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Selected Indicators of Soil health in Dhaka district at the Golden Jubilee of Bangladesh and Approaches for Their Sustainable Improvement towards Rice Production

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Abstract
Soil fertility and rice production are essential to pay attention for sustainable food security, climate-smart agriculture and soil health. Accordingly, assessments of selected soil health indicators, such as, pH, organic matter and cation exchange capacity (CEC) in all Upazilas of Dhaka district of Bangladesh were completed. Based on the results, a few approaches were used for the improvement in response to rice production at the field using locally available organic materials, viz. Rice straw compost (RSC), Mustard meal (MM) and Tricho-compost (TC) each at the rates of 0, 3 and 6 t ha^{-1} under the increased soil temperature of 2 to 4°C. The stated parameters of soil health in Dhaka district at the Golden Jubilee of Bangladesh were found to be improved a little till 2020s compared to those of the 1970s and 2000. These improvements were found to boost up by the treatments. The yields of different varieties of rice were increased from 4.3 to 7.6 for BRRI Dhan 28; 3.7 to 7.7 for BRRI Dhan 74 and 4.5 to 8.8 t ha^{-1} for BR 3 by the treatments and the order of their effectiveness for grain yields is RSC > MM > TC; for protein contents is TC > MM > RSC and for gas fluxes is RSC > TC > MM. Organic matter contents, pH and CEC of the studied soils were significantly ($p \geq 0.05$) improved by these treatments. Therefore, the studied approaches should be put in place regarding sustainability of soil health and food security.
Key words: *Golden jubilee of Bangladesh, increased soil temperature, locally available organic materials, rice production, soil health.*

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I. Introduction

Soil fertility and rice production were the most frequently mentioned issues identified not only in all the countries of Asia but also in the rest of the world. Hence, it is essential to pay attention for sustainable rice production, climate-smart agriculture and soil health. Healthy soil is the basis of successful crop production and that can be achieved through successful soil enactment, i.e., by managing key performance indicators (KPIs) of soil health. The KPIs of soil health or soil quality mainly include: organic matter, pH, CEC, macro-micro nutrients, salinity-sodicity, soil texture, structure, bulk density, water holding capacity, porosity, heavy metal contents, soil respiration, microbial biomass, earthworms, etc. Based on soil performance indicators, a farmer has a clear insight into soil's health and actions required to ensure it remains in good shape. It can be said that having only one of the aforementioned soils KPIs outside their optimum, leads to lower plant quality and yield. On the other hand, the Earth's climate is changing rapidly and predicting the consequences of climate change on soil health, agriculture and food security are not only critically important but also very difficult to determine.

Rice is a major food crop widely grown around the world, with a total harvested area of approximately 160 million hectares, producing more than 700 million tons annually (FAO, 2020). The FAO (2018) Rice Market Monitor reported that 681 million tons of rice were grown in Asia, representing 90% of the global rice production. To keep pace with the increasing global population, rice production needs to increase approximately 40% by the end of 2030 (OECD-FAO, 2018). Bangladesh has been struggling in achieving food security over the past 40 years, food grain production has been increased almost 4 times, i.e., from 9.774 to 35.731 million tons between 1972 and 2014 (MCCI, 2014). However, country's Food Security Index and Global Hunger Index scores remain among the lowest in South Asia (Osmani et al., 2016). In Bangladesh, with advancement of time, nutrient mining increases due to increasing cropping intensity (191%; BBS, 2017), use of modern varieties, nutrient leaching, gaseous loss, soil erosion and imbalanced application of fertilizers with no or little addition of organic manure. Higher is the crop yield, higher is the nutrient removal from soil. About 45% of net cultivable areas of Bangladesh contain less than 1% OM (FRG, 2012). Organic matter is a good source of nutrients and known as the store house of nutrients. Organic manure is a good means of soil rejuvenation (Jeptoo et al., 2013). So, use of organic matter could be an inevitable practice in the coming years for ensuring sustainable crop productivity without affecting soil fertility (Heikamp et al., 2011). Soil pH plays a vital role in the availability of plant nutrients. It is the key factor for good soil performance. Straw incorporation is a common management practice to improve soil fertility and boost up crop yields (Liu et al., 2014; Huang et al., 2013). However, straw additions to rice paddies increase emissions of the potential greenhouse gas methane (Jiang et al., 2019; Conrad, 2007). The modification in agricultural management practices (such as soil tillage), the soil organic matter is exposed to more oxidizing conditions, releasing CO_2 into the environment, contributing to global warming (Min & Rulik, 2020).

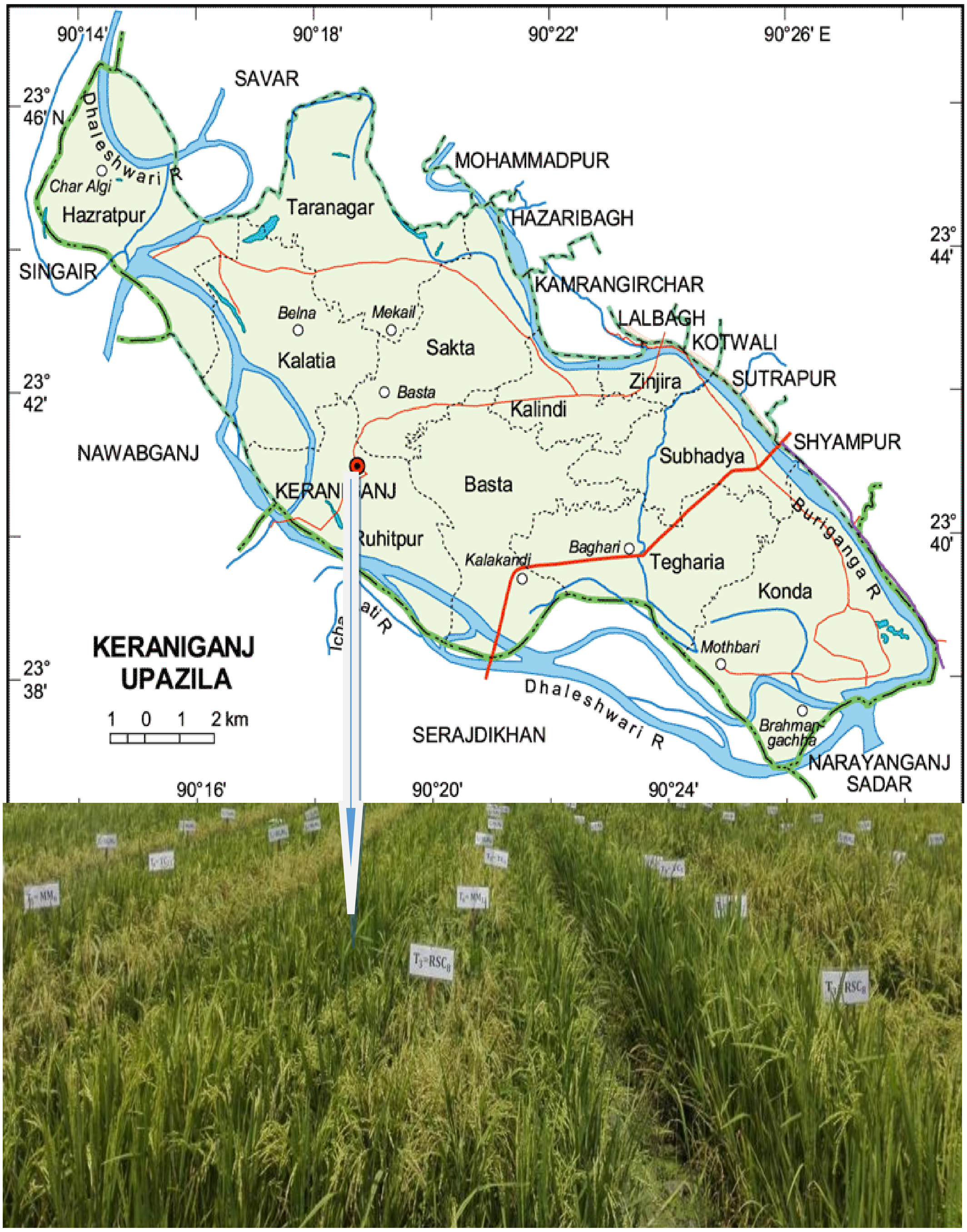
Global warming and increased emissions of anthropogenic greenhouse gases (GHGs) has become an international issue of great concern. Carbon dioxide is considered to be the major contributor to anthropogenic GHGs, accounting for 76% of total emissions in 2010 (IPCC, 2014). The current CO_2 concentration of 379 ppm is expected to rise between 485 and 1000 ppm by 2100 (Cheng et al., 2008). Moreover, the earth has experienced its fourth consecutive hottest year in 2019 (IPCC, 2019), which will face warming of 2°C between 2030 and 2050 (IPCC, 2018) and will have dominate effects on surface soil temperature of 0.57°C/decade (Fang et al., 2019). 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). Many measures have been taken to improve soil fertility and productivity. The most effective measure is increasing the organic input, such as with the application of organic manure or compost (Xin et al., 2017) and straw incorporation (Zhang et al., 2016). Crop straw, an easy-to-get, nutrient-rich resource, has great value for improving soil fertility can be treated as a natural organic fertilizer and used as an alternative to chemical fertilizers (Wang et al., 2017). Straw incorporation has significant beneficial effects on crop yields, soil properties, soil organic matter and soil nutrients (Zhang et al., 2018). However, up to now, the use of straw incorporation in different climates and soil types have led to inconclusive results (Pituello et al., 2016).

Considering the above facts, the present study was performed to - identify vulnerable zones and/or soil health most prone to climate change at the era of Golden Jubilee of Bangladesh; finding out the strategies for climate-smart rice production and adaptation regarding food security; finding out the ways of reducing emissions of methane and carbon dioxide gases from rice field; and dissemination of information.

II. Materials and Methods

The study was conducted by the financial support of climate change trust fund (CCTF) project entitled 'Assessment of Impacts of Climate Change on Soil Health and Food Security, and Adaptation of Climate-smart Agriculture in Most Adversely Affected Areas of Bangladesh'. The project was implemented in two phases (Phase I: Jan.'17 to Dec.'18, ID 410 DU and Phase II: Jan.'19 to Dec.'20, ID 573 DU) within four years. During this period soil samples were collected from all Upazilas of Dhaka district and then preserved and analyzed in the laboratories of the Department of Soil, Water and Environment, University of Dhaka, Dhaka 1000, Bangladesh. This work has been done to provide the information about the comparison of soil health with the 1970s, 2000 and 2020s. Secondary data were reviewed (mainly Reconnaissance soil survey data of SRDI 1970s and existing literature on 2000) in order to compare the data obtained from soil survey and experiments under the present study.

2.1 Set up of experiments: On the basis of the analyses regarding soil health, field experiment was conducted at Chandipur in Keraniganj (23°40´N, 90°18´E) of Dhaka district in Bangladesh (Photograph1) during February to June, 2018 using T. Boro rice varieties of BRRI dhan 28, BRRI dhan 74 and BR 3 as test crops in order to improve the soil health regarding food security. Locally available smart indigenous soil organic materials, such as, rice straw compost (RSC), mustard meal (MM) and tricho-compost (TC) and elevated soil temperatures were considered for this study. Selected properties of the soil at field site and the composition of potential amendments used are presented in the Tables1&2, respectively, and the visual symptoms are in photographs 2-4. The experiment was conducted following completely randomized block design having the doses of 0, 3 and 6 t ha^{-1} of each bio-fertilizers, 2 levels of soil temperatures, which were maintained for about a month during late tillering to panicle initiation stages of rice by the rise of 2 to 4°C (St 2°C and St 4°C: Photographs 5-6), i.e., 25-26°C and 27-28°C from the daily field temperatures of 23-24°C in the experimental plots. Three replications were considered for this experiment. Basal doses of N, P_2O_5 and K_2O applied at the rates of 40, 30, 15 kg ha^{-1} from Urea, TSP and MoP fertilizers, respectively. The bio-fertilizers, whole TSP, MoP and half of the Urea were applied during soil preparation by thorough mixing of the fertilizers with the soil. The remaining Urea was top dressed in two splits, one at active tillering and another at panicle initiation stage of rice. Rice seedlings were collected from the local farmers and were transplanted at the rate of 3 seedlings per hill. The hill to hill and row to row distances were 20 cm. Irrigation and intercultural operations were performed when required.



Photograph 1 Location of the study site

2.2 Soil, Plant and Compost analyses: Selected properties of the soil used were determined. The bulk soil samples were air-dried and crushed to 1 and 2 mm before analysis. Particle size distribution of the soil was determined by Hydrometer method (Piper, 1966). Soil pH was measured by the soil-water ratio of 1:2.5 (Jackson, 1973). Organic matter content was determined by wet combustion with $K_2Cr_2O_7$ (Nelson & Sommers, 1982). Cation exchange capacity was determined by saturation with 1 M CH_3COONH_4 (pH 7.0), ethanol washing, NH_4^+ displacement with acidified 10 % NaCl, and subsequent analysis by steam (Kjeldhal method) distillation (Chapman, 1965). The sample of the selected organic amendments was digested by means of nitric acid - perchloric acid (2:1) extract as described by Jackson (1973). Total P content of the organic amendments was determined by colorimetric method (Jackson, 1973). Other nutrients were analyzed by following the methods as stated above. Growth parameters and yield attributes of plant samples were recorded as per requirement and after harvesting the crop at maturity.

2.3 Gas sampling and analysis: Emissions of the CO_2 and CH_4 gases from the surface of studied soil were measured following chamber method (Hutchinson & Misier, 1981). Five replications were considered and the emissions of the gases were allowed for 2 hours within the chamber and then through an airtight 100 mL syringe adjusted with 3-way bulb and suitable needles were attached with the bulbs through which the gas samples were collected from the chamber.

Table 1 Selected properties of the soil (1-15 cm; oven dry basis) used from the experimental site at Keraniganj in Dhaka district of Bangladesh.

Properties	Values
Soil series	Tejgaon
General soil type	Non-calcareous dark grey floodplain soils
Particle density (g cm^{-3})	2.49
Bulk density (g cm^{-3})	1.25
Moisture content (%)	2.39
Porosity (%)	48.32
Textural class	Clay loam
Soil reaction (pH)	6.1
Electrical conductivity (µS cm^{-1})	63.4
Organic matter (%)	1.1
C/N ratio	9.4
Cation exchange capacity (c mol kg^{-1})	43.0
Total Nitrogen (g kg^{-1})	0.68
Available Nitrogen (m mol kg^{-1})	1.58
Available Phosphorus (m mol kg^{-1})	0.33
Available Sulfur (m mol kg^{-1})	0.43
Exchangeable K^+ (c mol kg^{-1})	4.9
Exchangeable Ca^{2+} (c mol kg^{-1})	21.8
Exchangeable Mg^{2+} (c mol kg^{-1})	7.6

Table 2 Ingredients and nutrient contents of organic amendments used in the experiments.

Organic Amendments	**Rice straw compost (RSC)**	**Mustard meal (MM)**	**Tricho-compost (TC)**
Ingredients	Decomposed straw of rice	By-product of mustard oil seed crop	Spore suspension of a *Tricho-derma harzianum* + processed raw materials
OM (%)	48.0	44.2	64.5
N (%)	0.96	4.9	2.32
P (%)	0.16	0.13	0.23
K (%)	0.43	1.90	1.81
S (%)	0.19	0.87	0.68

Rice Straw Compost **Mustard Meal** **Tricho-compost**

Photographs 2-4 Visual symptoms of the used amendments

Photographs 5-6 Instrument and approaches for the elevation of soil temperature by 2 and 4˚C during field study

Gases were sampled at 9 am, 12 noon and 15 pm to get average of emissions of CO_2 and CH_4. The CO_2 and CH_4 concentrations in the collected gas samples were measured by a portable 800-5 $O_2/CO_2/CH_4$ METER which is manufactured by the Columbus Instruments. Gas samples collected in 100 mL airtight syringes were injected to the machine through its tube and obtained the results on a percentage basis and finally calculated as m^2/h. Emissions of CO_2 and CH_4 were analyzed at 30 and 90 days after transplantation (DAT) of rice. The analysis of variance of the data and the test of significance of the different treatment means were evaluated by Tukey's Range Test at 5% ($p \geq 0.05$) level.

III. Results and Discussion

3.1 Selected indicators of soil health at the Golden Jubilee of Bangladesh

Soil is the essential resource for crop production. To achieve effective and justifiable food production, the soil needs to be healthy and which can be achieved through efficacious soil enactment mainly management of soil nutrients, soil pH, organic matter, soil moisture, etc.

3.1.1 Soil pH at the Golden Jubilee of Bangladesh: It is established that soil pH plays a dynamic role in the availability of plant nutrients. It is the crucial factor for good soil performance. So, regardless the amount of applied fertilizers, if soil pH is not optimum for a certain plant, the yield will fail. Soil health or soil quality is a concept that has increased in popularity over the past several years, especially since the early 1990s. 'Soil health' is an important focus for many agricultural groups interested in regenerative and sustainable crop and livestock production as well as land management (Idowu et al., 2019). To understand and use soil health as a tool for sustainability, physical, chemical, and biological properties must be employed to verify which respond to the soil use and management within a desired timescale (Cardoso et al., 2013). Among the soil health indicators, representative retorts of soil pH, organic matter and CEC in Dhaka district at the golden jubilee of Bangladesh have been studied and reviewed considering three-time intervals of 2020, 2000 and 1970s and the relevant statistics of these indicators with the value of maximum, minimum, mean and standard deviation is presented in Table 3.

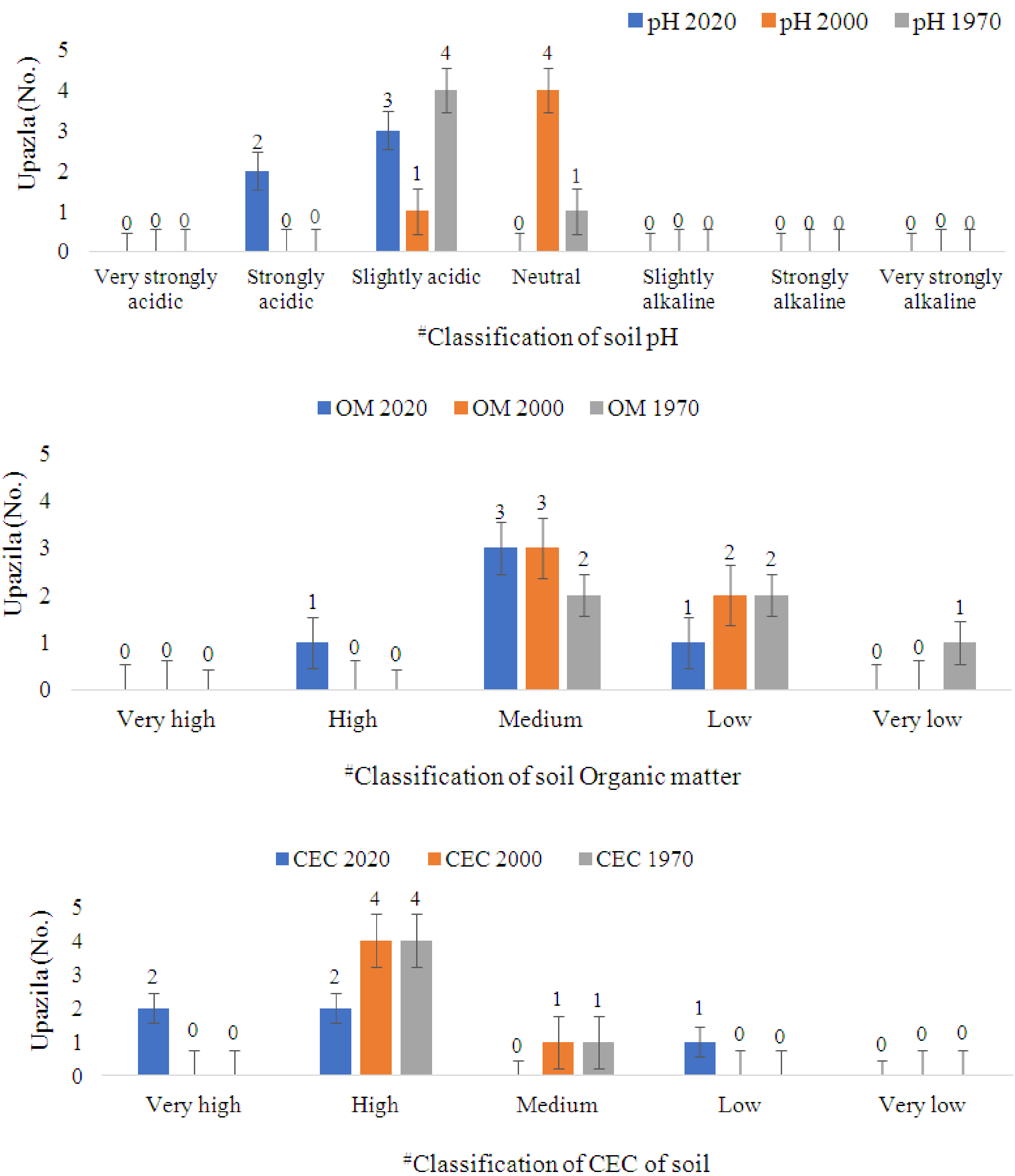
Table 3 Typical responses for the comparison of selected soil health indicators in Dhaka district at the golden jubilee of Bangladesh.

Indicators	Minimum			Maximum			Mean			SD (±)		
	2020	**2000**	**1970s**	**2020**	**2000**	**1970s**	**2020**	**2000**	**1970s**	**2020**	**2000**	**1970s**
pH	5.06	6.50	5.65	6.04	7.00	7.30	5.64	6.70	6.15	0.38	0.19	0.66
Organic Matter (%)	1.61	1.10	0.89	4.49	2.67	2.06	2.92	1.77	1.52	1.08	0.69	0.47
CEC (cmolkg^{-1})	7.00	7.60	10.13	43.46	23.20	24.14	27.48	17.94	17.48	16.31	6.27	5.08

Current status of the studied indicators was compared with their previous status, as represented in the Reconnaissance Soil Survey (SRDI, 1970s), reliable literature and reports (2000s) and Upazila Nirdeshika of SRDI, 1999 and 2000. The comparative studies on soil pH, organic matter and CEC between the year 2020 and the previous years of around 2000 and 1970 are shown in figure 1. Soil pH recorded in different locations of all the upazilas in Dhaka district ranged from 5.06 to 6.04 in 2020, 6.50 to 7.00 in 2000 and 5.65 to 7.30 in 1970s. A brief statistics of the data shown that the maximum value of soil pH in Dhaka district was determined in 1970s followed by 2000 and 2020 among the studied soils, which revealed that soil pH in Dhaka district decreased within the advent of time, while the opposite trend was detected for the minimum values of soil pH during these periods. On the other hand, the highest mean value of soil pH was recorded in 2000 followed by 2020 and 1970s (Tab3). These results are reinforced by the findings of Lal and Mathur (1988), who reported that the excessive application of ammonia-based N fertilizers, as well as application for long periods, can reduce soil pH. On the other hand, the use of organic amendments both alone or in conjunction with inorganic fertilizers can reduce the decline in soil pH and helps to improve soil fertility and crop productivity.

Based on the classification of soil pH (FRG, 2012), the studied soils are clustered into strongly acidic to neutral categories in reaction (Fig1). But there were differences in soil pH categories in Upazila levels at the golden jubilee of Bangladesh. The pH of the soil has an enormous influence on soil biogeochemical processes. Soil pH is, therefore, described as the 'master soil variable' that influences myriads of soil biological, chemical, and physical properties and processes that affect plant growth and biomass yield (Minasny et al., 2016). Most of the nutrients are available at 5.5-7.0 pH (Ghimire et al., 2017). So, pH should be kept between 5.5 and 7.0 by the soil and crop managements.

3.1.2 Contents of soil organic matter (SOM) at the Golden Jubilee of Bangladesh: The SOM contents in typical agricultural soils ranges from 1 to 6% (Ghimire et al., 2020). The SOM modifies soil physical, chemical, and biological properties by affecting water-infiltration and water-holding capacities, compaction, aggregation, nutrient cycling, cation exchange capacity, and microbial activity. The organic matter contents of the studied soils ranged from 1.61 to 4.49 (%) with a mean value of 2.92 (%) in 2020 followed by 1.10 to 2.67 (%) having mean value of 1.77% in 2000. The lowest mean value 1.52% of organic matter in different upazilas of Dhaka district were recorded in 1970s, which were ranged from 0.89 to 2.06 (%). According to the SOM classification of FRG (2012; Fig1) the SOM contents of Dhaka district ranged from very low to high classes with the differences in Upazila levels in subsequent marked years. The high values of SOM contents were determined only in 2020 and the low contents of SOM were in 1970s among the same sample number of Upazilas. It indicates that SOM contents of Dhaka district increased than those of the previous years, which is supported by the BRRI (2007-08) and Pampolino et al. (2008). They demonstrated that in the rice-rice-rice systems, the SOM tends to increase. On the other hand, the use of organic amendments both alone or in conjunction with inorganic fertilizers can help to improve soil fertility and crop productivity *(*Lal & Mathur, 1988). Moreover, recent increase in production not only indicated the production of grain but also the production of straw, which maintaining good grain/straw ratios. Hence, the demand of soil nutrients has been replenishing through the crop residues/straw incorporation into the soils resulting not only the improvement of SOM but also act as safe guard for food security through sustainable food production.



#Classification on the basis of fertilizer recommendation guide (FRG, 2012)

Fig. 1 Changes in soil pH, organic matter and CEC status of the studied site in Dhaka district at the golden jubilee of Bangladesh.

3.1.3 Cation Exchange Capacity (CEC) of soils at the Golden Jubilee of Bangladesh: Cation exchange capacity is one of the most influential indicators of soil health which continues to support both the agricultural production and to keep up the status of soil fertility. The CEC gives an indication of the potential of a soil to hold plant nutrients, by estimating the capacity of the soil to retain cations, which are positively-charged substances. It directly affects the amount and frequency of fertilizer application. The mean values of the CEC in the soils of different Upazilas of Dhaka district were 27.48 for 2020, 17.94 for 2000 and 17.48 cmol kg^{-1} for 1970s (Tab3), indicate that the CEC of the soil have been increasing with the advent of time, which might be due to the beneficial effects of modernization of agriculture. Among the three targeted time intervals, the highest value of CEC was obtained in 2020 in Dhaka district. The present studied CEC status of Dhaka district can be grouped as low to very high categories on the basis of FRG (2012; Fig1). But the CEC status was low to medium in both 2000 and 1970s. The higher CEC values represent the comparatively high chemical activity of a soil, and it was found that the CEC was significantly correlated with active acidity and organic matter contents (Alam et al., 2007).

3.1.4 Correlation matrix among soil pH, Organic matter and CEC status in Dhaka district: The interrelationships among the soil pH, organic matter and CEC within the target years of 2020, 2000 and 1970s were studied and are presented in Tab4 and Fig2. The statistical analysis showed that there was significant positive correlation (r = 0.9258*) between soil organic matter in 2020 versus CEC 1970s in different Upazilas of Dhaka district (Tab4). These findings are quite agreed well with the reports of Ghimire *et al.* (2012), who reported that cropping systems that increase crop residue return to the soil can enrich the SOM which influences CEC and also improve crop productivity. No significant relationship was observed for the soil pH between 2000 and 1970s of the same Upazilas but negative correlations were attained in the soil pH between 2020 and 2000 studies (Fig2). Continuous use of ammonia-based nitrogen fertilizers to enhance crop yields have resulted in soil acidification that lowered soil fertility (Ghimire & Bista, 2016). The subsistence nature of farming and the reliance of the majority of the rural population on agriculture for income and employment opportunities has resulted in tremendous pressure on limited land to produce more crops (Bista et al., 2010), thereby reducing soil health and food security.

3.2 Tiller production: Vegetative growth such as plant height, tiller production and fresh or dry weights of crops are not only significance for planning and policymaking regarding to the management of low, medium, high - lands under changing climates, fodder production and production of bulk materials for energy goods, etc. but also for grain yield of rice. Accordingly, the present study was conducted to evaluate the impacts of soil temperature elevation and indigenous organic amendments on the tiller production of rice grown under field condition, which demonstrated that the application of different bio-fertilizers, their rates and rise of soil temperatures had significant positive influences on most of the treatments regarding tiller production (Fig3). The maximum number of tillers (28/hill) were obtained by the T_7 (TC_6) treatment followed by T_5 (MM_6: 25/hill) under 4°C > T_7 (TC_6: 24/hill) under 2°C for BR 3 rice (Fig3). The order of the tiller production by the applied bio-fertilizers is as TC_6 > MM_6 > RSC_6 > TC_3 > MM_3, regardless of rice varieties and elevation of soil temperature, suggesting that the rate of application of all the fertilizers should be increased for further trials. The maximum increase over control (IOC %) ranged from 23 to 69 for BRRI Dhan 28 followed by 17 to 56 for BR 3 and 7 to 47% for BRRI Dhan 74 under temperature elevation of 4°C. The rise of soil temperatures of 2 to 4°C were found to have significant ($p \geq 0.05$) positive influences on tiller production, except for the BRRI Dhan 74, where the effects were recorded negative under 4°C (Fig3). Holydays (1976) revealed that the tiller is one of the important organs of the vegetative growth of crops. The amount of growth was quantitatively expressed as an increase in length of stem and root or other organs of plants, an increase in the area of leaves, and an increase in dry weight and fresh weight increment of the plant. He also added that the yield of crops may be considered in biological as well as agricultural terms. Biological yield has been as total production of plant material by a crop whereas economical yield or commercial yield takes into account only those plant organs for which particular crops are cultivated and harvested. From these statements, it is clear that the effects of elevated soil temperature and types of applied fertilizers on the productive tillers are justified not only as biological as well as agricultural terms but also as economical yield or commercial yield of rice.

Table 4 Correlation matrix of the studied soil health indicators in Dhaka district at the golden jubilee of Bangladesh

	pH 2020	pH 2000	pH 1970s	OM 2020	OM 2000	OM 1970s	CEC2020	CEC 2000
pH 2000	-0.7550							
pH 1970s	0.5045	0						
OM 2020	0.1545	-0.1832	-0.5548					
OM 2000	0.7823	-0.7291	0.0825	0.6103				
OM 1970s	-0.0009	-0.3955	-0.7513	0.8201	0.5618			
CEC 2020	-0.0234	0.0608	-0.5218	0.5574	-0.0349	0.2465		
CEC 2000	-0.3526	0.2088	-0.8238	0.7997	0.0299	0.6470	0.7906	
CEC 1970s	0.1826	-0.3612	-0.6915	0.9258*	0.5366	0.8283	0.7100	0.8217

*Indicates the coefficient correlation (r) is significant at 5% level.

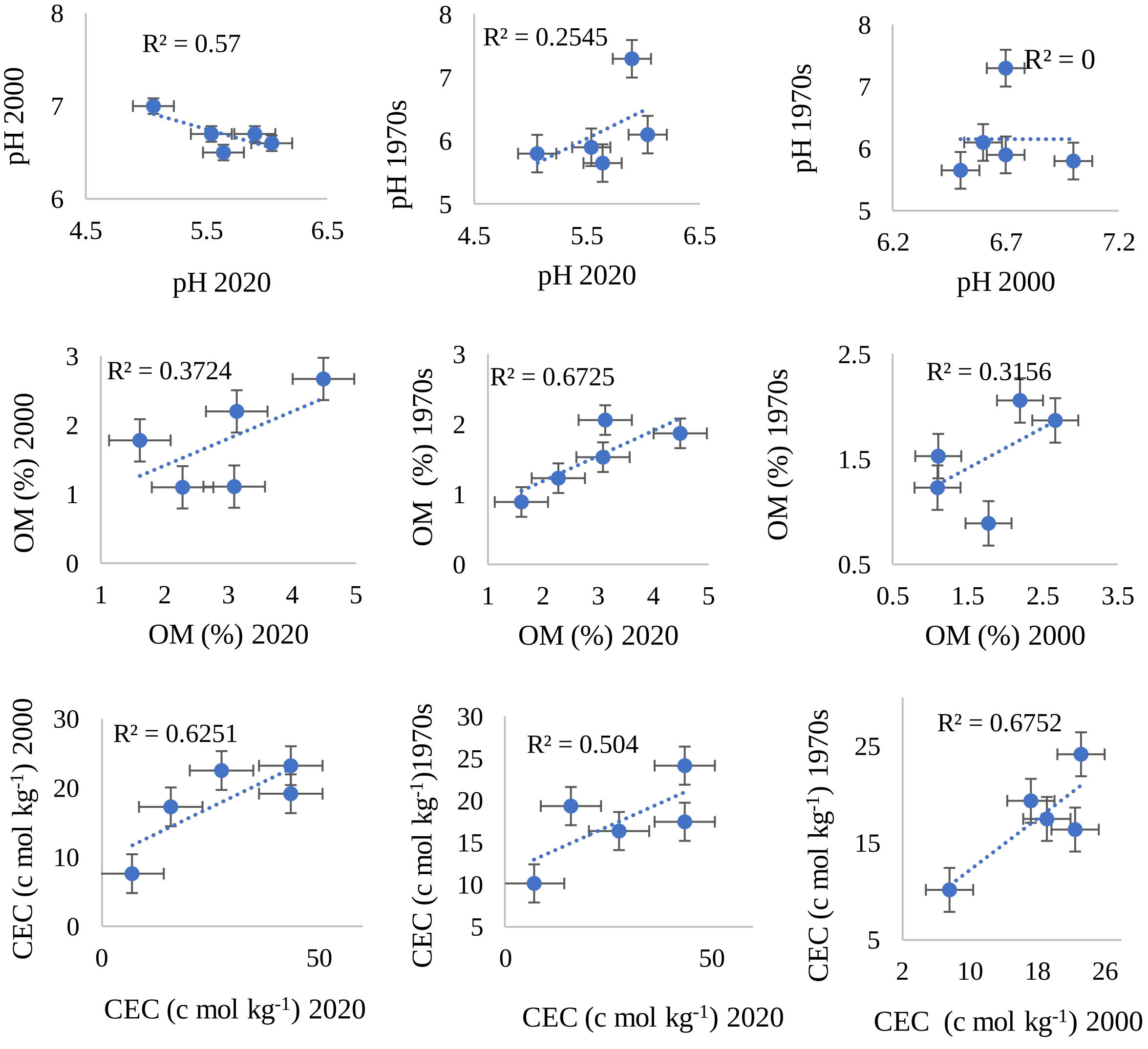


Fig. 2 Relationships among soil pH, organic matter and CEC of the studied site at the golden jubilee of Bangladesh.

3.3 Grain yield of rice: To meet the future demand, rice production need to be increased at least by 40% within 2050 even under hostile climatic conditions. Accordingly, the evaluation on the impacts of soil temperature elevation and indigenous organic amendments on different varieties of rice production under field condition was made. The results revealed that the levels of elevated soil temperature (St 2°C and St 4°C) and the applied rice straw compost (RSC), mustard meal (MM) and tricho-compost (TC) were found to have significant ($p \geq 0.05$) positive effects on the grain yield of rice. The yields of different varieties of rice were increased from 4.3 to 7.6 for BRRI Dhan 28, 3.7 to 7.7 for BRRI Dhan 74 and 4.5 to 8.8 t ha^{-1} for BR 3 by the treatments. These effects of bio-fertilizers were more pronounced with their lower doses, except for BRRI Dhan 74 under 2°C rise of soil temperature (Tab5), suggesting that the higher doses of the applied fertilizers are not economically effective concerning the grain yield of these rice varieties.

The maximum amounts of grain yield and harvest index (HI) of rice were obtained by the BR 3 (T_9 = 8.8 t ha^{-1}; HI 0.58) followed by the BRRI Dhan 74 (T_{11} = 7.7 t; HI 0.52) under the temperature elevation of 4°C (Tab4). Almost similar trends of effects were observed for these varieties by the same treatments under temperature elevation of 2°C, except for BRRI Dhan 74, where the maximum grain yield was obtained by the T_3 and maximum HI was determined by T_2 treatment (Table 5). The rate of increments (increase over control = IOC %) of the grain yields were more distinct with BRRI Dhan 74 > BR 3 > BRRI Dhan 28 and these increments were highly distinct with the higher temperature elevation. The order of effectiveness of the applied bio-fertilizers for grain yields is RSC > MM > TC (Tab5). The present results are sustained by the findings of Mehdizadeh et al. (2013). They revealed that the use of organic fertilizers especially in composted form produces positive effect on soil health and fertility, which consequently increased crop yield on a long-term basis. Straw incorporation has significant beneficial effects on crop yields, soil properties, soil organic matter and soil nutrients (Zhang et al., 2018). Poultry manure application to cropland is a sustainable option for diversifying agro-ecosystems, improving soil health and improving farm economics (Hoovera et al., 2019). It was reported that poultry manure amended soils were increased productivity. The repeated application of poultry manure to cropland has potential to improve soil health characteristics such as soil organic matter and soil fertility (Lin et al., 2018).

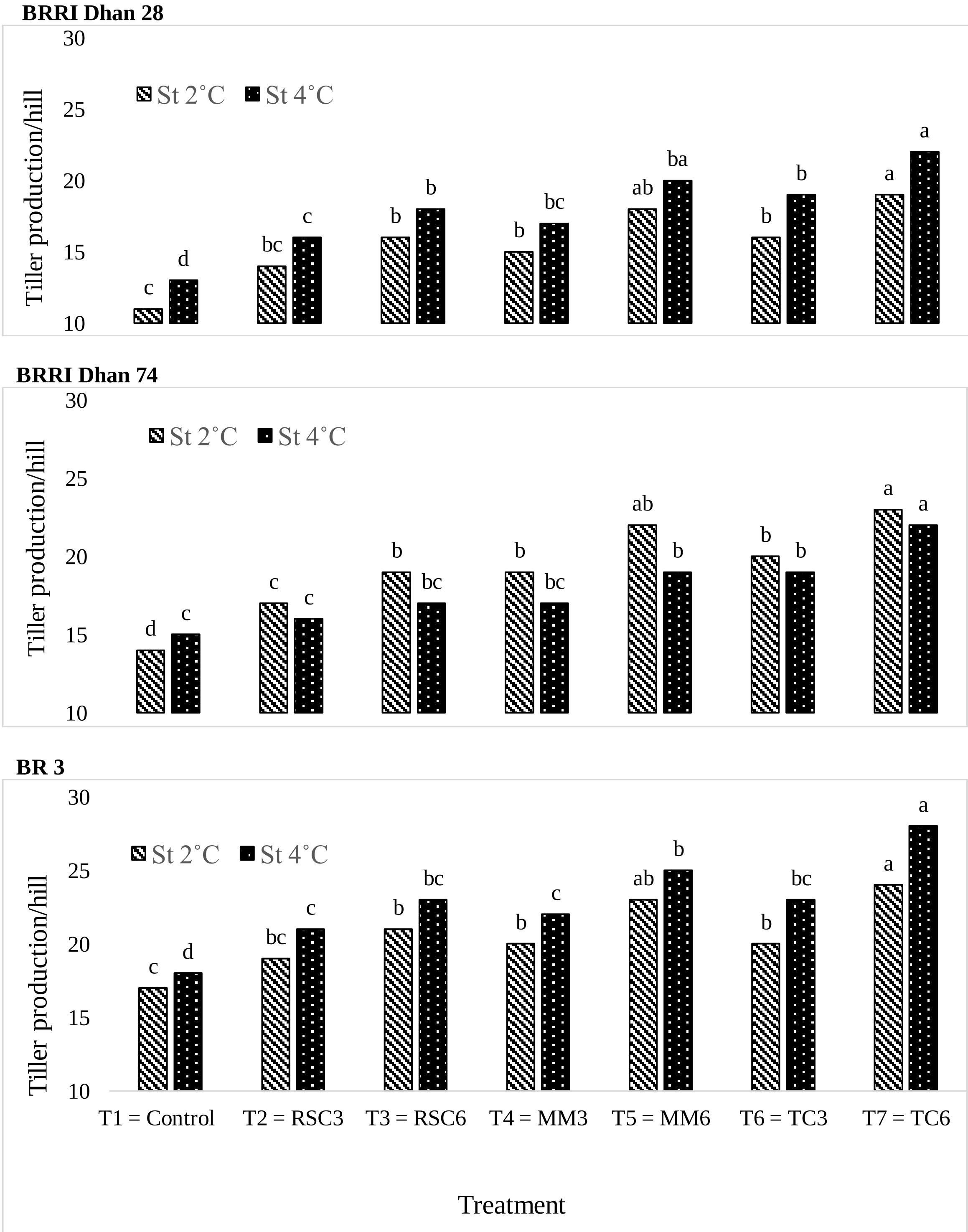


Fig. 3 Effects of soil temperature elevation and indigenous organic amendments on productive tillers of rice grown under field condition at Keraniganj of Dhaka district in Bangladesh.

Table 5 Impacts of soil temperature elevation and indigenous organic amendments on different varieties of rice production (t ha^{-1}) under field condition at Keraniganj of Dhaka district in Bangladesh.

Treatment		BRRI Dhan 28			BRRI Dhan 74			BR 3		
No.	Denotation	Grain Yield	IOC (%)	Harvest Index	Grain Yield	IOC (%)	Harvest Index	Grain Yield	IOC (%)	Harvest Index
Elevation of soil temperature (St) by 2°C										
T_1	$RSC_0MM_0TC_0$ (Control)	4.32 c	-	0.41	3.65 d	-	0.40	4.51 d	-	0.43
T_2	RSC_3	7.21 a	67	0.51	6.71 a	84	0.50	8.23 a	82	0.56
T_3	RSC_6	5.69 b	32	0.42	6.98 a	91	0.48	5.91 b	31	0.47
T_4	MM_3	5.81 b	34	0.48	5.36 c	47	0.45	5.96 b	32	0.49
T_5	MM_6	4.61 c	7	0.46	5.06 c	39	0.47	4.84 d	7	0.46
T_6	TC_3	5.21 b	21	0.52	6.13 b	68	0.48	5.64 bc	25	0.49
T_7	TC_6	4.91 c	14	0.49	5.26 c	44	0.47	5.12 cd	14	0.48
Elevation of soil temperature (St) by 4°C										
T_8	$RSC_0MM_0TC_0$ (Control)	4.21 d	-	0.40	3.31 e	-	0.40	4.42 e	-	0.41
T_9	RSC_3	7.62 a	81	0.55	6.82 b	106	0.50	8.77 a	98	0.58
T_{10}	RSC_6	4.96 c	18	0.44	6.47 bcd	95	0.49	5.29 cd	20	0.46
T_{11}	MM_3	6.12 b	45	0.53	7.69 a	132	0.52	6.51 b	47	0.51
T_{12}	MM_6	4.98 c	18	0.51	6.02 d	82	0.49	5.36 cd	21	0.49
T_{13}	TC_3	5.59 b	33	0.47	6.58 bc	99	0.50	5.92 bc	34	0.49
T_{14}	TC_6	4.62 cd	10	0.45	6.29 cd	90	0.48	4.96 de	12	0.47

RSC = Rice straw compost (t ha^{-1}), MM = Mustard meal (t ha^{-1}), TC = Trico-compost (t ha^{-1}).

3.3.1 Protein content of rice grain: Rice is the staple food mainly for South East-Asia and its production program needs to focus on development of nutrient rich rice regarding to the reduction of malnutrition of the population and more specific to developing countries. Rice grain quality is a complex character and the demand for high-quality cereals as a source of protein has become increasingly evident (Fitzgerald et al., 2009). Improving protein content in rice will help to enhance its nutritional profile and energy. Hence, the present study has been focused to improve the nutritional value of protein content of rice grown under elevated soil temperature and application of indigenous organic amendments under the field condition. The results revealed that the maximum contents of protein among the rice varieties were obtained by the T_7 (Tricho-compost at the rate 6 t ha^{-1}) treatment under 4°C rise of soil temperature and the values were 11.2 for the BRRI Dhan 74 followed by 10.3 and 10.1% by BR 3 and BRRI Dhan 28, respectively, except for the BRRI Dhan 74, where the value was 10.6% followed by 9.8 for BR 3 and 9.6% BRRI Dhan 28 under the soil temperature rise of 2°C (Fig. 4). The higher rates of applied fertilizers and temperature levels were found to have significant ($p \leq 0.05$) positive increase in protein content of rice grain and the effects were more distinct with BRRI Dhan 74 (Fig. 4). However, the rate of increment (increase over control) of protein content was maximum in BRRI Dhan 28 followed by BR 3 > BRRI Dhan 74. The effects of different types of bio-fertilizers are in the order of TC_6 > MM_6 > RSC_6 > TC_3 > MM_3 (Fig4). The findings of the present experiment would be useful for the increment of nutritional values of rice grain which is essential to recover the malnutrition of the population. World Food Program (2015) reported that more than half of the world's population is suffering from one or more vitamin and/or mineral deficiency in rice and about 3 billion people are affected by malnutrition and 3.1 million children die each year out of malnutrition (Gearing, 2015). On the other hand, the component of nutritive value of rice is bran, an important source of protein, vitamins, minerals, antioxidants, and phytosterols (Iqbal et al., 2005; Schramm et al., 2007). Rice bran protein has a great potential in the food industry, having unique nutraceutical properties (Saunders, 1990). The amount of protein content in rice is relatively low (8.5%) as compared to other cereals like wheat (12.3%), barley (12.8%) and Millet (13.4%: Shobha-Rani et al., 2006). But the present study demonstrated that the protein contents of the studied rice grains were increased by about 2.5% (7.5-10.1% for BRRI Dhan 28; 8.4-11.2% for BRRI Dhan 74 and 7.8-10.3 % for BR 3). Hence, the improvement in protein content of the grain would be useful to reduce malnutrition. Protein has a significant influence on the structural, functional, and nutritional properties of rice. It is a major factor in determining the texture (e.g., stickiness), pasting capacity, and sensory characteristics of rice. So, it deserves attention for the development of better-quality rice proteins (Juliano, 2007). From the stated facts, the present study also revealed that the rise of soil temperature, application of bio-fertilizers, their rates of application and rice varieties showed significant ($p \geq 0.05$) positive influences on protein content of rice. Therefore, the approaches should be put in place considering the above-mentioned facts.

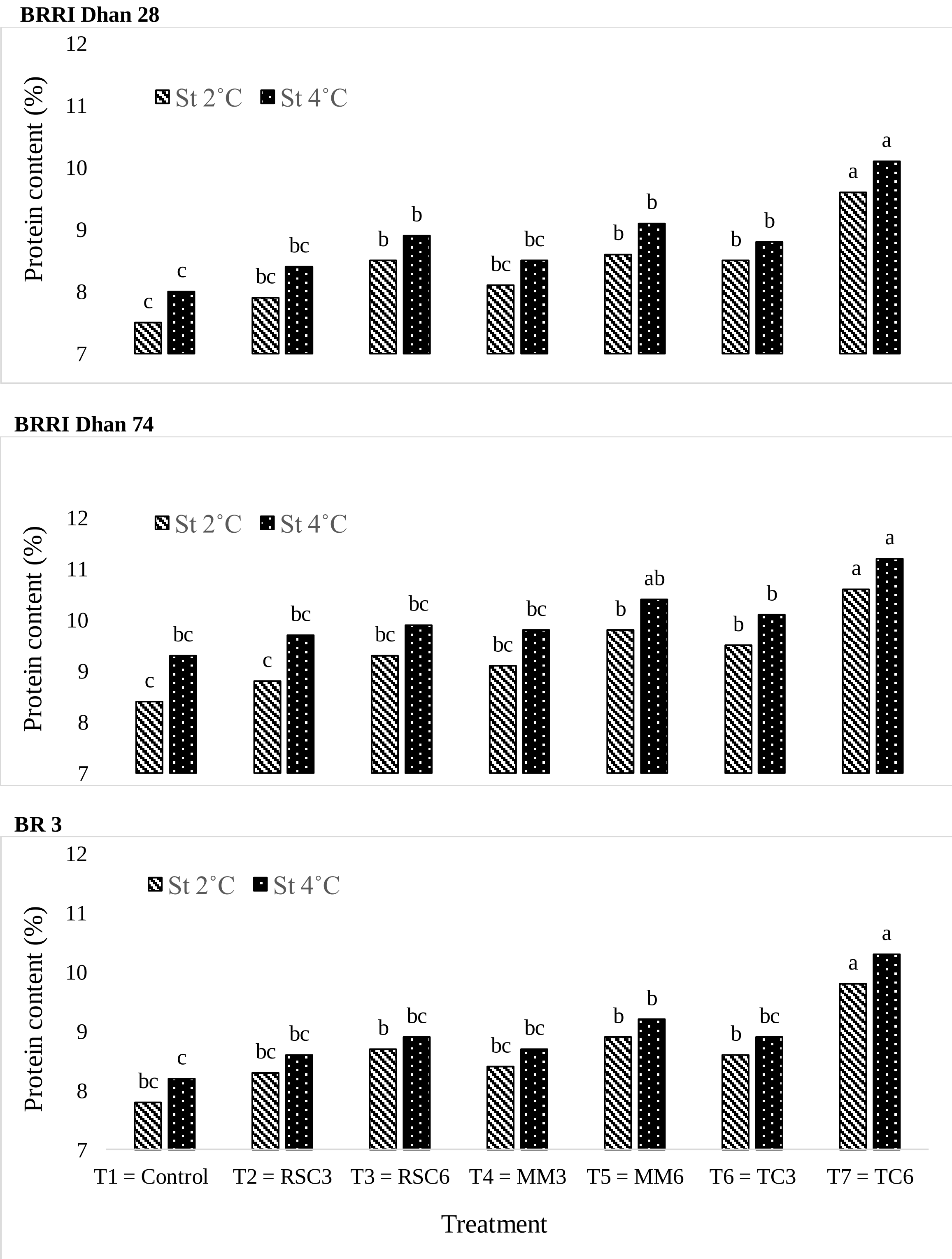


Fig. 4 Impacts of elevated soil temperature and indigenous organic amendments on grain protein content (%) of rice grown under field condition at Keraniganj of Dhaka district in Bangladesh.

3.4 Emissions of CO_2 and CH_4 from the soil surface: The emissions of CO_2 were found to be increased significantly ($p \geq 0.05$) by most of the treatments during 30 and 90 days of the experiment (Fig5). The IOC (increase over control) values of CO_2 were ranged from 35 to 100% for 30 days and 21 to 79% for 90 days under 2°C temperature elevation. While these values of IOC were ranged from 10 to 49 and 9 to 53% under 4°C rise of soil temperature, except for the T_3 (RSC_6), where the maximum amount of CO_2 was recorded and followed by the T_7 (TC_6) > T_2 (RSC_3: Fig. 5) treatments. The elevation of soil temperature of 4°C was also found to be decreased CH_4 emissions, except for the T_7 (TC_6) treatment, where the maximum amount of CH_4 emission was noticed and followed by the T_6 (TC_3) > T_4 (MM_3) > T_3 (RSC_6) treatments, which revealed that the types of bio-fertilizers had marked influences on the emissions of these trace gases. The IOC of CH_4 emissions were ranged from 47 to 94 and 42 to 62% during 30 and 90 days of the experiment, respectively under 2°C temperature elevation, while these IOC values ranged from 16 to 58 and 7 to 68% under 4°C rise of soil temperature (Fig5). Forecasting the magnitudes of climate change on soil health, agriculture and food security are not only critically important but also very difficult to determine. Moreover, the recent CO_2 concentration of about 400 ppmv is expected to rise to between 1.2 and 2.5 folds by 2100 and the earth has experienced its fourth consecutive hottest year in 2019 that will face warming of 2°C between 2030 and 2050 (IPCC, 2019) and which will have dominated effects on surface soil temperature of 0.57°C/decade (Fang et al., 2019). However, the present study attained a few positive approaches regarding to the solution of the stated problems but which need to be confirmed by further trails under variable soil-plant-climatic conditions.

3.5 Improvement of Soil Health

Soil is the fundamental resource for every crop. However, to achieve successful and sustainable production, the soil needs to be healthy. Soil health is presented as an integrative property that reflects the capacity of soil to respond to agricultural intervention, so that it continues to support both the agricultural production and the provision of other ecosystem services. Healthy soil is the key condition for plentiful and quality yield and that can be achieved through successful soil enactment, i.e., by managing mainly soil nutrients, soil pH, Organic matter, soil moisture, etc. Accordingly, the effects of different bio-fertilizers and elevated soil temperatures on soil pH and organic matter contents under rice production are stated below:

***3.5.1 Soil organic matter*:** Organic matter is not only known as the store house of plant nutrients but also full of organisms vital for proper soil performance, which contains both living and dead organisms as well as humus those are playing vital role regarding soil health as well as food security. The present study demonstrated that the contents of SOM were found to be increased significantly ($p \geq 0.05$) by the applied bio-fertilizers and the increments were distinct with the RSC treatments followed by TC. The higher doses of these treatments were exerted prominent effects and the maximum content of SOM was recorded in the T_{10} (RSC_6 @ St 4°C) treatment followed by the T_{11} (MM_3 @ St 4°C) > T_4 (MM_3 @ St 2°C) > T_3 (RSC_6 @ St 2°C) till 4 months of the study (Tab6).

The contents of SOM were increased strikingly after 1 month under 2°C, where the IOC ranged from 88 to 118 %. These increments were also prominent after 4 months under the temperature elevation of 4°C, where the IOC ranged from 65 to 88% (Tab6). The present results are in accordance with findings of Xin et al. (2017) and Zhang et al. (2016). They reported that many measures have been taken to improve soil fertility and productivity. The most effective measure is increasing the organic input, such as with the application of organic manure or compost and straw incorporation. Crop straw, an easy-to-get, nutrient-rich resource, has great value for improving soil fertility. Studies have reported that crop straw is rich in nutrients and organic materials, can be treated as a natural organic fertilizer, and used as an alternative to chemical fertilizers (Wang et al., 2017). Therefore, straw incorporation seems promising to maintain and restore soil fertility. However, up to now, the use of straw incorporation in different climates and soil types have led to inconclusive results (Pituello et al., 2016).

3.5.2 Soil reaction (pH): The values of soil pH increased significantly ($p \geq 0.05$) by the treatments as compared to the control and these increments were more pronounced after 4 months of the study (Tab6). The elevation of soil temperature of 4°C had no marked influences on soil pH, though there were significant ($p \geq 0.05$) variations in soil pH values exhibited by the different types and rates of the applied bio-fertilizers. The maximum increases in soil pH (5.7) were determined by the $T_9 = T_{14} > T_{13} = T_2$ after 1 month and $T_7 > T_6 = T_5 > T_4 = T_{12} = T_{14}$ after 4 months. These trends resemble that after one month, the elevation of soil temperature up to 4°C had influence on the increase in soil pH but after 4 months of elevation of soil temperature of 2°C performed better compared to the elevation of soil temperature of 4°C in order of the increment of soil pH (Tab6). The elevated temperature (St 2-4°C) was found to have significant ($p \geq 0.05$) positive effects on soil pH and the effects were more noticeable with the higher rates of applied fertilizers and temperature elevation (Tab6). These increments of soil pH by the treatments might be due to their physiognomies effects. The general achievements of the present study disclosed that the crop production should not be depended on luck. Be the one who determines the path of successful farming by measuring soil regularly to get the right information about soil performance factors. On the other hand, the Earth's climate is changing rapidly and human activity is altering the planet's biota and physical properties, from local to global scales, at an accelerating rate.

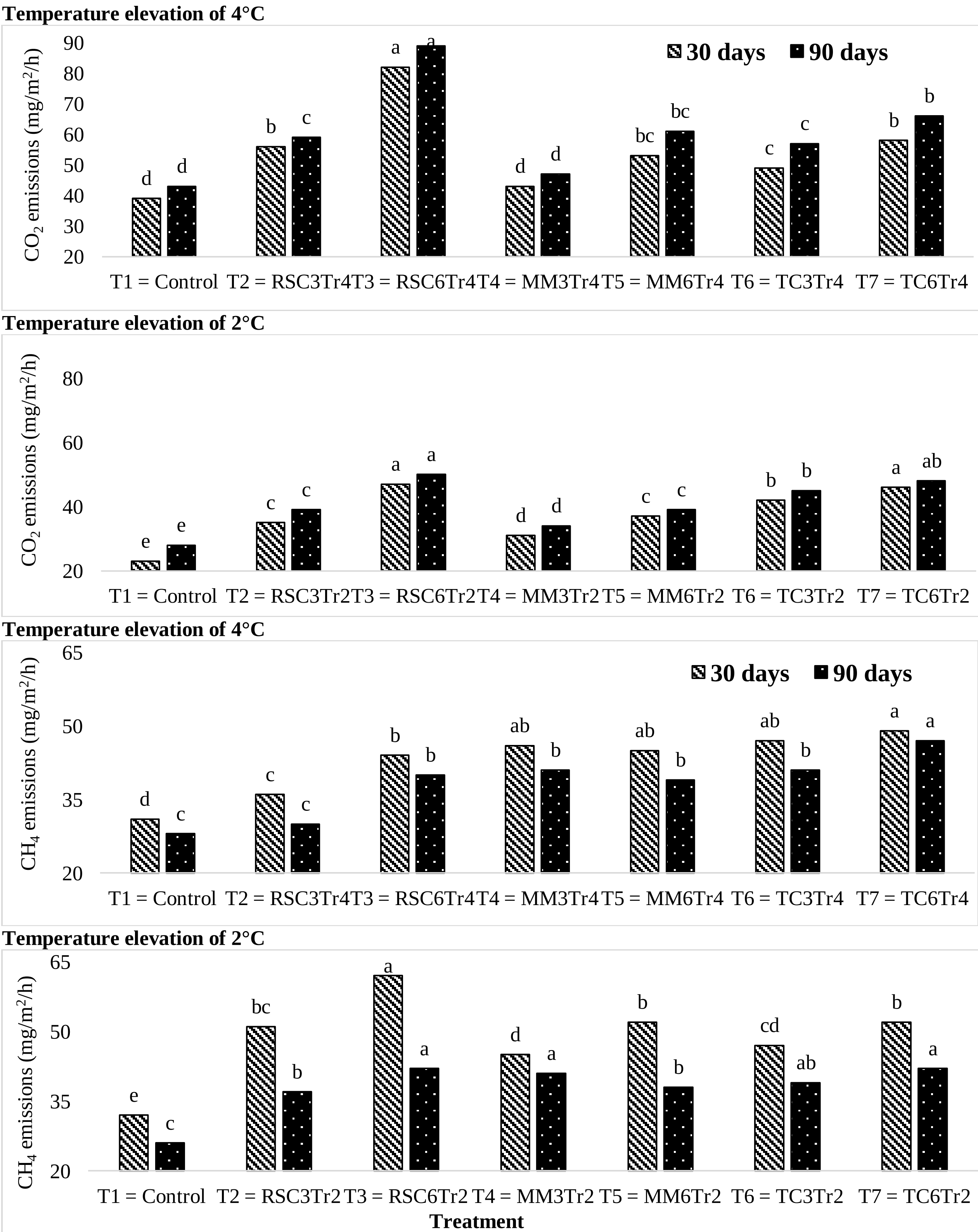


Fig. 5 Impacts of elevated soil temperature and indigenous organic amendments on CO_2 and CH_4 emissions at 30 and 90 days of rice grown under field condition at Keraniganj of Dhaka district.

Table 6 Impacts of different bio-fertilizers and elevated soil temperatures on soil pH and organic matter contents in the soils under consecutive rice and vegetable production at Keraniganj of Dhaka district.

Treatment		**Content of soil organic matter (%)**				**Soil pH**			
No.	Denotation	**1 month**	**#IOC (%)**	**4 months**	**IOC (%)**	**1 month**	**IOC (%)**	**4 months**	**IOC (%)**
Elevation of soil temperature (St) by 2°C									
T_1	$RSC_0MM_0TC_0$ (Control)	0.76 d	-	1.00 e	-	5.4 b	-	6.1 c	-
T_2	RSC_3	1.53 b	101	1.90 d	90	5.6 a	4	6.3 bc	3
T_3	RSC_6	1.66 a	118	2.41 b	141	5.5 ab	2	6.2 c	2
T_4	MM_3	1.62 ab	113	2.76 a	176	5.4 b	0	6.4 b	5
T_5	MM_6	1.50 bc	97	2.09 c	109	5.5 ab	2	6.5 ab	7
T_6	TC_3	1.43 c	88	2.28 b	128	5.4 b	0	6.5 ab	7
T_7	TC_6	1.55 b	104	1.69 d	69	5.4 b	0	6.6 a	8
Elevation of soil temperature (St) by 4°C									
T_8	$RSC_0MM_0TC_0$ (Control)	0.91 c	-	1.03 d	-	5.4 b	-	6.2 b	-
T_9	RSC_3	1.57 b	73	2.43 b	136	5.7 a	6	6.3 ab	2
T_{10}	RSC_6	1.71 a	88	2.83 a	175	5.5 b	2	6.2 b	0
T_{11}	MM_3	1.69 ab	86	2.72 a	164	5.4 b	0	6.3 ab	2
T_{12}	MM_6	1.55 b	70	2.53 b	146	5.5 b	2	6.4 a	3
T_{13}	TC_3	1.50 b	65	2.41 b	134	5.6 ab	4	6.3 ab	2
T_{14}	TC_6	1.62 ab	78	2.21 c	115	5.7 a	6	6.4 a	3

*RSC = Rice straw compost, MM = Mustard meal, TC = Trico-compost, Tr = Rise of soil temperature,
#IOC = Increase over control. In a column, means followed by a common letter are not significantly different 5% level by Tukey's Range Test.

3.5.2 Soil reaction (pH): The values of soil pH increased significantly ($p \geq 0.05$) by the treatments as compared to the control and these increments were more pronounced after 4 months of the study (Tab6). The elevation of soil temperature of 4°C had no marked influences on soil pH, though there were significant ($p \geq 0.05$) variations in soil pH values exhibited by the different types and rates of the applied bio-fertilizers. The maximum increases in soil pH (5.7) were determined by the $T_9 = T_{14} > T_{13} = T_2$ after 1 month and $T_7 > T_6 = T_5 > T_4 = T_{12} = T_{14}$ after 4 months. These trends resemble that after one month, the elevation of soil temperature up to 4°C had influence on the increase in soil pH but after 4 months of elevation of soil temperature of 2°C performed better compared to the elevation of soil temperature of 4°C in order of the increment of soil pH (Tab6). The elevated temperature (St 2-4°C) was found to have significant ($p \geq 0.05$) positive effects on soil pH and the effects were more noticeable with the higher rates of applied fertilizers and temperature elevation (Tab6). These increments of soil pH by the treatments might be due to their physiognomies effects. The general achievements of the present study disclosed that the crop production should not be depended on luck. Be the one who determines the path of successful farming by measuring soil regularly to get the right information about soil performance factors. On the other hand, the Earth's climate is changing rapidly and human activity is altering the planet's biota and physical properties, from local to global scales, at an accelerating rate.

IV. Conclusion

The present study concluded that soil health in the different Upazilas of Dhaka district at the Golden Jubilee of Bangladesh were found to be improved a pintsized till 2020s compared to those of the 1970s and 2000s. These improvements were found to boost up by the applied treatments. The rise of soil temperature, application of bio-fertilizers, their rates of application and rice varieties showed significant ($p \geq 0.05$) positive influences on growth-yield and grain quality of rice. The contents of soil organic matter were found to be increased significantly ($p \geq 0.05$) by the applied bio-fertilizers and the increments were distinct with the RSC treatments followed by TC. The elevated soil temperature of 4°C was found to be decreased CO_2 and CH_4 emissions from rice fields though the bio-fertilizers had increased the emissions. These approaches should be put in place considering the sustainability of soil health and food security, provided the government should come forward to help these target people in order to build a 'Developed Bangladesh' – the dream of Bangabandhu Sheikh Mujibur Rahman, the Father of the Nation and the Honorable Prime Minister Sheikh Hasina, the Mother of Humanity and the Champion of the Earth.

Declaration

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