T_7 > T_3$ treatments, regardless of rice varieties. The 7.6% of the total variation in rice production during the first trial of the experiment could be elucidated by MBC content (Figure 2A). Almost similar observations have been made by Goyal *et al.* (1992), Natsheh and Mousa (2014), Akter *et al.* (2017), and Bilkis *et al.* (2018). At elevated temperature, the grain yield was found to be increased. This might be due to an improved rate of photosynthesis and more translocation of assimilates towards grain (Anjali and Dhananjaya, 2019).

The practice of field temperature contributed a greater number of fruits (8/plants) by TC at 2.5 t ha^{-1} (T_6). The elevated soil temperature of 26–28°C exerted the most pronounced effect on the number of fruits recorded as 10 fruits/plant along with TC at 2.5 t ha^{-1} (T_{13}) and the magnitude of the effects was also amplified in case of the following treatments (Table 4). The number of fruits was counted and found least in T_8 treatment, where the elevated temperature of 26–28°C was practiced without the application of any selected organic amendments. The 61.2% of the total variation in bottle gourd production during the second trial of the experiment could be caused by MBC content (Figure 2B). The findings of the present study exert strong synergies with the results of Ibrahim and El-Kader (2015). They found the highest yield of bottle gourd by applying tricho-compost in the field. Tricho-compost contributed the highest yield of bottle gourd because of its high nutrient contents and the flourishment of *Trichoderma* spp. even under stressful conditions.

Table 4 Influences of elevated soil temperature and different rates of organic amendments on the yield of BR 3, BRRI dhan 29, BRRI dhan 74, and subsequent BARI Lau–1 crops as well as soil organic carbon content in post-harvest soils

Treatment	Rice production			Bottle gourd production	Soil organic carbon content (%)				
	BR 3 (t ha^{-1})	BRRI dhan 29 (t ha^{-1})	BRRI dhan 74 (t ha^{-1})	BARI Lau–1 (fruits/plant)	May 2018^{A}	IOC	Jan 2019^{B}	IOC	Changes in 2019^{C}
T_1	4.81 ± 0.11^{h}	4.40 ± 0.10^{j}	3.52 ± 0.02^{k}	2.0 ± 0.5^{c}	0.43 ± 0.02^{h}	0	0.62 ± 0.03^{h}	0	44.2
T_2	6.69 ± 0.09^{c}	8.71 ± 0.06^{b}	7.04 ± 0.10^{c}	6.0 ± 1.0^{abc}	0.86 ± 0.27^{def}	100.0	1.02 ± 0.09^{f}	64.5	18.6
T_3	4.35 ± 0.15^{j}	5.85 ± 0.05^{de}	7.90 ± 0.12^{b}	4.0 ± 1.5^{bc}	0.94 ± 0.16^{ab}	118.6	1.32 ± 0.11^{c}	112.9	40.4
T_4	6.49 ± 0.07^{d}	5.89 ± 0.09^{d}	5.70 ± 0.07^{i}	5.0 ± 1.0^{abc}	0.92 ± 0.13^{bc}	114.0	1.42 ± 0.19^{b}	129.0	54.4
T_5	6.09 ± 0.10^{f}	4.78 ± 0.12^{i}	5.30 ± 0.03^{j}	3.0 ± 0.5^{bc}	0.86 ± 0.07^{def}	100.0	0.93 ± 0.05^{g}	50.0	8.1
T_6	6.06 ± 0.05^{f}	5.44 ± 0.21^{f}	6.93 ± 0.03^{d}	8.0 ± 1.0^{ab}	0.82 ± 0.15^{f}	90.7	1.22 ± 0.01^{d}	96.8	48.8
T_7	5.64 ± 0.14^{g}	5.04 ± 0.04^{h}	6.03 ± 0.08^{h}	4.0 ± 1.5^{bc}	0.88 ± 0.14^{cde}	104.7	0.95 ± 0.04^{g}	53.2	8.0
T_8	4.17 ± 0.04^{k}	4.30 ± 0.02^{k}	3.42 ± 0.01^{l}	2.0 ± 0.5^{c}	0.51 ± 0.01^{g}	18.6	0.63 ± 0.02^{h}	1.6	23.5
T_9	6.84 ± 0.08^{b}	8.86 ± 0.01^{a}	7.07 ± 0.11^{c}	7.0 ± 1.0^{abc}	0.88 ± 0.14^{cde}	104.7	1.22 ± 0.01^{d}	96.8	38.6
T_{10}	4.71 ± 0.21^{i}	5.17 ± 0.07^{g}	6.67 ± 0.09^{e}	5.0 ± 1.4^{abc}	0.98 ± 0.16^{a}	127.9	1.53 ± 0.05^{a}	146.8	56.1
T_{11}	6.19 ± 0.09^{e}	6.42 ± 0.02^{c}	8.25 ± 0.01^{a}	8.0 ± 0.7^{ab}	0.96 ± 0.16^{ab}	123.3	1.41 ± 0.02^{b}	127.4	46.9
T_{12}	4.80 ± 0.04^{h}	5.21 ± 0.09^{g}	6.42 ± 0.21^{g}	6.0 ± 1.1^{abc}	0.88 ± 0.11^{cde}	104.7	1.32 ± 0.10^{c}	112.9	50.0
T_{13}	6.97 ± 0.05^{a}	5.80 ± 0.14^{e}	6.90 ± 0.19^{d}	10.0 ± 0.8^{a}	0.84 ± 0.08^{ef}	95.4	1.22 ± 0.11^{d}	96.8	45.2
T_{14}	4.17 ± 0.27^{k}	4.80 ± 0.29^{i}	6.60 ± 0.09^{f}	7.0 ± 1.7^{abc}	0.91 ± 0.10^{bcd}	111.6	1.12 ± 0.08^{e}	80.7	23.1
LSD at 5%	0.034	0.058	0.030	0.303	0.019		0.013		

Note: ^{A} Soil after harvesting rice, ^{B} soil after harvesting bottle gourd, ^{C} changes of soil organic carbon content in 2019 were calculated by using an equation: %C = [(B – A)/A] × 100. IOC = increase over control.

In a column, the means with a dissimilar letter(s) are significantly different at 5% level by Tukey's range test.The least significance difference (LSD) value at 5% level of probability indicated that the grain yield of crop varieties and soil organic carbon contents in both trials were distinct at that or lesser levels of probability.

Changes in Microbial Biomass Carbon

The MBC contents of the studied soils showed a significant variation during different stages of rice transplantation. The amounts of MBC in the studied soils were maximum at 60 days after transplantation (DAT) of rice, compared to other growth stages of rice during the first trial of the experiment (Figure 1A). The maximum MBC content was recorded for T_{13} ($TC_{2.5}TE_{26–28}$) over T_8 treatment, where 3°C of soil temperature was increased without the application of organic amendments. In the second trial of the experiment, the MBC was found to be highest in 90 DAT, followed by 60 DAT and 30 DAT (Figure 1B). The T_9 treatment ($RSC_4TE_{26–28}$) endorsed the maximum content of MBC among all other treatments and the least MBC was recorded in T_8 treatment ($TE_{26–28}$ + no organic amendments) which indicated that the application of different amendments played a variable but significant role in the order of increment of MBC in the soils. Figures 1A and 1B show that MBC content was not only affected by the temperature but also increased with the highest degree of temperature. During the first trial, MBC was found to be increased most at 60 DAT. It might be due to the hot water application at 30 DAT. Hot water alone could kill the fungal communities in soil. But the addition of tricho-compost tended to increase the abundance of *Trichoderma* spp. which markedly increased MBC contents in the second trial of the experiment. The present study is partially agreed with the finding of Joshi *et al.* (2017).

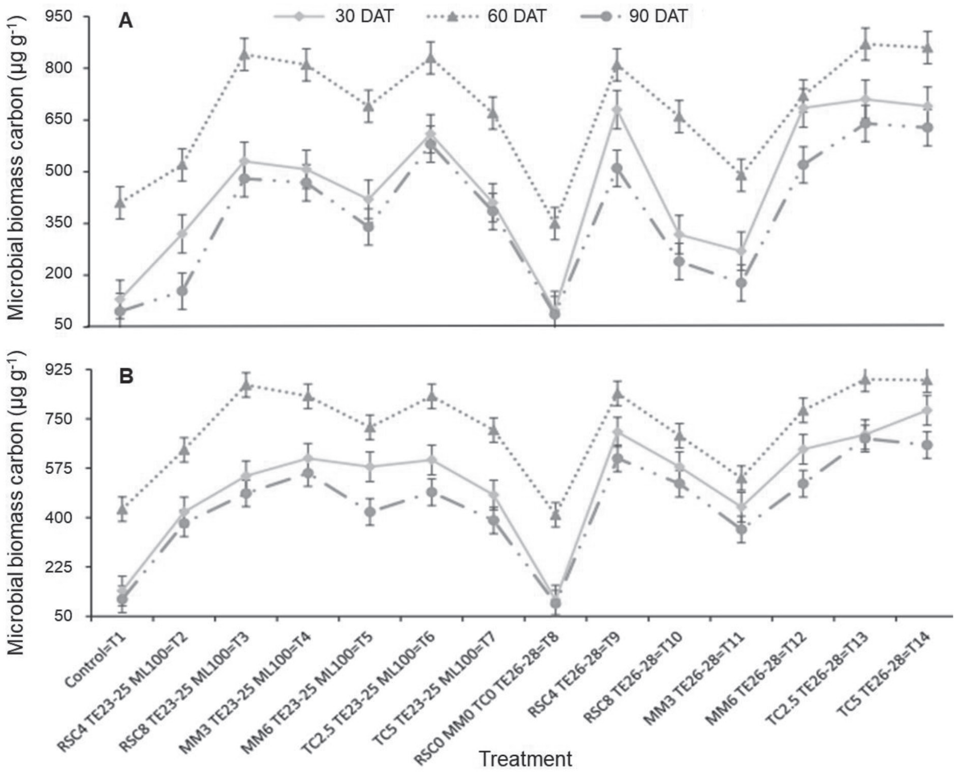

Figure 1 Changes in microbial biomass carbon content at different growth stages of rice plants as affected by elevated soil temperature and selected organic amendments in (A) the first and (B) second trials of the experiment. DAT = days after transplantation

Variations in Soil Organic Carbon Content

The low content of the major nutrients and organic carbon (OC) in the studied soil indicated in need for soil amendments (Table 1). Accordingly, the soil was amended with organic materials including rice straw compost, mustard meal, and tricho-compost to improve its initial low content of OC in response to elevated soil temperature (26–28°C from 23–25°C). Among those amendments, RSC at 8 t ha^{-1} (T_3) contributed greater content of OC (0.94%) of soil (May 2018) followed by MM at 3 t ha^{-1} (T_4) and TC at 5 t ha^{-1} (T_7) under field temperature (Table 4). The effect of elevated temperature along with RSC at 8 t ha^{-1} (T_{10}) was found most striking on soil OC content (0.98%) among all the treatments. The OC was increased most (127.9%) over control in $RSC_8TE_{26–28}$ (T_{10}) treatment in the first trial. The 28.56% of the total variation in the OC content of soil could be explained by MBC content in preceding soil (Figure 2C).

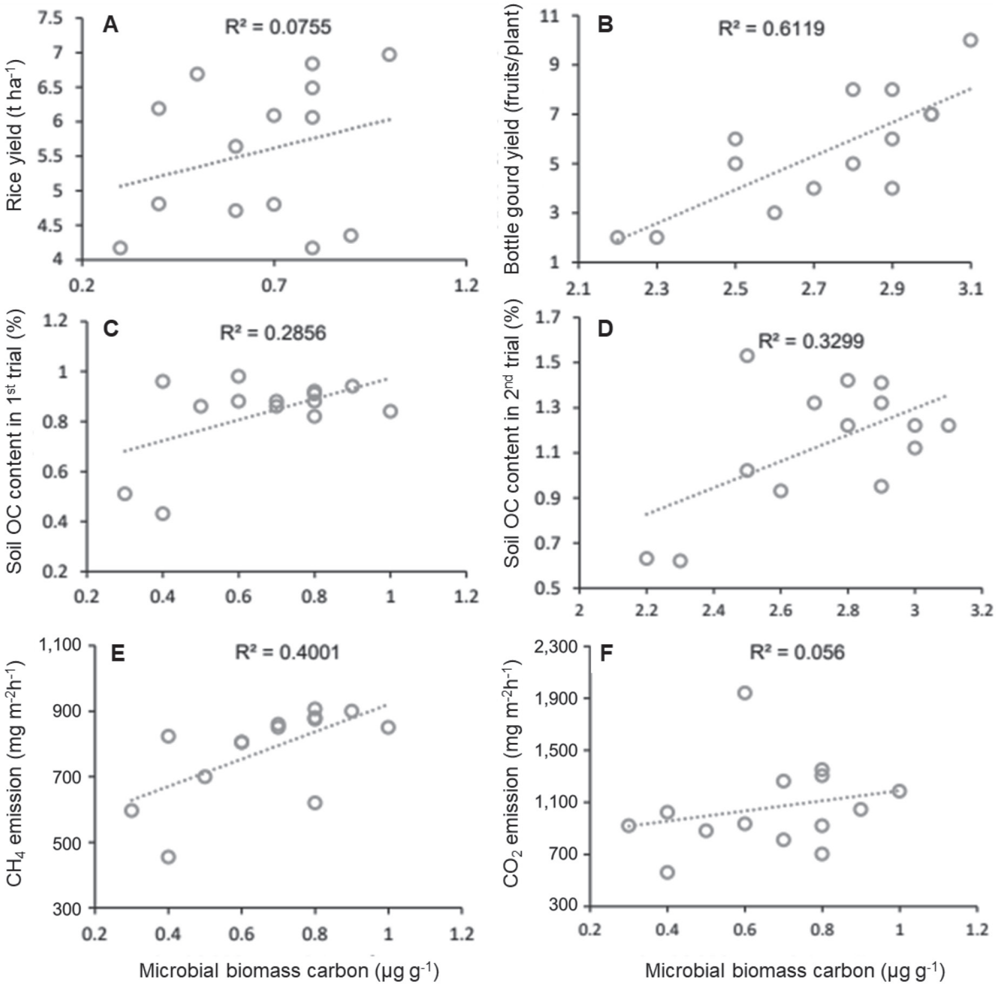

Figure 2 Contribution of microbial biomass carbon to (A) rice production, (B) bottle gourd production, (C) soil organic carbon (OC) content in the first trial, (D) soil OC content in the second trial, (E) CH_4 emission, and (F) CO_2 emission. The correlation coefficient (R^2) values indicated the changes in one variable by the value of another variable

The carry-over effects of the treatments on the OC content in soil (January 2019) were also assessed and found highest (1.53%) by $RSC_8TE_{26–28}$ (T_{10}) treatment. In the second trial, OC content was increased most (146.8%) over control in T_{10} treatment which proved the greatest sustainability of RSC as compared to MM and TC (Table 4). Soil OC content was increased with the application of the increased rates of organic amendments and soil temperature rise. Carbon from the atmosphere can be transferred to the soil through carbon-fixing autotrophic organisms. The productivity of these autotrophic organisms might be flourished by soil temperature rise which significantly synthesized atmospheric carbon dioxide into organic material. Almost similar aptitudes have also been reported by Mahmoud *et al.* (2009), Ibrahim and El-Kader (2015), and Akter *et al.* (2017). The temperature rise accelerated the rate of organic matter decomposition and the mineralization of different organic materials which were applied in the field. This temperature elevation may support high plant productivity and organic matter input to soil and consequently increase soil OC content (Anjali and Dhananjaya, 2019). The 32.99% of the total variation in the OC content of soil could be interpreted by MBC content in succeeding soil (Figure 2D).

Effects on Methane Emission

Methane (CH_4) emission from the studied soil was significantly influenced by the practice of field temperature (23–25°C), accompanied by the increased dosages of RSC, MM, and TC, especially at 30th day after experiment installation showing a range of 300 to 1,200 mg m^{-2} h^{-1}. The applied RSC at 8 t ha^{-1} under field condition (T_3) exerted a peak of CH_4 emission (1,200 mg m^{-2} h^{-1}) followed by TC at 5 t ha^{-1} (T_7) and MM at 6 t ha^{-1} (T_5) treatments at 30th day (Figure 3A). The soil temperature elevation of 3°C had a less pronounced effect on CH_4 emission as detected 990 mg m^{-2} h^{-1} by TC at 5 t ha^{-1} (T_{14}) and the magnitude of CH_4 emission was also lessened for the rest of the treatments. The CH_4 emission was statistically identical with all the treatments except for the T_8 treatment, where soil temperature was raised to 26–28°C from the daily field temperature of 23–25°C without the application of the selected organic amendments. The CH_4 emission rates dropped to atmospheric levels at the final sampling date of the 90th day. This might be due to the increment of organic matter decomposition by a maximum number of microorganisms between the 15th and 30th days. Increased rates of RSC, MM, and TC application led to higher CH_4 emission under field temperature of 23–25°C. The 40.01% of the total variation in CH_4 concentration could be explained by MBC content (Figure 2E). On account of this variation, microbial biomass and its metabolites could be a substrate for CH_4 production.

Effects on Carbon Dioxide Emission

Carbon dioxide (CO_2) emission from the studied soil was comparatively small in the quantities at an initial stage and increased significantly ($P \leq 0.05$) with the advent of time. The application of increased dosages of RSC, MM, and TC had the most striking effects on CO_2 emission under elevated soil temperature (26–28°C). The field temperature (23–25°C) had greater effects on CO_2 emission with RSC at 8 t ha^{-1} (T_3) measured as 1,104 mg m^{-2} h^{-1} succeeded by TC at 5 t ha^{-1} (T_7) and MM at 6 t ha^{-1} (T_5) at 60th day (Figure 3B). In addition, the CO_2 emission was noted in its peak (1,800 mg m^{-2} h^{-1}) by $RSC_8TE_{26–28}$ (T_{10}) treatment at both the 30th and 60th days, and the magnitude of CO_2 emission was also augmented in case of the rest of the amendments. The CO_2 emission was statistically identical with all the treatments except for the control (T_1). The CO_2 emission was found to be least (320 mg m^{-2} h^{-1}) in control, where field conditions were practiced without the application of any selected organic amendments. The CO_2 emission rates were observed maximum in 60th day succeeded by 90th, 30th, and 15th days. The 5.6% of the total variation in CO_2 emission could be explained by MBC content (Figure 2F). The soil MBC content and CO_2 emission were increased by the combined effects of the application of organic amendments and soil temperature rise of 3°C. These results are quite analogous to the CO_2 flux reported by Chang *et al.* (2008) and Liu *et al.* (2010) with a strong relationship between CO_2 flux and soil temperature.

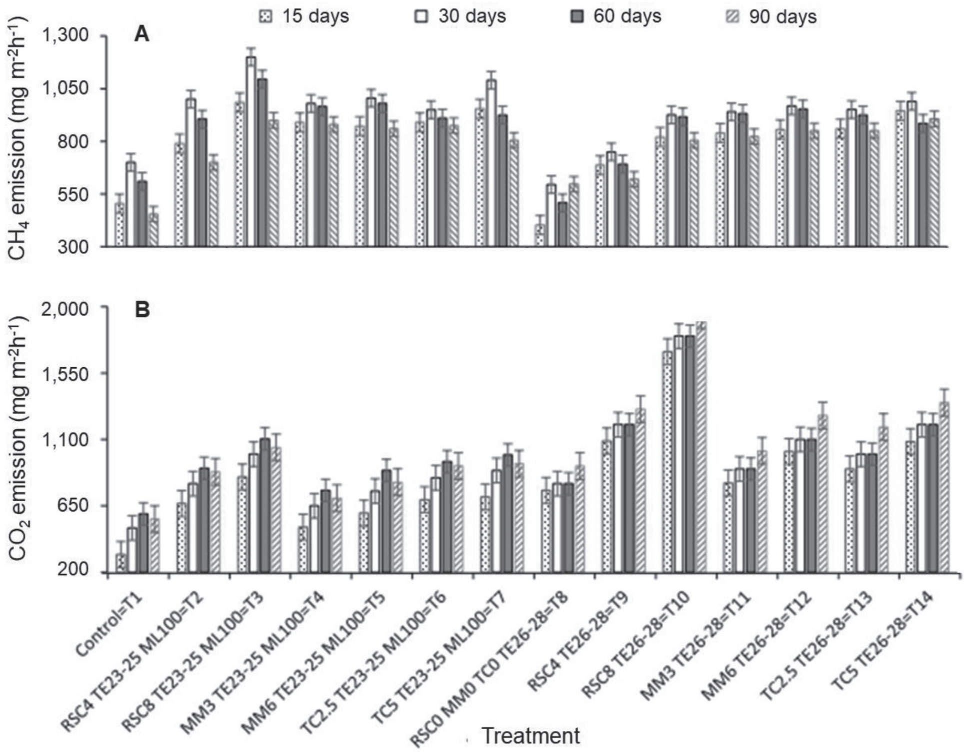

Figure 3 Changes in (A) CH_4 and (B) CO_2 emissions as affected by elevated soil temperature and the selected rates of organic amendments compared to field conditions

CONCLUSIONS

It is concluded from the present study that the integrated effects of soil temperature rise and selected rates of organic amendments were found to be effective in increasing the soil microbial biomass in a reasonable quantity, and thereby enhanced rice and bottle gourd production. The effects of tricho-compost were most prominent in the analyzed soil properties and crop production as compared to rice straw compost and mustard meal by considering the carry-over effects of the applied organic amendments. Mustard meal application led to lesser CH_4 emission under elevated soil temperature, but this temperature rise caused higher CO_2 emission. Moreover, the practice of tricho-compost and mustard meal in the field can be an effective countermeasure to alleviate the drastic effects of climate change on food security by augmenting crop production, increasing microbial biomass, and lessening methane emission.

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