



# Soil Temperature and Moisture Stress: Response of Some Selected Physico-chemical Properties of Soil Along with Practice of Plant and Microbes-derived Organic Fertilizers

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## Authors' contributions

This work was carried out in collaboration among all authors. Author MHRK designed the research. Author MSI performed the field study, collected the sample, analyzed the data and wrote the whole paper. Author FF managed the literature searches. All authors read and approved the final manuscript.

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## ABSTRACT

In favor of assessing the influences of soil temperature elevation and moisture stress on physico-chemical properties of soil including soil reaction (pH), organic carbon (OC) content, availability of Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca) and Magnesium (Mg), field experiments were carried out over two seasons incorporated with organic materials of tricho-compost (TC), rice straw compost (RSC) and mustard meal (MM). Temperature elevation of 3°C from daily field temperature (23-25°C), and two different moisture levels - moist (70% moisture) and saturated (>100% moisture) - were considered simultaneously along with the application of TC at the dosages of 0, 2.5, 5; RSC at 0, 4, 8 and MM at 0, 3, 6 t ha<sup>-1</sup>. Elevated temperature markedly augmented OC (0.41 to 0.98%), N (1.07 to 4.98 m mol kg<sup>-1</sup>), P (0.39 to 0.86 m mol kg<sup>-1</sup>), K (0.12 to 0.34 c mol kg<sup>-1</sup>), Ca (2.13 to 5.97 c mol kg<sup>-1</sup>) and Mg (1.09 to 2.93 c mol kg<sup>-1</sup>) contents in soil during first season with RSC followed by MM and TC. The moist condition of soil, accompanied by the selected amendments had almost collateral effects on the aforesaid analyzed properties of soil in contrast to saturated condition. The carry-over effects of these treatments were most striking on

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selected properties in subsequent soil with TC succeeded by MM and RSC. Among the used amendments, TC exerted the most striking effect on nutrient availability because of the abundance of *Trichoderma* spp. even under stress conditions. The elevated temperature significantly ( $P \leq .05$ ) reduced the C/N ratios during both seasons which accelerated the organic matter decomposition and markedly influenced availability of N (45.39%), P (49.23%) and K (21.83%) revealed from regression analysis, irrespective of seasons. Moreover, the practice of tricho-compost over its sustainability – under climatic stress conditions - can therefore be good determinative over recovery of soil health via ameliorating soil organic matter and nutrient status.

**Keywords:** *Elevated soil temperature; moisture stress; physico-chemical properties of soil; tricho-compost.*

## 1. INTRODUCTION

Increase in global mean surface temperature has been observed over recent centuries, particularly after industrial revolution. Climate change manifests itself on different time-scales: through changes in the nature of single, short-lived extreme weather events and through incremental changes that build up over decades. In ten years spanning of 2009-2018, 20-40% of the global population had already experienced warming of 1.5°C in at least one season [1]. In the continuation of this ascending trend, the Earth will face warming of 2.0°C between 2030 and 2052. There's broad consensus in the scientific community that atmospheric warming has been driven by increases in atmospheric greenhouse gases caused mostly by anthropogenic activities. Nearly 200 nations have formally acknowledged in joint statements and international agreements that human activity is accountable for global climate change. About 97% of climate scientists agree that human activity is causing climate change [2]. Sizable increases in atmospheric temperature associate with the surface soil temperature implying the dominate effects of climate warming on surface soil temperature, reporting the sharp soil warming in surface of 0.57°C/decade [3]. Alongside, anthropogenic climate change expectedly enhances global mean evaporation owing to the larger moisture demand of the atmosphere with higher air temperatures and thereby leads to decrease in soil moisture availability [4]. Predicted changes in soil temperature and moisture could result in variation of terrain and hydrologic conditions, alteration of the distribution and growth rate of vegetation, enhancement of soil organic carbon (SOC) decomposition and increased emission of carbon dioxide (CO<sub>2</sub>) from the soil to the atmosphere [5,6].

Because of the topography and geographical location of Bangladesh, the agriculture sector

and soil health which are mightily susceptible to elevated soil temperature and moisture scarcity have attracted the scientific interests at present. The climate change affects the net primary productivity in interactive effect with land management practices by affecting soil processes, regardless of the particular regions [7,8]. Climate change influences composite set of measurable physical (soil structure, infiltration, bulk density, plant available water and distribution, etc.) and chemical (organic matter turnover, carbon and nitrogen mass and balance, nutrient cycling and availability, etc.) soil properties [9] which relate to functional soil processes through a range of predicted global climate change drivers such as elevated temperature, altered precipitation pattern, soil moisture scarcity, atmospheric nitrogen (N) deposition and so on [10]. Soil temperature between 21-38°C increases the organic matter decomposition by increasing the movement of soluble substrates in the soil and stimulating microbial activities [11]. Nutrient availability in the soil is comprehensively influenced by the decomposition of organic matter. Water-soluble phosphorus (P) increases with soil temperature from 5-25°C due to the increase in the movement of P in soil controlled by diffusion. Soil moisture stress may have deleterious effect on chemical soil properties. Residual effects of organic amendments on chemical properties of soil was studied by earlier researcher [12] and found significant increase in organic matter and electrical conductivity. Long-lasting application of organic amendments increased organic carbon by up to 90% versus unfertilized soil and up to 100% versus chemical fertilizer application. Repeated application of composted materials enhances soil N content by up to 90%, storing it for mineralization in future cropping seasons, often without including nitrate leaching to groundwater [13]. Organic amendments play a pivotal role in climate change mitigation by soil carbon sequestration (uptake of CO<sub>2</sub> from

atmosphere – a step of biological carbon cycle), the size of which is dependent on their type, the rates and the frequency of application. Henceforth by taking these statements into account, the objectives of the present study are to screen out an environmentally sustainable way to attenuate the caustic influences of elevated temperature and moisture paucity on chemical soil properties, to ameliorate soil fertility status by the usage of rice straw compost, mustard meal and tricho-compost under changing climatic conditions and to assess the residual effects of the used amendments regarding their sustainability.

## 2. MATERIALS AND METHODS

### 2.1 Description of Study Site

Field experiments were carried out at Chandipur, Keraniganj (23°40'N, 90°18'E), Dhaka, Bangladesh from February, 2018 to May, 2018 (first season) and October, 2018 to January, 2019 (second season). The field was formerly

cultivated with Grass Pea (*Lathyrus sativus*) at the early period of Rabi season. The site map of the study area is delineated in Fig. 1. The soil belongs to Tejgaon soil series having pH of 5.55, 56.91  $\mu\text{S cm}^{-1}$  of electrical conductivity, 0.51 % of organic carbon, 1.07 m mol  $\text{kg}^{-1}$  of available N, 0.39 m mol  $\text{kg}^{-1}$  of available P, 0.41 m mol  $\text{kg}^{-1}$  of available S, 0.12 c mol  $\text{kg}^{-1}$  of exchangeable K, 2.13 c mol  $\text{kg}^{-1}$  of exchangeable Ca and 1.09 c mol  $\text{kg}^{-1}$  of exchangeable Mg.

### 2.2 Organic Amendments

Three different indigenous organic amendments viz. Rice Straw Compost (RSC) - decomposed straw of rice plants, Mustard Meal (MM) - byproduct of mustard oil seed crop and Tricho-compost (TC) - spore suspension of a *Trichoderma harzianum* with processed raw materials of cow dung, vegetable residue, etc. were applied at the rates of 0, 4, 8; 0, 3, 6; and 0, 2.5, 5 t  $\text{ha}^{-1}$ , respectively. RSC and MM were plant-derived whereas TC was *Trichoderma spp.* derived organic amendments.

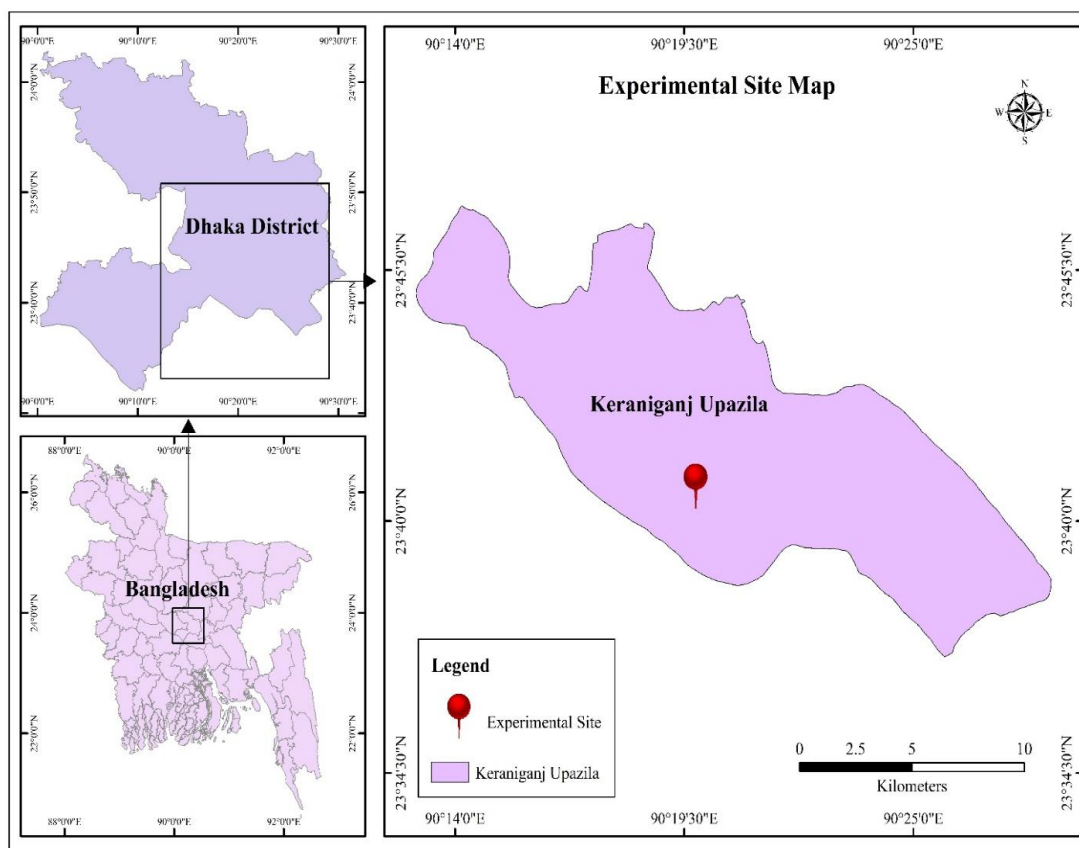


Fig. 1. Site map of the study area

**Table 1. Denotation and combination of treatments as applied in the field experiment**

Treatment		Arrangement of the treatments		
Code	Denotation	Organic amendment (rate t ha <sup>-1</sup> )	Soil temperature(°C)	Soil moisture level (%)
T <sub>1</sub>	Control(RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> TE <sub>23-25</sub> ML <sub>100</sub> )	Control soil	23-25	> 100
T <sub>2</sub>	RSC <sub>4</sub> TE <sub>23-25</sub> ML <sub>100</sub>	Rice straw compost at 4	23-25	> 100
T <sub>3</sub>	RSC <sub>8</sub> TE <sub>23-25</sub> ML <sub>100</sub>	Rice straw compost at 8	23-25	> 100
T <sub>4</sub>	MM <sub>3</sub> TE <sub>23-25</sub> ML <sub>100</sub>	Mustard meal at 3	23-25	> 100
T <sub>5</sub>	MM <sub>6</sub> TE <sub>23-25</sub> ML <sub>100</sub>	Mustard meal at 6	23-25	> 100
T <sub>6</sub>	TC <sub>2.5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	Tricho-compost at 2.5	23-25	> 100
T <sub>7</sub>	TC <sub>5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	Tricho-compost at 5	23-25	> 100
T <sub>8</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> TE <sub>26-28</sub>	Control soil	26-28	*
T <sub>9</sub>	RSC <sub>4</sub> TE <sub>26-28</sub>	Rice straw compost at 4	26-28	*
T <sub>10</sub>	RSC <sub>8</sub> TE <sub>26-28</sub>	Rice straw compost at 8	26-28	*
T <sub>11</sub>	MM <sub>3</sub> TE <sub>26-28</sub>	Mustard meal at 3	26-28	*
T <sub>12</sub>	MM <sub>6</sub> TE <sub>26-28</sub>	Mustard meal at 6	26-28	*
T <sub>13</sub>	TC <sub>2.5</sub> TE <sub>26-28</sub>	Tricho-compost at 2.5	26-28	*
T <sub>14</sub>	TC <sub>5</sub> TE <sub>26-28</sub>	Tricho-compost at 5	26-28	*
T <sub>15</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> ML <sub>70</sub>	Control soil	23-25	70
T <sub>16</sub>	RSC <sub>4</sub> ML <sub>70</sub>	Rice straw compost at 4	23-25	70
T <sub>17</sub>	RSC <sub>8</sub> ML <sub>70</sub>	Rice straw compost at 8	23-25	70
T <sub>18</sub>	MM <sub>3</sub> ML <sub>70</sub>	Mustard meal at 3	23-25	70
T <sub>19</sub>	MM <sub>6</sub> ML <sub>70</sub>	Mustard meal at 6	23-25	70
T <sub>20</sub>	TC <sub>2.5</sub> ML <sub>70</sub>	Tricho-compost at 2.5	23-25	70
T <sub>21</sub>	TC <sub>5</sub> ML <sub>70</sub>	Tricho-compost at 5	23-25	70

\*Soil moisture was practiced in these plots as required for elevating soil temperature of 26-28°C from the daily field temperature of 23-25°C

## 2.3 Experimental Design

The experiment was laid out in a split plot design with three replications, where three of the main plots was assigned for ambient field conditions (23-25°C temperature and saturated soil condition - >100% soil moisture), elevated soil temperature (26-28°C) as well as moist soil condition (70% soil moisture), respectively. In every of the main plots, different dosages of RSC, MM and TC, and rice varieties were used to the sub plots as per treatment. Each main plot consists of seven sub plots (2m × 2m). The residual effects of those treatments which were applied during rice cultivation (Feb'2018 – May, 2018) were evaluated for the subsequent bottle gourd production during Oct'2018 – Jan'2019. The denotation of the treatments and their combination used for the experiment are presented in Table 1.

## 2.4 Elevated Temperature Treatment

The soil temperature was raised by 3°C i.e. 26-28°C from the daily field temperature of 23-25°C (control plot) in the designed experimental plot by applying hot water on the furrow between the hills of rice plants 30 days after transplantation of seedlings and the heating practice was continued for 7 days separately within 40-90 days of rice growth. Temperature increment was maintained for about 6 to 7 hours in a day. The thermometers were inserted into the ground in each experimental plot to examine and record the temperature rise.

## 2.5 Soil Moisture Stress

Two different soil moisture levels such as moist (70% soil moisture) and saturated (> 100% soil moisture) conditions were practiced from 30 days after the transplantation of seedlings until maturity of rice plants by adding required amount of irrigation water. Measured amount of water for 100% soil moisture was multiplied by 0.7 to maintain 70% of soil moisture level. Saturated condition was practiced through continuous supply of irrigation water along with about 2-3 cm of standing water at the respective experimental plots, whereas moist condition was maintained through intermittent drainage of irrigation water. The field moisture content of the plots was monitored through the measurement of gravimetric water content.

## 2.6 Soil Analyses

Organic carbon content was determined by wet oxidation method [14]. For the determination of

available N by 10% NaCl extraction method [15] and for available P by Bray No. 1 extraction method [16] were used. The exchangeable cations ( $K^+$ ,  $Ca^{++}$  and  $Mg^{++}$ ) in soil samples were extracted with neutral normal 1 N ammonium acetate in addition of 3% nitric acid in the measured solution as described by researcher [17].  $K^+$  was determined by flame photometer, and  $Ca^{++}$  and  $Mg^{++}$  by atomic absorption spectrophotometer.

## 2.7 Statistical Analyses

One-way analysis of variance (ANOVA) was performed to identify the differences among the treatments. The statistical significance was accepted at  $P \leq 0.05$ . Multiple linear regression analysis was adopted to illustrate the potential contribution of C/N ratios on nutrient availability. All statistical analyses of the data were performed through using computer based statistical program Minitab-19 and IBM® SPSS® Statistics 20.

## 3. RESULTS AND DISCUSSION

### 3.1 Changes in Soil Organic Carbon

The low content of major nutrients and soil organic carbon (OC) in the studied soil indicated in need for soil amendments. The effect of elevated temperature along with RSC at 8 t ha<sup>-1</sup> (T<sub>10</sub>) was found most striking on soil OC (0.98%) among the treatments. The carry-over effects of the treatments on the OC content in subsequent soil (Jan' 2019) were found highest (1.53%) by RSC<sub>8</sub>TE<sub>26-28</sub> (T<sub>10</sub>) treatment. Alongside, the assignment of RSC at 8 t ha<sup>-1</sup> (T<sub>3</sub>) under saturated condition exerted the highest content of OC (0.94%), whereas 0.87% of OC was the maximum under moist condition (T<sub>17</sub>). The OC content was found least (0.34%) in T<sub>15</sub> treatment, where moist condition was practiced alone. As the residual effects of the treatments on the soil (Jan' 2019), OC content was found highest (1.42%) in MM at 3 t ha<sup>-1</sup> under saturated condition (T<sub>4</sub>) and 1.12% of OC by both RSC at 8 t ha<sup>-1</sup> (T<sub>17</sub>) and TC at 2.5 t ha<sup>-1</sup> (T<sub>20</sub>) under moist condition over T<sub>15</sub> treatment, as expected (Table 2). The changes of soil OC (%) were observed most prominent (98.5%) in 2019 by RSC<sub>4</sub>ML<sub>70</sub> (T<sub>16</sub>) treatment. Soil OC content was increased with soil temperature rise. Almost similar aptitudes have also been reported by previous researchers [18,19,20]. Temperature rise may support high plant productivity and organic matter input to soil and consequently increases

soil OC content [9]. Higher rice productivity was reported by earlier worker [21] under climatic stress conditions. These researchers also revealed that less water input reduced the OC content in soil compared to saturated condition which is quite corroborated the findings of the present study.

### 3.2 Changes in Nitrogen Availability

The statistical analyses demonstrated that N contents of soils were significantly ( $P \leq 0.05$ ) influenced by the elevated soil temperature along with RSC, MM and TC at their selected dosages, especially in the second trial of the experiment showed a range of 2.21 to 8.00 m mol kg<sup>-1</sup> and 1.15 to 5.64 m mol kg<sup>-1</sup> in the first trial of the experiment (Table 3). The MM at 6 t ha<sup>-1</sup> under elevated temperature of 26-28°C (T<sub>12</sub>) exerted the maximum N content (4.98 m mol kg<sup>-1</sup>) in the soil (May, 2018), whereas T<sub>8</sub> treatment (TE<sub>26-28</sub> + no organic amendments) endorsed the least N content (1.15 m mol kg<sup>-1</sup>) as expected. The carry-over effects of the treatments on the plant available N in soil (Jan' 2019) were also measured and found highest (8.00 m mol kg<sup>-1</sup>) in TC<sub>5</sub>TE<sub>26-28</sub> (T<sub>14</sub>; Table 3). Less water input, accompanied by TC at 5 t ha<sup>-1</sup> (T<sub>21</sub>) performed more striking effect on the availability of N content (5.64 m mol kg<sup>-1</sup>) in the soil (May, 2018) than saturated condition. The N contents in 2019 were increased up to 106.1% in T<sub>15</sub> treatment (ML<sub>70</sub> + no organic amendments). It might be due to less uptake of N content by the plants during first season which resulted lowest yield of rice among all treatments. During first trial of the experiment, 45.39% of the total variation in the N availability of soil in first season and 39.66% of variation in second season could be elucidated by C/N ratios of the respective soil (Fig. 2a and b). Ascending trend of N content in soil during both seasons was noticed with elevated temperature and less water input. These findings are in close conformity with the previous results stated by former investigators [9,11].

### 3.3 Changes in Carbon/Nitrogen Ratios

At field conditions, C/N ratios were found higher than those of temperature elevation and moist condition of soil and the highest value (33.0) was obtained in control (T<sub>1</sub>), where no organic amendments were applied (Table 3). At soil temperature elevation of 3°C, C/N ratios were decreased and ranged from 7.3 to 34.2 in rice soil with a few exceptions. The carry-over effects of the selected treatments on the C/N ratios of

the soil (Jan'2019) were most prominent than the first trial of experiment and ranged from 18.7 to 43.0 (Table 3). At less water input, C/N ratios were found to be decreased as compared to saturated condition which ranged from 8.7 to 34.0, except for the T<sub>15</sub> treatment (RSC<sub>0</sub>MM<sub>0</sub>TC<sub>0</sub>ML<sub>70</sub>) in rice soil (May, 2018). During the second season of the experiment, the effects of the selected treatments were most striking regarding the C/N ratio of soil (Jan' 2019) which ranged from 19.7 to 38.0.

### 3.4 Changes in Phosphorus Availability

The effect of elevated soil temperature of 26-28°C along with TC at 5 t ha<sup>-1</sup> (T<sub>14</sub>) was more pronounced on P content (0.86 m mol kg<sup>-1</sup>) in soil (May, 2018; Table 4). Treatment, T<sub>8</sub> encountered off-peak value (0.40 m mol kg<sup>-1</sup>) of P where soil temperature was raised without the application of any selected organic amendments and the magnitude of the effect for rest of the amendments was also amplified. Moist condition along with TC at 2.5 t ha<sup>-1</sup> (T<sub>20</sub>) had most prominent effect on plant available P content (0.83 m mol kg<sup>-1</sup>) in soil (May, 2018) and the least P content (0.72 m mol kg<sup>-1</sup>) was found in T<sub>15</sub> treatment as expected, where moist condition was practiced without the application of any organic amendments (Table 4). The carry-over effects of the treatments on the soil (Jan' 2019) were also assessed and found the maximal content of P (1.61 m mol kg<sup>-1</sup>) by the TC<sub>5</sub>ML<sub>70</sub> (T<sub>21</sub>), over T<sub>15</sub> treatment. The changes of P contents in 2019 were found most noteworthy (106.4%) in TC<sub>5</sub>ML<sub>70</sub> (T<sub>21</sub>) treatment. Mahmoud et al. [22] found high P content due to compost application in his study. Yilvaiaio and Pettovuori [23] observed that available P increased in soil with soil temperature of 7-28°C due to the increment in the movement of P in the soil controlled by diffusion which supports this study. C/N ratios using independent variable would be able to estimate 33.35% of total variation in the P availability in first trial and 49.23% of variation of second trial of the experiments (Fig. 2c and d).

### 3.5 Bioavailability of Potassium

The aftermath of temperature rise was increased most (0.34 c mol kg<sup>-1</sup>) by MM at 6 t ha<sup>-1</sup> and the magnitude of the effect on the availability of K contents in soil was also augmented for rest of the amendments (Table 4). The carry-over effects of the treatments on the bioavailability of K contents in the soil (Jan' 2019) were found highest (0.85 c mol kg<sup>-1</sup>) by TC<sub>5</sub>TE<sub>26-28</sub> (T<sub>14</sub>) over

**Table 2. Changes in soil organic carbon content (%) of post-harvest soils as influenced by elevated soil temperature and moisture levels along with different rates of organic amendments**

Treatment		Organic carbon content (%) in post-harvest soils				Changes in 2019 (%) <sup>c</sup>
Code	Denotation	May, 2018 <sup>a</sup>	*IOC (%)	Jan' 2019 <sup>b</sup>	*IOC (%)	
T <sub>1</sub>	Control	0.43 h	0	0.62 h	0	44.2
T <sub>2</sub>	RSC <sub>4</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.86 def	100.0	1.02 f	64.5	18.6
T <sub>3</sub>	RSC <sub>8</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.94 ab	118.6	1.32 c	112.9	40.4
T <sub>4</sub>	MM <sub>3</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.92 bc	114.0	1.42 b	129.0	54.4
T <sub>5</sub>	MM <sub>6</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.86 def	100.0	0.93 g	50.0	8.1
T <sub>6</sub>	TC <sub>2.5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.82 f	90.7	1.22 d	96.8	48.8
T <sub>7</sub>	TC <sub>5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.88 cde	104.7	0.95 g	53.2	8.0
T <sub>8</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> TE <sub>26-28</sub>	0.51 g	18.6	0.63 h	1.6	23.5
T <sub>9</sub>	RSC <sub>4</sub> TE <sub>26-28</sub>	0.88 cde	104.7	1.22 d	96.8	38.6
T <sub>10</sub>	RSC <sub>8</sub> TE <sub>26-28</sub>	0.98 a	127.9	1.53 a	146.8	56.1
T <sub>11</sub>	MM <sub>3</sub> TE <sub>26-28</sub>	0.96 ab	123.3	1.41 b	127.4	46.9
T <sub>12</sub>	MM <sub>6</sub> TE <sub>26-28</sub>	0.88 cde	104.7	1.32 c	112.9	50.0
T <sub>13</sub>	TC <sub>2.5</sub> TE <sub>26-28</sub>	0.84 ef	95.4	1.22 d	96.8	45.2
T <sub>14</sub>	TC <sub>5</sub> TE <sub>26-28</sub>	0.91 bcd	111.6	1.12 e	80.7	23.1
<b>LSD at 5%</b>		<b>.03</b>		<b>.03</b>		
T <sub>15</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> ML <sub>70</sub>	0.34 h	- 20.9	0.58 i	- 6.5	71.6
T <sub>16</sub>	RSC <sub>4</sub> ML <sub>70</sub>	0.82 def	90.7	0.89 h	43.6	98.5
T <sub>17</sub>	RSC <sub>8</sub> ML <sub>70</sub>	0.87 bcd	102.3	1.12 d	80.7	28.7
T <sub>18</sub>	MM <sub>3</sub> ML <sub>70</sub>	0.85 cde	97.7	1.02 e	64.5	20.0
T <sub>19</sub>	MM <sub>6</sub> ML <sub>70</sub>	0.80 ef	86.1	0.98 ef	58.1	22.5
T <sub>20</sub>	TC <sub>2.5</sub> ML <sub>70</sub>	0.79 f	87.7	1.12 d	80.7	41.8
T <sub>21</sub>	TC <sub>5</sub> ML <sub>70</sub>	0.85 cde	97.7	0.92 gh	48.4	8.2
<b>LSD at 5%</b>		<b>.03</b>		<b>.03</b>		

\*IOC = Increase over control. <sup>a</sup> Soil after harvesting rice; <sup>b</sup> Soil after harvesting bottle gourd;  $c = \{(b - a)/a\}\%$ . In a column, the means that do not share a letter are significantly different at 5% level by Tukey's Range Test. Treatments. T<sub>8</sub> – T<sub>14</sub> and T<sub>15</sub> – T<sub>21</sub> consecutively analyzed with T<sub>1</sub> – T<sub>7</sub> treatments by that test

**Table 3. Effect of by elevated soil temperature and moisture stress on Nitrogen content and C/N ratios incorporated with different rates of organic amendments**

Treatment		Available Nitrogen (m mol kg <sup>-1</sup> )			Carbon/Nitrogen ratios		
Code	Denotation	May, 2018 <sup>a</sup>	Jan' 2019 <sup>b</sup>	Changes in 2019 <sup>c</sup>	May, 2018 <sup>a</sup>	Jan' 2019 <sup>b</sup>	Changes in 2019 <sup>c</sup>
T <sub>1</sub>	Control	1.48 j	2.44 l	65.0	33.0 ab	42.0 a	27.3
T <sub>2</sub>	RSC <sub>4</sub> TE <sub>23-25</sub> ML <sub>100</sub>	3.43 i	4.93 k	43.7	28.7 cd	31.0 b	8.0
T <sub>3</sub>	RSC <sub>8</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.00 e	6.14 h	53.5	18.8 e	24.0 cd	27.7
T <sub>4</sub>	MM <sub>3</sub> TE <sub>23-25</sub> ML <sub>100</sub>	3.86 f	5.86 i	51.9	30.7 bc	15.8 f	- 48.5
T <sub>5</sub>	MM <sub>6</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.14 c	6.79 f	64.0	10.8 f	21.0 de	94.4
T <sub>6</sub>	TC <sub>2.5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	3.64 h	5.14 j	41.2	31.0 bc	44.0 a	41.9
T <sub>7</sub>	TC <sub>5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.00 e	7.14 e	78.5	17.6 e	23.8 cd	35.2
T <sub>8</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> TE <sub>26-28</sub>	1.15 k	2.21 m	92.2	34.2 a	43.0 a	25.7
T <sub>9</sub>	RSC <sub>4</sub> TE <sub>26-28</sub>	3.71 g	5.85 i	57.7	29.3 cd	41.0 a	39.9
T <sub>10</sub>	RSC <sub>8</sub> TE <sub>26-28</sub>	4.07 d	7.29 d	79.1	8.9 fg	21.0 de	136.0
T <sub>11</sub>	MM <sub>3</sub> TE <sub>26-28</sub>	4.01 e	6.21 g	54.9	19.2 e	27.0 bc	40.6
T <sub>12</sub>	MM <sub>6</sub> TE <sub>26-28</sub>	4.98 a	7.86 b	57.8	7.3 g	18.5 ef	153.4
T <sub>13</sub>	TC <sub>2.5</sub> TE <sub>26-28</sub>	4.37 b	7.71 c	76.4	28.0 d	41.0 a	46.4
T <sub>14</sub>	TC <sub>5</sub> TE <sub>26-28</sub>	4.42 b	8.00 a	81.0	18.2 e	18.7 ef	2.7
<b>LSD at 5%</b>		<b>.03</b>	<b>.03</b>		<b>.03</b>	<b>.03</b>	
T <sub>15</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> ML <sub>70</sub>	1.15 l	2.37 l	106.1	34.0 a	38.0 b	11.8
T <sub>16</sub>	RSC <sub>4</sub> ML <sub>70</sub>	3.81 h	5.36 h	40.7	16.4 e	19.7 ef	20.1
T <sub>17</sub>	RSC <sub>8</sub> ML <sub>70</sub>	4.43 d	6.57 e	48.3	8.7 g	16.0 fg	83.9
T <sub>18</sub>	MM <sub>3</sub> ML <sub>70</sub>	3.93 g	6.14 f	56.2	21.3 d	26.3 d	23.5
T <sub>19</sub>	MM <sub>6</sub> ML <sub>70</sub>	4.79 b	6.93 c	44.7	8.9 g	14.5 g	62.9
T <sub>20</sub>	TC <sub>2.5</sub> ML <sub>70</sub>	4.50 c	6.84 d	52.0	8.8 g	16.0 fg	81.8
T <sub>21</sub>	TC <sub>5</sub> ML <sub>70</sub>	5.64 a	7.21 a	27.8	12.1 f	23.0 de	90.0
<b>LSD at 5%</b>		<b>.03</b>	<b>.03</b>		<b>.03</b>	<b>.03</b>	

<sup>a</sup> Soil after harvesting rice; <sup>b</sup> Soil after harvesting bottle gourd;  $c = \{(b - a)/a\}\%$ . In a column, the means that do not share a letter are significantly different at 5% level by Tukey's Range Test. Treatments. T<sub>8</sub> – T<sub>14</sub> and T<sub>15</sub> – T<sub>21</sub> consecutively analyzed with T<sub>1</sub> – T<sub>7</sub> treatments by that test



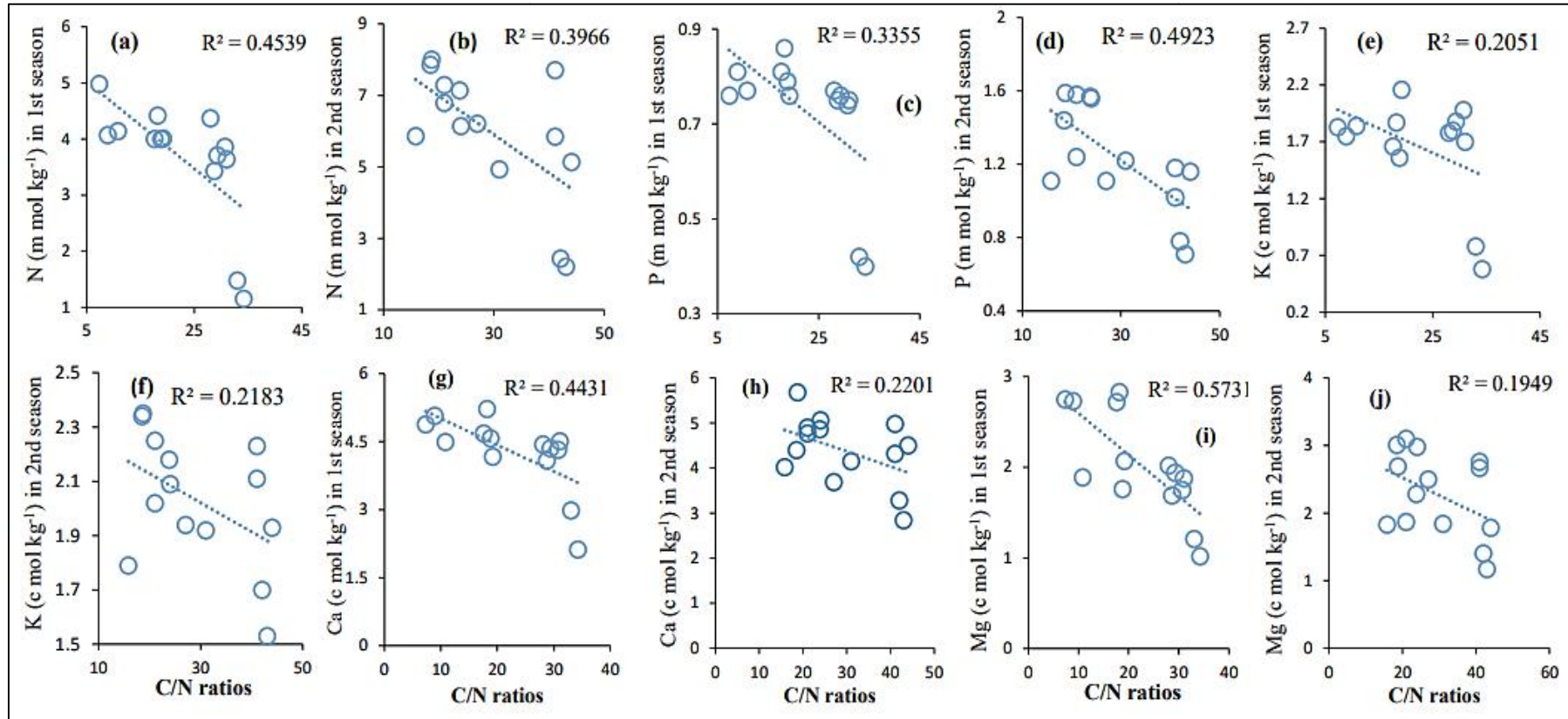


Fig. 2. Changes in N, P, K, Ca and Mg availability in first and second seasons of the experiment as affected by C/N ratios

**Table 4. Variations in Phosphorus and Potassium contents of post-harvest soils influenced by elevated soil temperature and moisture levels along with RSC, MM and TC**

Treatment		Available Phosphorus (m mol kg <sup>-1</sup> )			Exchangeable Potassium (c mol kg <sup>-1</sup> )		
Code	Denotation	May, 2018 <sup>a</sup>	Jan' 2019 <sup>b</sup>	Changes in 2019 <sup>c</sup>	May, 2018 <sup>a</sup>	Jan' 2019 <sup>b</sup>	Changes in 2019 <sup>c</sup>
T <sub>1</sub>	Control	0.42 d	0.78 h	85.7	0.12 e	0.27 fg	125.0
T <sub>2</sub>	RSC <sub>4</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.75 c	1.22 cd	62.7	0.14 de	0.32 ef	128.6
T <sub>3</sub>	RSC <sub>8</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.79 bc	1.56 a	97.5	0.21 c	0.52 c	147.6
T <sub>4</sub>	MM <sub>3</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.74 c	1.11 f	50.0	0.15 de	0.29 efg	93.3
T <sub>5</sub>	MM <sub>6</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.77 bc	1.24 c	61.0	0.27 b	0.34 e	25.9
T <sub>6</sub>	TC <sub>2.5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.75 c	1.16 ef	54.7	0.13 de	0.43 d	230.8
T <sub>7</sub>	TC <sub>5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	0.81 ab	1.57 a	93.8	0.15 de	0.55 bc	266.7
T <sub>8</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> TE <sub>26-28</sub>	0.40 d	0.71 i	77.5	0.10 e	0.24 g	140.0
T <sub>9</sub>	RSC <sub>4</sub> TE <sub>26-28</sub>	0.76 bc	1.02 g	34.2	0.15 de	0.43 d	186.7
T <sub>10</sub>	RSC <sub>8</sub> TE <sub>26-28</sub>	0.81 ab	1.58 a	95.1	0.21 c	0.58 b	176.2
T <sub>11</sub>	MM <sub>3</sub> TE <sub>26-28</sub>	0.76 bc	1.11 f	46.1	0.18 cd	0.40 d	122.2
T <sub>12</sub>	MM <sub>6</sub> TE <sub>26-28</sub>	0.76 bc	1.44 b	89.5	0.34 a	0.43 d	26.5
T <sub>13</sub>	TC <sub>2.5</sub> TE <sub>26-28</sub>	0.77 bc	1.18 de	53.3	0.12 e	0.57 bc	375.0
T <sub>14</sub>	TC <sub>5</sub> TE <sub>26-28</sub>	0.86 a	1.59 a	84.9	0.15 de	0.85 a	466.7
<b>LSD at 5%</b>		<b>.03</b>	<b>.02</b>		<b>1.44</b>	<b>2.59</b>	
T <sub>15</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> ML <sub>70</sub>	0.39 d	0.72 h	84.6	0.10 f	0.25 j	150.0
T <sub>16</sub>	RSC <sub>4</sub> ML <sub>70</sub>	0.76 bc	1.08 e	42.1	0.18 de	0.37 fg	105.6
T <sub>17</sub>	RSC <sub>8</sub> ML <sub>70</sub>	0.81 ab	1.60 a	97.5	0.24 bc	0.53 bc	120.8
T <sub>18</sub>	MM <sub>3</sub> ML <sub>70</sub>	0.75 c	0.92 f	22.7	0.21 cd	0.33 gh	57.1
T <sub>19</sub>	MM <sub>6</sub> ML <sub>70</sub>	0.74 c	1.41 b	90.5	0.31 a	0.41 ef	32.3
T <sub>20</sub>	TC <sub>2.5</sub> ML <sub>70</sub>	0.83 a	1.16 d	39.8	0.15 ef	0.48 cd	220.0
T <sub>21</sub>	TC <sub>5</sub> ML <sub>70</sub>	0.78 abc	1.61 a	106.4	0.23 bcd	0.72 a	213.0
<b>LSD at 5%</b>		<b>.03</b>	<b>.03</b>		<b>1.44</b>	<b>2.56</b>	

<sup>a</sup> Soil after harvesting rice; <sup>b</sup> Soil after harvesting bottle gourd; <sup>c</sup> =  $\{(b - a)/a\}\%$ . In a column, the means that do not share a letter are significantly different at 5% level by Tukey's Range Test

**Table 5. Changes in Calcium and Magnesium contents of post-harvest soils affected by elevated soil temperature, different moisture levels and organic amendments**

Treatment		Exchangeable Calcium(c mol kg <sup>-1</sup> )			Exchangeable Magnesium (c mol kg <sup>-1</sup> )		
Code	Denotation	May, 2018 <sup>a</sup>	Jan' 2019 <sup>b</sup>	Changes in 2019 <sup>c</sup>	May, 2018 <sup>a</sup>	Jan' 2019 <sup>b</sup>	Changes in 2019 <sup>c</sup>
T <sub>1</sub>	Control	2.98 k	3.28 l	10.1	1.21 h	1.40 j	15.7
T <sub>2</sub>	RSC <sub>4</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.08 j	4.15 i	1.7	1.69 g	1.84 h	8.9
T <sub>3</sub>	RSC <sub>8</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.57 e	5.06 b	10.7	1.76 f	2.98 b	69.3
T <sub>4</sub>	MM <sub>3</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.32 h	4.02 j	- 6.9	1.75 f	1.83 hi	4.6
T <sub>5</sub>	MM <sub>6</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.49 fg	4.77 e	6.2	1.89 de	1.87 h	- 1.1
T <sub>6</sub>	TC <sub>2.5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.51 f	4.50 f	- 0.2	1.88 e	1.78 i	- 5.3
T <sub>7</sub>	TC <sub>5</sub> TE <sub>23-25</sub> ML <sub>100</sub>	4.68 d	4.86 d	3.9	2.72 b	2.28 g	- 16.2
T <sub>8</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> TE <sub>26-28</sub>	2.12 l	2.84 m	34.0	1.02 i	1.17 k	14.7
T <sub>9</sub>	RSC <sub>4</sub> TE <sub>26-28</sub>	4.35 h	4.32 h	- 0.7	1.94 d	2.76 d	42.3
T <sub>10</sub>	RSC <sub>8</sub> TE <sub>26-28</sub>	5.07 b	4.90 d	- 3.4	2.73 b	3.10 a	13.6
T <sub>11</sub>	MM <sub>3</sub> TE <sub>26-28</sub>	4.17 i	3.69 k	- 11.5	2.07 c	2.50 f	20.8
T <sub>12</sub>	MM <sub>6</sub> TE <sub>26-28</sub>	4.88 c	4.40 g	- 9.8	2.75 b	3.01 c	9.5
T <sub>13</sub>	TC <sub>2.5</sub> TE <sub>26-28</sub>	4.44 g	4.98 c	12.2	2.02 c	2.67 e	32.2
T <sub>14</sub>	TC <sub>5</sub> TE <sub>26-28</sub>	5.22 a	5.68 a	8.8	2.83 a	2.69 e	- 5.0
<b>LSD at 5%</b>		<b>.03</b>	<b>.03</b>		<b>.03</b>	<b>.03</b>	
T <sub>15</sub>	RSC <sub>0</sub> MM <sub>0</sub> TC <sub>0</sub> ML <sub>70</sub>	2.02 j	2.78 k	37.6	1.09 i	1.22 j	11.9
T <sub>16</sub>	RSC <sub>4</sub> ML <sub>70</sub>	4.28 fg	4.41 f	3.0	1.72 fg	2.68 d	55.8
T <sub>17</sub>	RSC <sub>8</sub> ML <sub>70</sub>	5.02 b	5.14 a	2.4	1.78 e	3.08 a	73.0
T <sub>18</sub>	MM <sub>3</sub> ML <sub>70</sub>	4.25 g	4.29 g	0.9	1.78 e	1.87 g	5.1
T <sub>19</sub>	MM <sub>6</sub> ML <sub>70</sub>	4.64 c	4.74 d	2.2	1.90 d	2.27 e	19.5
T <sub>20</sub>	TC <sub>2.5</sub> ML <sub>70</sub>	4.46 e	4.89 c	9.6	1.97 c	2.13 f	8.1
T <sub>21</sub>	TC <sub>5</sub> ML <sub>70</sub>	5.97 a	5.19 a	- 13.1	2.93 a	2.78 c	- 5.1
<b>LSD at 5%</b>		<b>.03</b>	<b>.03</b>		<b>.03</b>	<b>.03</b>	

<sup>a</sup> Soil after harvesting rice; <sup>b</sup> Soil after harvesting bottle gourd;  $c = \{(b - a)/a\}\%$ . In a column, the means that do not share a letter are significantly different at 5% level by Tukey's Range Test

**Table 6. Correlation coefficient (r) of different properties of soil (May, 2018) and residual soil (Jan' 2019)**

		Soil (May 2018)						Soil (Jan'2019)					
		OC	N	P	K	Ca	Mg	OC	N	P	K	Ca	Mg
<b>Soil (May 2018)</b>	OC	1											
	N	0.83**	1										
	P	0.93**	0.91**	1									
	K	0.45*	0.65**	0.44*	1								
	Ca	0.84**	0.95**	0.90**	0.56**	1							
	Mg	0.69**	0.76**	0.63**	0.44*	0.45*	0.85**						
<b>Soil (Jan'2019)</b>	OC	0.84**	0.62**	0.72**	0.30NS	0.62**	0.59**	1					
	N	0.84**	0.94**	0.91**	0.57**	0.90**	0.82**	0.67**	1				
	P	0.71**	0.79**	0.77**	0.55**	0.87**	0.79**	0.51*	0.81**	1			
	K	0.53*	0.65**	0.65**	0.17NS	0.76**	0.71**	0.37NS	0.72**	0.79**	1		
	Ca	0.74**	0.85**	0.88**	0.43NS	0.91**	0.82**	0.49*	0.88**	0.86**	0.83**	1	
	Mg	0.46*	0.73**	0.26NS	0.84**	0.37NS	0.59**	0.51*	0.74**	0.71**	0.79**	0.82**	1

Significant at \*  $P < 0.05$  and \*\*  $P < 0.01$  (2-tailed); NS = not significant

T<sub>8</sub> treatment (Table 4). On the other hand, moist condition along with MM at 6 t ha<sup>-1</sup> (T<sub>19</sub>) attributed the best performance on K content in soil (0.31 c mol kg<sup>-1</sup>) than the saturated condition during first season. During second season, K contents were recorded maximum (0.72 c mol kg<sup>-1</sup>) in TC<sub>5</sub>ML<sub>70</sub> (T<sub>21</sub>) treatment. The K contents in both trials were statistically identical with all the treatments except T<sub>8</sub> and T<sub>15</sub> treatments, where field temperature and saturated moisture condition of soil were practiced without the application of any organic amendments (Table 4). The observations of the present study have been coincided with those reported by prior investigators [18,24,25]. Only 2.61% of the total variation in K availability of soil in first trial and 35.11% of variation in second trial could be demonstrated by C/N ratios in both seasons (Fig. 2e and f).

### 3.6 Variations in Calcium Availability

The practice of elevated temperature on the availability of Ca content in soil was most pronounced (5.22 c mol kg<sup>-1</sup>) along with TC at 5 t ha<sup>-1</sup> (T<sub>14</sub>) and the magnitude of the effects was also amplified for rest amendments, over T<sub>8</sub> treatment (TE<sub>26-28</sub> + no organic amendments), which had the least Ca content (2.12 c mol kg<sup>-1</sup>: Table 5). The moist condition, accompanied by TC at 5 t ha<sup>-1</sup> (T<sub>21</sub>) markedly increased the Ca content (5.97 c mol kg<sup>-1</sup>) in soil (May, 2018), while Ca content of 4.68 c mol kg<sup>-1</sup> was noted in TC at 5 t ha<sup>-1</sup> under saturated condition (T<sub>7</sub>) presented in Table 5. The least value of available Ca content was attained from T<sub>15</sub> treatment (ML<sub>70</sub> + no organic amendments). The Ca contents were increased up to 37.6% in 2019 at T<sub>15</sub> treatment which contributed the least yield among all treatments during both trials of experiment. These results resemble with the prior researchers [11,26].

### 3.7 Changes in Magnesium Availability

Elevated temperature was endorsed prominent ramifications on Mg content (2.83 c mol kg<sup>-1</sup>) with TC at 5 t ha<sup>-1</sup> (T<sub>14</sub>) and the magnitude of these effects on the availability of Mg contents in soil was also amplified in case of the following amendments. The carry-over effects of the treatments on the availability of Mg contents in the soil (Jan' 2019) were found that the Mg contents were significantly ( $P \leq 0.05$ ) influenced by the different treatments, especially RSC<sub>8</sub>TE<sub>26-28</sub> (T<sub>10</sub>) which endorsed the highest Mg content (3.10 c mol kg<sup>-1</sup>). At moist condition, the statistical

analyses demonstrated that Mg content during first season was recorded highest (2.93 c mol kg<sup>-1</sup>) by TC at 5 t ha<sup>-1</sup> (T<sub>21</sub>) among all the treatments (Table 5), whereas the least content of Mg was observed in T<sub>15</sub> treatment during both the trials of the experiment. The changes of Mg contents in soil were found most striking (69.3%) in 2019 from RSC<sub>8</sub>TE<sub>23-25</sub>ML<sub>100</sub> (T<sub>3</sub>) treatment.

### 3.8 Relationship among Properties of Soils (May, 2018 and Jan' 2019)

The relationships among the properties of preceding rice soil (May, 2018) and the properties of succeeding soil (Jan' 2019) are presented in Table 6 which shows that organic carbon ( $r = 0.84^{**}$ ), N ( $r = 0.84^{**}$ ), P ( $r = 0.71^{**}$ ), K ( $r = 0.53^{**}$ ), S ( $r = 0.65^{**}$ ) and Ca ( $r = 0.74^{**}$ ) contents of succeeding soil are markedly influenced by the organic carbon content of preceding rice soil. The N content of preceding soil is strongly correlated with all analyzed nutrient contents of the subsequent soil. The P content of soil (May, 2018) shows collateral behavior like N content. The S content of preceding soil has strong effect on organic carbon ( $r = 0.77^{**}$ ), N ( $r = 0.77^{**}$ ), S ( $r = 0.55^{**}$ ) and Ca ( $r = 0.59$ ) contents of soil (Jan' 2019). Besides, the Ca content of the preceding soil exerts strong influence on all the analyzed nutrient contents of the subsequent soil. These relationships are confirming that the aforementioned soil properties contents in the second season are strongly controlled by the analyzed properties of the studied soil in the first trial.

## 4. CONCLUSION

The present study deduced that soil organic matter status was markedly ameliorated at elevated soil temperature due to the imposition of tricho-compost followed by rice straw compost and mustard meal in field by considering their sustainability as well. A direct relationship was observed between soil temperature elevation and organic matter decomposition rate; subsequently, the amounts of plant available nutrients were increased. Less moisture input in soil, accompanied by the applied organic amendments had quite similar effects on the analyzed chemical soil properties compared to saturated conditions which consequently led to an efficacious irrigation water use during crop production. The present study recommended to incorporate relatively cheap biofertilizer, tricho-

compost in field to a great extent against changing climatic conditions.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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