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SELECTED PARAMETERS OF SOIL HEALTH IN CUMILLA DISTRICT AT THE GOLDEN JUBILEE OF BANGLADESH AND STRATEGIES FOR THEIR SUSTAINABLE IMPROVEMENT TOWARDS RICE PRODUCTION

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Key words: 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, elevated soil temperature and moisture levels, locally available organic-fertilizers, rice production, soil health.

Abstract

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. Accordingly, assessments of selected soil health indicators, such as, pH, organic matter and cation exchange capacity (CEC) in all 17 Upazilas of Cumilla district of Bangladesh were completed under the financial support of the Climate Change Trust Fund (CCTF). A few strategies were used for the improvement of soil health in response to smart rice production at the field site using locally available organic-fertilizers, viz. Vermicompost (V), Rice husk ash (RHA) and Burned poultry litters (BPL) at the rates of 0, 4 and 8 t ha^{-1} under the soil temperature elevation of 2 to 3°C (i.e. 25 to 28°C) and moisture levels of 60 and 90%. The above mentioned parameters of soil health at the Golden Jubilee of Bangladesh were found to be improved slightly compared to those of the 1970s and 2000s. These trends of improvement were found to be enhanced by the stated treatments. The yields of different rice varieties were increased from 4.4 - 5.5 to 8.4 – 9.1 t ha^{-1} by the treatments and the order of their effectiveness for grain yields and protein contents were V > BPL > RHA. Organic matter contents, pH and CEC of the studied soils were increased by these treatments and decreased CH_4 emissions from the studied rice field. However, these approaches of sustainability cannot be provided by the poor farmers and therefore, the government should come forward to help these farmers 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.

Introduction

Magnitudes of climate change on the soils and associated environments are well documented. Soil recovers the environment by performing like sieving action, adsorption and precipitation, decomposition of organic matter, filtering to remove substances from water and to decompose organic pollutants. Soil is the fundamental resource for every crop production. However, to achieve successful and sustainable farming, the soil needs

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to be healthy. In other words, healthy soil is the primary condition for abundant and quality yield. 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 basis of successful farming and that can be achieved through successful soil enactment, i.e., by managing mainly nutrients, soil pH, Organic matter, soil moisture and soil salinity, etc.

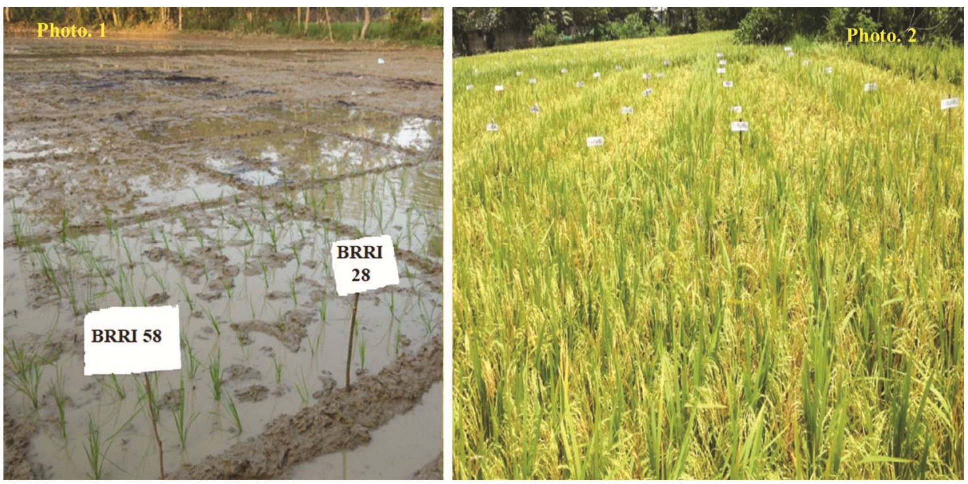
Soil pH plays a vital role in the availability plant nutrients. It is the key factor for good soil performance. Ranging from acid to alkaline, it determines the success of plant growth and final yield. So, regardless the amount of applied fertilizers, if soil pH is not optimum for a certain plant, the yield will fail. Organic matter is a soil layer full of organisms vital for proper soil performance. It contains both living and dead organisms as well as humus. Organic matter is known as the store house of plant nutrients. Key performance indicators (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 soil KPIs outside their optimum, leads to lower plant quality and yield. 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. Predicting the consequences of climate change on soil health, agriculture and food security are not only critically important but also very difficult to determine. Temperatures are predicted to increase by over 2^0C and carbon dioxide concentrations to exceed more than 450 ppmv, which will reduce yields of current cultivars of cereals, such as rice and wheat. In addition, increased draughts, floods and saline intrusion, in different parts of the country, will also cause crop losses.

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[(1)]. However, country's Food Security Index and Global Hunger Index scores remain among the lowest in South Asia[(2)]. In Bangladesh, with advancement of time, nutrient mining increases due to increasing cropping intensity (191%)[(3)], 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[(4)]. Organic manure is a good source of nutrients and it's a good means of soil rejuvenation(5). So, use of organic matter could be an inevitable practice in the coming years for ensuring sustainable crop productivity without affecting soil fertility(6). As a general rule, use of organic fertilizers especially in composted form produces positive effect on soil health and fertility, which consequents increased crop yield on a long-term basis(7). Many measures have been taken to improve soil fertility and productivity. The most effective measure is increasing the organic matter input, such as with the application of organic manure or compost(8) and straw incorporation(9). Crop straw, an easy-to-get, nutrient-rich resource, has great value for improving soil fertility(10). 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(11). 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(12). Straw incorporation has significant beneficial effects on crop yields, soil properties, soil organic matter and soil nutrients(13). Poultry manure application to cropland is a sustainable option for diversifying agro-ecosystems, improving soil health and improving farm economics(14). Reported increased productivity from poultry manure amended soils likely indicates that repeated application to cropland has potential to improve soil health characteristics such as soil organic matter and soil fertility(15). Against this aforesaid background, the present study was concentrated to - identify agro-economic vulnerable zones and/or soil health most prone to climate change at the era of Golden Jubilee of Bangladesh and finding out the strategies for climate-smart rice production and adaptation; and dissemination of information.

Materials and Methods

The studied soils were collected at a depth of 0 - 15 cm from all Upazilas (Barura, Brahmanpara, Burichong, Cumilla Adarsha Sadar, Cumilla Sadar South, Chandina, Chauddagram, Daudkandi, Debidwar, Homna, Laksam, Lalmai, Monohorgonj, Meghna, Muradnagar, Nangalkot and Titas) of Cumilla 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 done to provide the information on the comparison of soil health among the years of 1970s, 2000s and 2020. Secondary data of 1970s and 2000s were used from Reconnaissance Soil Survey, Upazila Land and Soil Resources Utilization Guide (ULSRUG) of Cumilla district and authentic published articles on the relevant areas around 2000s) in order to compare the data obtained from the present soil investigation and experiments during 2019 to 2020.

Set up of experiments: On the basis of the analyses regarding soil health, field experiments were conducted at Moddhom Majigacha of Cumilla (23°27'00"N and 91°12'00"E) district of Bangladesh during February to June, 2018 with T. Boro rice Varieties (BRRI dhan 28, BRRI dhan 58: Photographs: 1-2) in order to improve the soil health and food security. Locally available indigenous soil organic materials, such as, Vermicompost (V), Burned poultry litters (BPL), Rice husk ash (RHA) and Climatic elements (soil moisture levels and elevated soil temperatures) were considered for this study. The experiments were conducted following completely randomized block design having the doses of 0, 4 and 8 t ha^{-1} of each organic-fertilizers with 3 replications (considered within the plot) under 2 levels of soil moisture (60 and 90% soil moisture) and the soil temperatures were maintained (Technique in Photographs: 3-4) for about a month at 25-27°C and 25-28°C (i.e., soil temperature elevation of ST 2°C and ST 3°C) during late tillering to panicle initiation stages. Basal dose 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



Photographs 1-2. Visual symptoms of the rice varieties used in the field experiment.

Photographs 3-4. Instrument and approaches for the elevation of soil temperature rise of 2 and 3°C during field study.

amendments, full dose of 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 one at panicle initiation stages of rice. Rice seedlings of BRRI Dhan 28 and BRRI Dhan 58 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 regarding the maintenance of soil moistures (60 and 90%) and intercultural operations were performed when required. Selected properties of the soil at field site and the potential amendments used are presented in Table 1 and Table 2, respectively.

Table 1. Selected properties of the initial soil used in the experiment on oven dry weight basis.

Properties values	
A. Physical	
Particle density (g cm^{-3})	2.45
Bulk density (g cm^{-3})	1.23
Porosity (%)	49.80
Moisture content (%)	2.49
Particle size distribution	
Sand (%)	8.87
Silt (%)	57.75
Clay (%)	33.38
Textural class	Silty clay loam
B. Chemical	
pH	5.11
EC (Saturation extract, 1:5; dS m^{-1})	0.28
Organic matter (%)	1.17
Total nitrogen (g kg^{-1})	0.60
C/N ratio	11.33
Available NH_4^+ (mg kg^{-1})	17.95
Available NO_3^- (mg kg^{-1})	36.35
Available phosphorus (mg kg^{-1})	13.04
Available sulfur (mg kg^{-1})	21.16
Exchangeable Cations ($cmol_c$ kg^{-1}):	
Potassium (K^+)	0.23
Calcium (Ca^{2+})	9.16
Magnesium (Mg^{2+})	1.91
Cation Exchange Capacity ($cmol_c$ kg^{-1})	12.89

Soil, Plant and Compost analyses: Selected characteristics of the studied soils were determined by following standard methods. 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[16]. Soil pH was measured by the soil-water ratio of 1:2.5[17]. Organic matter content was determined by wet combustion with $K_2Cr_2O_7$[18]. 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[19]. The sample of the selected organic amendments was digested by means of nitric acid - perchloric acid (2:1) extract as described by Jackson[17]. Total P content of the organic amendments was determined by colorimetric method[17]. Other nutrients were analyzed by the following methods those were discussed earlier. Growth parameters and yield attributes of plant samples were recorded as per requirement and after harvesting the crop at maturity.

Table 2. Selected compositions of different organic amendments used in the experiment.

Nutrient element (%)	Vermi-compost	Rice husk ash	Burned poultry litter
Organic-C	14.01	1.94	7.25
Total N	1.03	6.00	1.99
C:N ratio	13.6	0.32	3.6
Total P	0.60	2.68	1.90
Total K	0.52	1.98	1.62
Total S	0.27	0.02	0.07
Total Ca	0.83	0.88	16.68
Total Mg	0.76	0.25	2.65

Gas Sampling and analysis: Emissions of the CO_2 and CH_4 gases from the surface of studied soil were measured following chamber method of Hutchinson and Moisier[20]. 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. 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 mg m^2/h. Emissions of CO_2 and CH_4 were analyzed at 40 and 80 days after transplantation (DAT) of rice.

Statistical analysis: The analysis of variance of the data and the test of significance of the different treatment means were assessed by Tukey's Range Test at 5% ($p \geq 0.05$) level.

Results and Discussion

Selected indicators of soil health at the Golden Jubilee of Bangladesh (2020), 2000s and 1970s: Soil health is a widely discussed issue regarding sustainable agriculture and quality of the soil resources. The idea of a healthy soil must be conveyed through useful measurements of soil health indicators that are sensitive to changes in soil processes and represent connections among soil biological, chemical, and physical properties. To achieve effective and reasonable food production, the soil needs to be healthy and which can be achieved through effective soil enactment, i.e., by managing mainly nutrients, soil pH, organic matter, soil moisture, etc.

Statuses of soil pH at the Golden Jubilee of Bangladesh (2020), 2000s and 1970s: The instant statistics on the typical responses among the three soil health indicators, such as, soil pH, organic matter and CEC in Cumilla district at the golden jubilee of Bangladesh were examined and reviewed considering the three-time intervals, viz. 2020, 2000 and 1970s is presented in Table 3. Present status of the studied indicators was compared with their previous status, as depicted in the Reconnaissance Soil Survey (SRDI, 1970s), authentic literature and reports (2000) and Upazila (ULSRUG) Nirdeshika of SRDI, 1999 and 2000.

Table 3. Typical responses for the comparison of selected soil health indicators in Cumilla district at the golden jubilee of Bangladesh (2020), 2000s and 1970s.

Indicators	Minimum			Maximum			Mean			SD (±)		
	2020	2000	1970s	2020	2000	1970s	2020	2000	1970s	2020	2000	1970s
pH	4.3	4.6	4.5	6.5	6.0	5.8	5.28	5.38	5.17	0.66	0.54	0.43
Organic matter (%)	0.62	0.76	0.57	5.16	1.83	3.24	2.12	1.30	1.57	1.41	0.34	0.82
CEC (c mol/kg)	5.37	6.43	6.03	29.38	15.1	19.82	13.92	11.25	12.24	6.99	3.07	3.92

The comparative studies on soil pH, organic matter and CEC between the year 2020 and the previous years of around 2000 and 1970s are shown in figure 1. The studied soil pH ranged from 4.3 to 6.5 in 2020, 4.6 to 6.0 in 2000 and 4.5 to 5.8 in 1970s in different Upazilas of Cumilla district. The higher values of soil pH in Cumilla district were determined during 2020 followed by 2000 and 1970s among the studied Upazilas, while almost reverse trend was detected for the minimum values of soil pH during these periods (Table 3). On the other hand, the highest mean value of soil pH was recorded in 2000 followed by 2020 and 1970s. These results are supported by the findings of Lal and Mathur[21], 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.

According to the classification of soil pH[4], the studied soils of 2 Upazilas are placed in very strongly acidic in reaction in 2020 and 1970s and no soil was detected in this class during 2000 (Fig. 1). There was also difference in the number of soils in strongly acidic and slightly acidic categories within the stated time intervals and there was no existence of soil in the rest of the categories of soil pH as per FRG 2012 at the golden jubilee of Bangladesh. It is well known that the soil pH is an important chemical property that affects the availability of nutrients to crops and most of the nutrients are available at 5.5 to 7.0 pH. The present results of the soils from the different Upazilas of Cumilla district are in close conformity with the stated facts and are partially agree well with findings of Ghimire *et al*.[22], who reported that soil pH varies with the nature of parent material, climatic conditions, soil organic matter and topography.

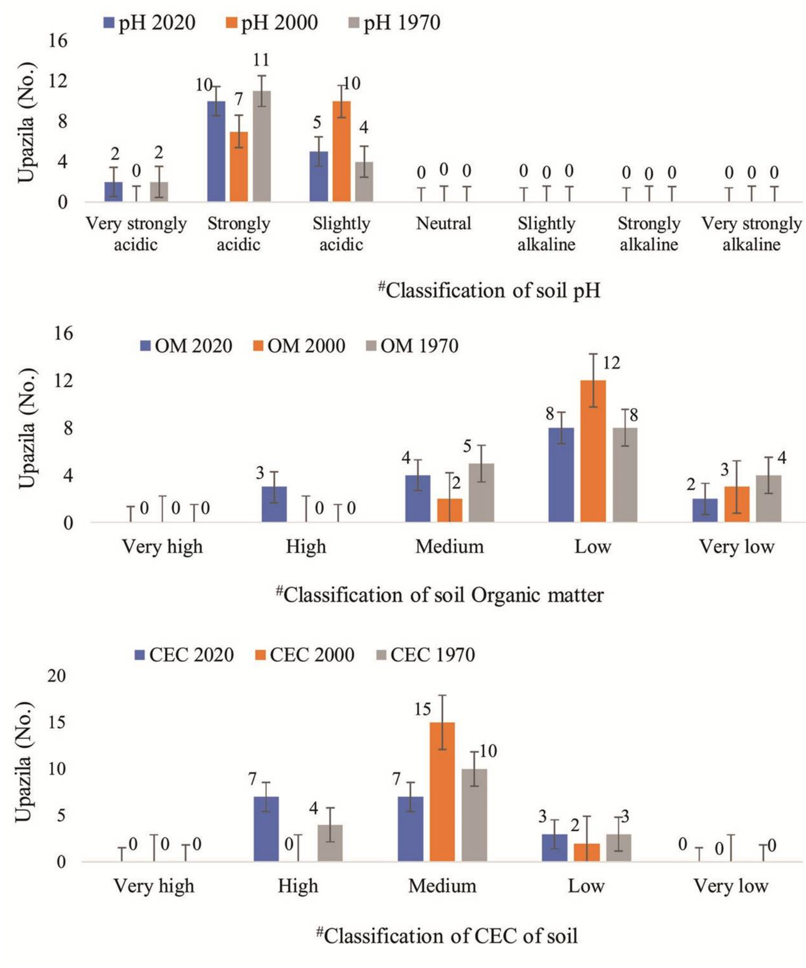


Fig. 1. Changes in soil pH, organic matter and CEC of the soils in Cumilla district at the golden jubilee of Bangladesh (2020) as compared to 2000s and 1970s.

Contents of soil organic matter at the Golden Jubilee of Bangladesh (2020), 2000s and 1970s: Organic matter contents in soils from different Upazilas of Cumilla district were ranged from 0.62 to 5.16 (%) with a mean value of 2.12 (%) in 2020 followed by 0.57 to 3.24 (%) having a mean value of 1.57% in 1970s and the lowest mean value of 1.30% was recorded in 2000 and ranged from 0.76 to 1.83% (Table 3). As per FRG,[4] classification on soil organic matter content, the studied soils in Cumilla district mainly included into very low to medium classes. The high status of organic matter contents was observed only in 2020 among the soils of 2000 and 1970s. It indicates that organic matter contents in the soils of Cumilla district increased than those of the previous years, which was possible due to the bumper production in the current decayed and that is a good indication for the better management of soil-plant relationship regarding sustainable agriculture. The present results are also in accordance with the findings of BRRI[23]. They revealed that the long-term fertilizer trials at BRRI and BAU farms with rice-rice (anaerobic-anaerobic) cropping systems were found to have slightly increased in the soil organic matter. Other studies at the IRRI in Philippines over the period of 1983-2008 also demonstrated that in the rice-rice-rice systems, the SOM tends to increase[24]. Hence, the bumper production not only indicated the production of grain but also the production straw, i.e., maintaining good grain/straw ratios. Therefore, the question of nutrient mining or the depletion of soil organic matter have been overcoming through the leaving of leaf-litter straw into the soils and ultimately act as a safe guard for food security.

Cation Exchange Capacity of soils at the Golden Jubilee of Bangladesh (2020), 2000s and 1970s: The mean values of the CEC in the soils of Cumilla district were 13.92 for 2020, 11.25 for 2000 and 12.24 $cmol_c$ kg^{-1} for 1970s (Table 3), indicating that the CEC statuses of the studied soils were also increased during 2020s. The CEC statuses of Cumilla district were ranged from low to high categories (Fig. 1)[4] and the number of the higher categories of soils were more at the golden jubilee of Bangladesh. The higher statuses of CEC of the soils were determined for 7 soils during 2020, 4 soils during 1970s but no soil was found to this category during 2000. This might be due to the bumper crops production during the early and later part of the golden jubilee of Bangladesh. These findings can be supported by Ayoola,[25] who stated that addition of organic material (crop residue and agricultural byproducts) increased CEC by 16%. Therefore, the incorporation of straw, manure, litter, bio-fertilizers, etc. are of great importance regarding the long-term food security that requires a balance between increasing crop production, maintaining soil health and environmental sustainability.

Relationships among the pH, Organic matter and CEC in the soils of Cumilla district: Correlation statistics was performed (Table 4 and Fig. 2) to study the relationships and the interrelationships among of the soil pH, organic matter and CEC statuses within the time intervals of 2020, 2000s and 1970s. The results evinced that there were significant positive correlations ($r = 0.8884^{***}$, $p<0.001$ in 2020 versus 2000s; 0.7045^{**}, $p<0.01$ in 2020 versus 1970s and 0.8329***, p<0.001 in 2000 versus 1970s) in CEC within the mentioned time intervals (Fig. 2). In the case of pH and organic matter, positive correlations were observed except for the relationships of organic matter between 2020 and 1970s. Among

Table 4. Correlation matrix of studied soil health indicators in Cumilla district at the golden jubilee of Bangladesh (2020), 2000s and 1970s.

	pH2020	pH2000	pH1970s	OM2020	OM2000	OM1970s	CEC2020	CEC2000
pH2000	0.4448							
pH1970s	0.2415	0.1658						
OM2020	-0.0429	0.4252	-0.4153					
OM2000	0.2269	-0.0606	-0.0667	0.3032				
OM1970s	0.3162	0.0780	0.0142	-0.0603	0.3515			
CEC2020	0.1445	0.5601*	-0.0451	0.3124	0.2602	0.4748*		
CEC2000	0.1145	0.4769*	-0.1165	0.3796	0.4801*	0.5187*	0.8884***	
CEC1970s	0.1489	0.3813	-0.1476	0.3956	0.4421	0.6305**	0.7045**	0.8329***

***, ** and * indicates p <0.001, p<0.01 and p<0.05, respectively.

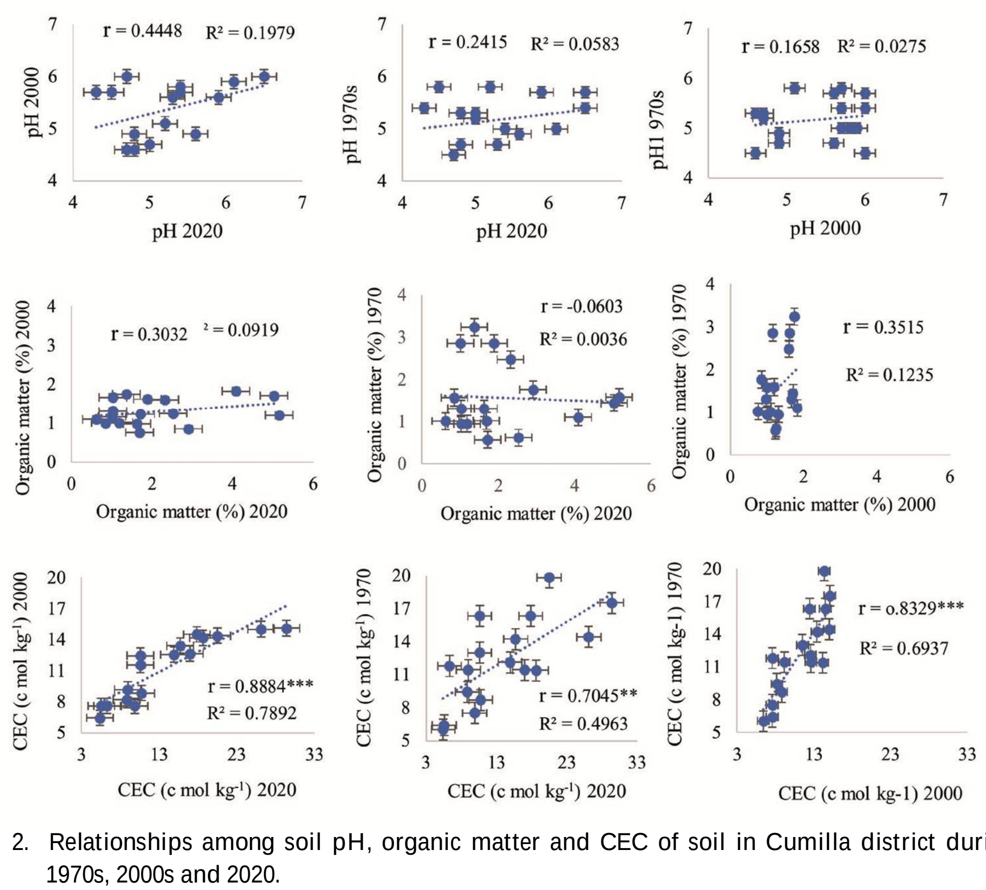


Fig. 2. Relationships among soil pH, organic matter and CEC of soil in Cumilla district during 1970s, 2000s and 2020.

the interrelationships of pH, organic matter and CEC statuses in the soils of Cumilla district, positive correlations were obtained at the golden jubilee of Bangladesh, except for a few relationships. Significant positive relationships between CEC versus pH; CEC versus organic matter; CEC versus CEC at the studied time intervals (Table 4/Fig. 2). The present results are in close agreement with the findings of Ghimire *et al*.(26), 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.

Tiller production of rice: Plant height, tiller production and fresh or dry weights of crops have special significance regarding planning and policymaking for the management of low, high, medium -lands and fodder production or bulk materials for energy goods, etc. Impacts of soil temperature elevation and indigenous organic amendments on the tiller production of rice grown under field condition at Cumilla district of Bangladesh demonstrated that the maximum number of productive tillers were obtained by the T_7 (V_8) treatments and the numbers were 24 and 26 per hill for BRRI Dhan 28 and BRRI Dhan 58, respectively under the temperature rise of 3°C (Fig. 3) followed by T_6 (V_4) treatments under the same temperature level. The single effects of moisture and temperature levels were found to have mostly additive. The effects of the lower levels of soil moisture (M_{60}) with the higher levels of temperature (ST 3°C) were found mostly significant ($p \geq 0.05$) for both the rice varieties and the effects were quite pronounced with the BRRI Dhan 58, which received vermicompost at the rate of 8 t ha^{-1} followed by the same dose of BPL > RHA (Fig. 3). Holydays(27) revealed that the tiller is

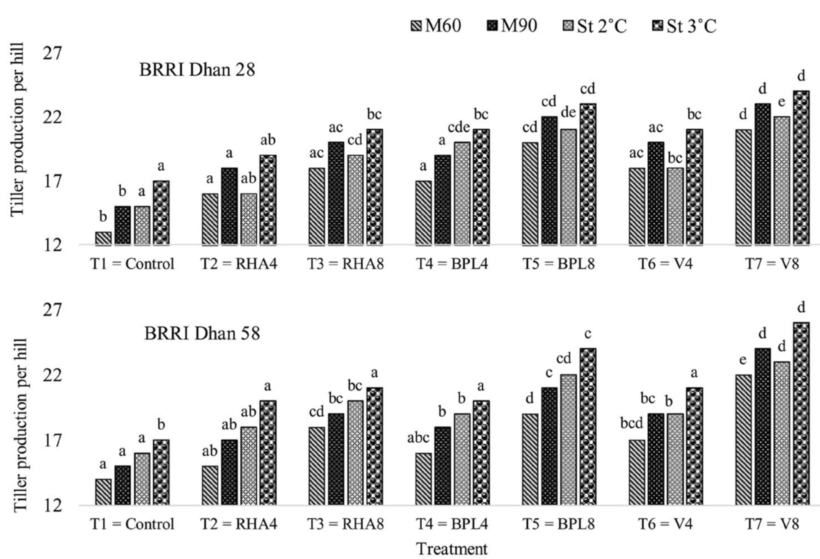


Fig. 3. Impacts of climatic elements and indigenous organic amendments on tiller production of rice grown under field condition at Cumilla district in the golden jubilee of Bangladesh.

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 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 effects of climatic elements, i.e., 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.

Grain yield of rice: Rice is the most well-known cereal and staple food which serves as major carbohydrate for more than half of the world population. To meet the future demand, its production need to be increased at least by 40% within 2050. Accordingly, the present attempt was made on the impacts of soil temperature elevation and indigenous organic amendments on the grain yield of rice grown under field condition. In this study, two levels of moisture (M60 and M90) and elevated soil temperature (ST 2°C and ST 3°C, where moisture levels were maintained by frequent irrigation as per requirement of rice) and the applied vermicompost (V), burned poultry litter (BPL) and rice hull ash (RHA) were found to have significant ($p \geq 0.05$) positive effects on the grain yield of rice and the effects were more pronounced with their higher levels/doses regardless of the types of the amendments (Fig. 4). The raise of soil temperature exerted better responses on grain yield compared to moisture treatments. The effects of moisture and elevated soil temperature were more distinct (4% more with moisture; 11.5% with Temp.) with BRRI Dhan 28 compared to BRRI Dhan 58 (1% moisture; 10.6% temp.). However, BRRI Dhan 58 was found to be increased 6% more grain yield compared to BRRI Dhan 28, regardless of the treatments. The present results are in agreements with the findings of Mehdizadeh *et al*.(7) They reported 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(13). Poultry manure application to cropland is a sustainable option for diversifying agro-ecosystems, improving soil health and improving farm economics(14). Lin *et al.*(15) reported increased productivity from poultry manure amended soils likely indicates that repeated application to cropland has potential to improve soil health characteristics such as soil organic matter and soil fertility.

Protein content of rice grain: More than half of the world's population is suffering from one or more vitamin and/or mineral deficiency in rice(28). About 3 billion people are affected by micronutrient malnutrition and 3.1 million children die each year out of malnutrition(29). Accordingly, rice production program needs to focus on development of nutrient rich rice regarding to the reduction of malnutrition of the population and more specifically to developing countries as their staple food is rice. Therefore, the present attempts to improve the nutritional value of rice have been concentrated on protein content. In the present study, maximum content of protein in both the rice varieties were

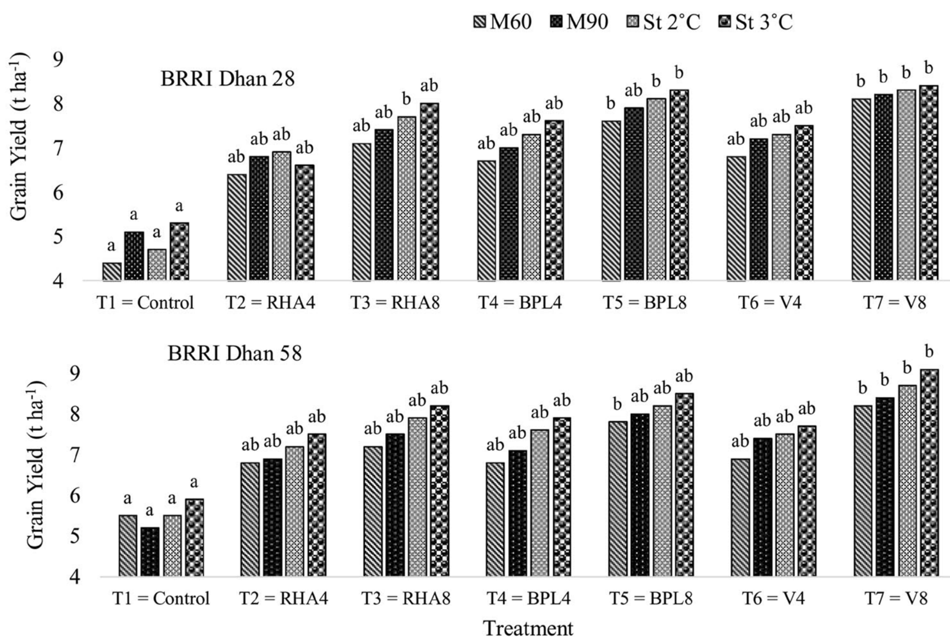


Fig. 4. Impacts of climatic elements and indigenous organic amendments on the grain yield of rice grown under field condition at Cumilla district in the golden jubilee of Bangladesh.

obtained by the T_7 (V, 8 t ha^{-1}) under 3°C raise of soil temperature and the values were 11.3% for BRRI Dhan 28 and 11.5% for BRRI Dhan 58 followed by 11.0 and 11.4%, respectively where the raise of soil temperature was 2°C (Fig. 5). In most cases, the higher levels of moisture, temperature and fertilizer rates were found to have significant ($p \leq 0.05$) positive responses on the protein content of rice grain and the effects were more distinct with BRRI Dhan 58 (Fig. 5). The effects of different types of fertilizers for the increase of protein content are in the order of V > RHA > BPL, regardless of soil moisture and raise of soil temperature. The present effort demonstrated that the application of organic-fertilizers and the temperature rise of up to 29°C were strongly effective for the increment grain protein content. Rice grain quality is a complex character and the demand for high-quality cereals as a source of protein has become increasingly evident[30,31]. Improving protein content in rice will help enhance its nutritional profile. Protein content in rice grain is an important source of nutrition and energy. 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%)[32]. 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. Therefore, it deserves attention for the development of better-quality rice proteins[33]. On the other hand, the component of nutritive value of rice is bran, an important source of protein, vitamins, minerals, antioxidants, and phytosterols[34,35]. Rice bran protein has a great potential in the food industry, having unique nutraceutical properties[36]. Improvement in these components in the grain can be useful to reduce malnutrition.

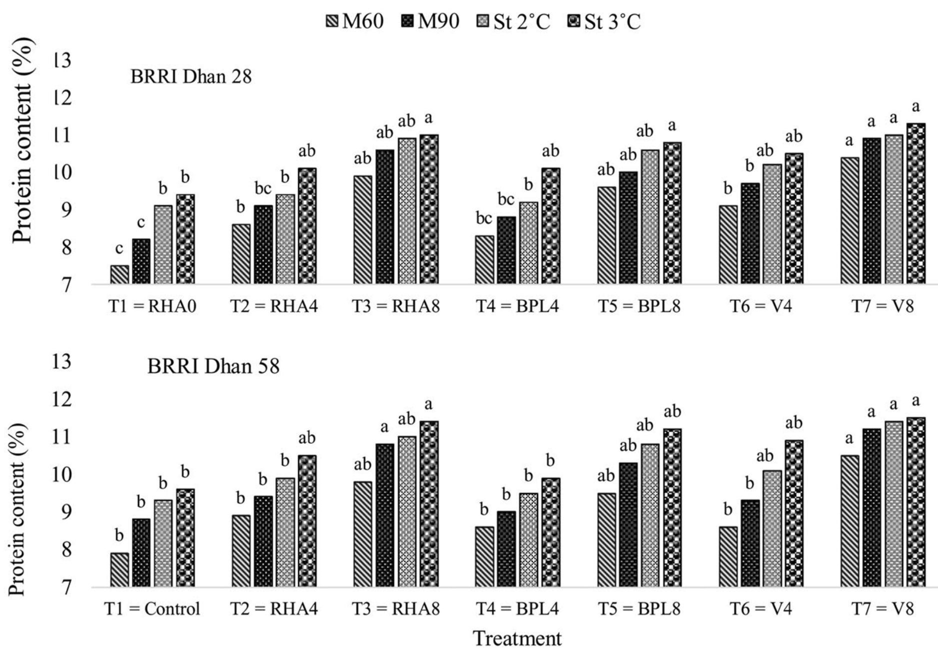


Fig. 5. Impacts of climatic elements and indigenous organic amendments on protein content of rice grown under field condition at Cumilla district in the golden jubilee of Bangladesh.

Improvement of Soil Health: Impacts of soil temperature elevation and indigenous organic amendments on soil organic matter, CEC and soil pH at the harvesting stage of rice grown in the field at Cumilla district of Bangladesh are explained below:

Organic matter: Soil organic matter contents at the post-harvest soils revealed that the boost up of organic matter contents were significantly influenced by V > BPL > RHA, which were found to be induced by the higher moisture level (M_{90}) and raise of soil temperature (St 3°C: Table 5). These effects of all the applied organic-fertilizers, moisture levels and raise of soil temperature were more pronounced for the production of BRRI Dhan 58. The maximum contents of organic matter were 1.91% followed by 1.78 and 1.76% by V_8, BPL_8 and RHA_8, respectively in the post-harvest soils under BRRI Dhan 58, while by the same treatments and same conditions, these values of organic matter were 1.76, 1.67 and 1.60%, respectively at the soils under BRRI Dhan 28 cultivation.

Table 5. Impacts of climatic elements and indigenous organic amendments on soil organic matter, CEC and soil pH at the harvesting stage of rice grown in the field at Cumilla district of Bangladesh.

Treatment No. and Denotation	Boost up of organic matter (%) at post-harvest soil											
	BRRI Dhan 28						BRRI Dhan 58					
	M_{60}	M_{90}	IOC (%)	St 2°C	St 3°C	IOC (%)	M_{60}	M_{90}	IOC (%)	St 2°C	St 3°C	IOC (%)
T_1 = Control	1.12c	1.28c	-	1.22c	1.40b	-	1.22c	1.28c	-	1.29c	1.38c	-
T_2 = RHA_4	1.31bc	1.43b	12	1.38bc	1.45b	4	1.40bc	1.52b	19	1.48bc	1.62bc	18
T_3 = RHA_8	1.41ba	1.53ab	20	1.48b	1.60ba	15	1.48b	1.64ba	28	1.59b	1.76ba	28
T_4 = BPL_4	1.36b	1.55ab	22	1.47b	1.64ab	17	1.48b	1.64ba	28	1.57b	1.74b	26
T_5 = BPL_8	1.47ab	1.60a	26	1.59ab	1.67ab	20	1.53ba	1.69ab	32	1.64ba	1.78ba	29
T_6 = V_4	1.52a	1.57a	23	1.62a	1.69ab	21	1.62a	1.64ba	28	1.71ab	1.72b	25
T_7 = V_8	1.55a	1.64a	28	1.67a	1.76a	26	1.67a	1.79a	41	1.78a	1.91a	39
Changes in cation exchange capacity ($cmol_c$ kg^{-1}) at post-harvest soil												
T_1 = Control	13.9a	16.8a	-	17.1a	18.3a	-	15.1a	17.6a	-	18.9a	19.7a	-
T_2 = RHA_4	14.8ab	17.6ab	5	18.0ac	18.9ab	3	15.6ab	18.3ab	4	19.2a	20.2a	3
T_3 = RHA_8	16.6abcd	19.1ab	14	18.7abc	19.5ab	7	17.1abc	19.4ab	10	19.7a	20.8a	6
T_4 = BPL_4	15.4abc	18.3ab	9	19.3abc	20.1abc	10	15.9ab	18.9ab	7	19.9a	20.3a	3
T_5 = BPL_8	17.1bcd	19.2ab	14	20.4bc	21.2bc	16	17.5abc	19.6ab	11	20.7ab	21.6ab	10
T_6 = V_4	17.8cd	18.9ab	13	20.9b	21.6bc	18	18.2bc	19.3ab	10	21.2ab	22.1ab	12
T_7 = V_8	19.1d	20.4b	21	21.5b	22.8c	25	19.8c	20.6b	17	22.9b	24.2c	23
Changes in soil reaction (soil pH) at post-harvest soil												
T_1 = Control	5.08 d	5.10 d	-	5.15 c	5.20 d	-	5.12 c	5.20 c	-	5.17 c	5.23 e	-
T_2 = RHA_4	5.80 c	6.11 cd	20	6.23 bc	6.59 cd	27	6.18 b	6.57 bc	26	6.35 bc	6.64 d	27
T_3 = RHA_8	6.12 b	6.59 bc	29	6.70 a	7.15 b	38	6.25 b	7.10 ba	37	6.56 b	7.20 b	38
T_4 = BPL_4	6.00 b	6.30 c	24	6.42 b	6.59 cd	27	6.23 b	6.50 bc	25	6.46 b	6.61 cd	26
T_5 = BPL_8	6.59 a	6.95 a	36	6.78 a	7.32 ab	41	6.62 a	7.15 ab	38	6.84 a	7.34 ab	40
T_6 = V_4	6.30 ba	6.50 bc	27	6.65 ab	6.80 c	31	6.47 ab	6.59 bc	27	6.50 b	6.85 c	31
T_7 = V_8	6.55 a	6.63 b	30	6.70 a	7.49 a	44	6.59 a	7.37 a	42	6.87 a	7.50 a	43

*RHA = Rice husk ash, #BPL = Burnt poultry litter, $V = Vermicompost, Subscripts are the rates of 0, 4 and 8 t ha^{-1}, St = Soil temperature, which was raised up to 2°C and 3°C from the usual field soil temperature. M_{60} and M_{90} = Soil moisture conditions of 60 and 90%, which were maintained during rice production. Means followed by a common letter (s) are not significantly different at 5% level.

Cation exchange capacity (CEC): The CEC of the post-harvest soils were increased by the V, BPL and RHA treatments and the increments were more pronounced by the T_7 (V_8) treatment, irrespective of soil moistures, raise of soil temperatures and rice varieties

(Table 5). The increments of the CEC of the soils were more distinct the higher levels of raise of temperature (St 3°C) followed by the higher level of soil moisture (M_{90}). The values of the increase in CEC were higher in the soils under BRRI Dhan 28 (Table 5). Among the applied fertilizers, V_8 ranked first followed by $V_4 \geq BPL_8 \geq RHA_8$, resemble that the higher dose of the applied fertilizers should be increased for further study in order to find out the best doses under variable soil and plant conditions.

Soil reaction (soil pH): The applied organic-fertilizers exerted significant ($p \geq 0.05$) increased in soil pH at the post-harvest soils (Table 5) and the increments were highly distinct with their higher doses, demonstrated that the rate of application of the fertilizers should be increased for further studies. The rate of increments was more pronounced with the $V_8 > BPL_8 > RHA_8$, except for the soils under moisture M_{90} having the BRRI Dhan 28. The management of soil moisture and elevated temperature (St 2-3°C) were found to have significant ($p \geq 0.05$) effects on soil pH and the effects were more noticeable with the higher rates of applied fertilizers and higher levels of moisture and temperature elevation (Table 5). These increments of soil pH by RHA and BPL were might be due to their burning effects, on the other hand, the increments of soil pH by vermicompost might be owing to its release of alkaline metals (Table 5).

Emission of CO_2 and CH_4 from the studied rice field: The emission of CO_2 was found to be increased significantly ($p \leq 0.05$) by the treatments during 40 and 80 days after transplantation (DAT) of rice. The increments were significantly pronounced with time and temperature levels (Table 6). The maximum amount (53 mg/m^2/h) of CO_2 emission was recorded by the T_7 (V_8) treatment, where the rise of soil temperature was 3°C, followed by the same treatment at the temperature rise of 2°C at 80 DAT. But the same treatment (T_7) having 3°C rise of soil temperature at 40 DAT ranked 3rd followed by the same treatment where the soil temperature elevation was 2°C (Table 6), demonstrated that the rise of soil temperature of 2 to 3°C significantly induced emissions CO_2, regardless of fertilizers, moisture levels and time; and the emissions were more distinct with the V_8 treatments. The IOC (increased over control) values of CO_2 emissions were ranged from 22 to 91% at 40 DAT and 24 to 104% at 80 DAT under 2°C temperature elevation. While these values were ranged from 25 to 96 and 19 to 96% at 40 and 80 DAT, respectively. The emissions of CO_2 decreased with the higher moisture level but increased with time and the increments were most pronounced with the raises of soil temperatures (Table 6). The order of emissions of CO_2 from the applied bio-fertilizers is as $V_8 > V_4 > BPL_8 > BPL_4 > RHA_8 > RHA_4$, regardless of time, temperature and moisture levels (Table 6). The present results are quite comparable with the CO_2 flux reported by Chang *et al.*(37) and Liu *et al.*(38). The revealed that there had strong relationship between CO_2 flux and soil temperature.

The emissions of CH_4 were decreased significantly ($p \leq 0.05$) with time and rises of soil temperatures but increased significantly with the higher moisture level. Though the

Table 6. Impacts of climatic elements and indigenous organic amendments on the emissions of methane and carbon dioxide from rice field at Cumilla district of Bangladesh.

Treatment No. and Denotation	Methane emissions (mg $m^{-2}h^{-1}$) at 40 days after transplantation							
	M_{60}	IOC (%)	M_{90}	IOC (%)	St 2°C	IOC (%)	St 3°C	IOC (%)
T_1 = Control (*$RHA_0{}^{\#}BPL_0{}^{\$}V_0$)	13 g	-	19 a	-	10 e	-	7 f	-
T_2 = RHA_4	15 f	15	22 f	16	11 e	10	10 e	43
T_3 = RHA_8	19 e	46	24 e	26	14 d	40	13 d	86
T_4 = BPL_4	21 d	62	25 d	32	14 d	40	12 d	71
T_5 = BPL_8	25 c	92	29 c	53	18 c	80	15 c	114
T_6 = V_4	29 b	123	36 b	89	21 b	110	17 b	143
T_7 = V_8	36 a	177	44 a	132	26 a	160	21 a	200
	Methane emissions (mg $m^{-2}h^{-1}$) at 80 days after transplantation							
T_1 = Control (*$RHA_0{}^{\#}BPL_0{}^{\$}V_0$)	10 d	-	15 e	-	8 f	-	6 d	-
T_2 = RHA_4	11 d	10	19 d	27	10 e	25	9 c	50
T_3 = RHA_8	14 cd	40	23 c	53	13 de	63	9 c	50
T_4 = BPL_4	15 c	50	25 bc	67	14 d	75	10 c	67
T_5 = BPL_8	19 ab	90	31 ab	107	21 c	163	13 b	117
T_6 = V_4	20 b	100	27 b	80	16 b	100	14 b	133
T_7 = V_8	26 a	160	32 a	113	23 a	188	19 a	217
	Carbon dioxide emissions (mg $m^{-2}h^{-1}$) at 40 days after transplantation							
T_1 = Control (*$RHA_0{}^{\#}BPL_0{}^{\$}V_0$)	17 e	-	11 f	-	23 d	-	24 e	-
T_2 = RHA_4	20 d	18	14 e	27	28 c	22	30 d	25
T_3 = RHA_8	26 c	53	18 d	64	31 bc	35	35 c	46
T_4 = BPL_4	25 c	47	19 d	73	29 c	26	32 d	29
T_5 = BPL_8	31 bc	82	24 c	118	33 bc	43	36 c	50
T_6 = V_4	33 b	94	22 b	100	36 b	57	40 b	67
T_7 = V_8	39 a	129	27 a	145	44 a	91	47 a	96
	Carbon dioxide emissions (mg $m^{-2}h^{-1}$) at 80 days after transplantation							
T_1 = Control (*$RHA_0{}^{\#}BPL_0{}^{\$}V_0$)	22 f	-	14 e	-	25 e	-	27 e	-
T_2 = RHA_4	27 e	23	19 d	36	31 d	24	32 d	19
T_3 = RHA_8	31 d	41	23 cd	64	36 cd	44	39 c	44
T_4 = BPL_4	32 d	45	25 c	79	35 cd	40	37 c	37
T_5 = BPL_8	38 c	73	28 b	100	41 bc	64	45 bc	67
T_6 = V_4	43 b	95	29 b	107	45 b	80	47 b	74
T_7 = V_8	48 a	118	35 a	150	51 a	104	53 a	96

*RHA = Rice husk ash, #BPL = Burnt poultry litter, $V = Vermicompost applied at the rates of 0, 4 and 8 t ha^{-1}, St = Soil temperature, which was raised up to 2 and 3°C from the usual field soil temperature. M_{60} and M_{90} = Soil moisture conditions of 60 and 90% were maintained during rice production. Means followed by a common letter (s) are not significantly different at 5% level.

elevation of soil temperature of 3°C decreased CH_4 emission distinctly but the applied fertilizers were found to have significant ($p \leq 0.05$) positive effects on CH_4 emissions and the effects were more pronounced at 40 DAT (Table 6). The maximum amount of CH_4 emission (44 mg/m^2/h) was noticed by the T_7 (V_8) treatment having the higher level of moisture at 40 DAT. The order of emissions of CH_4 is as $V_8 > V_4 > BPL_8 > BPL_4 > RHA_8 > RHA_4$, regardless of time, temperature and moisture levels (Table 6), which revealed that the types of bio-fertilizers had marked influences on the emissions of CH_4. The IOC of CH_4 emissions were ranged from 10 to 160 and 25 to 188% during 40 and 80 DAT, respectively under 2°C temperature elevation, while these values were ranged from 43 to 200 and 50 to 217% under 3°C rise of soil temperature (Table 6).

The overall achievements of the present study unveiled that the crop production should not be governed by luck. Be the one who determines the path of successful production by measuring soil regularly to get the right information about soil enactment 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. Forecasting the concerns of climate change on soil health, agriculture and food security are not only critically important but also very challenging to determine. Temperatures are predicted to increase by over 2°C and carbon dioxide concentrations to exceed more than 450 ppm, which will reduce yields of current cultivars of cereals like rice. The present results demonstrated that the production of rice and soil health were not significantly improved by the application of organic-fertilizers like vermicompost, burnt poultry litter and rice husk ash under elevated soil temperature but also reduced the emissions of CH_4 from the rice field. About 45% of net cultivable areas of Bangladesh contain less than 1% OM [(4)]. But the present study on soil health at 2020 evinced that the organic matter statuses were found to be increased a little through the addition of crop residues and organic fertilizers at the experimental sites. Organic manure is a good source of nutrients and it's a good means of soil rejuvenation [(5)]. So, the use of organic matter could be an inevitable practice in the coming years for ensuring sustainable crop productivity without affecting soil fertility [(6)].

Conclusion

Soil pH, organic matter and the CEC as important indicators of soil health were found to be a pintsized improvement at the Golden Jubilee of Bangladesh (2020). These trends of development were found to be enhanced by the application of organic-fertilizers. The present study also concluded and the increments were distinct with the vermicompost followed by burned poultry litter and rice hull ash treatments. The elevation of soil temperature of 3°C (i.e., from 25 to 28°C at field soil) was found to be decreased CH_4 emissions from rice fields. 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. These strategies should be put in place regarding sustainable food security but the poor farmers could not be able to bear the financial load and therefore, 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.

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