CHAPTER 4:

OBJECTIVE 1
4.1. RESULTS

4.1.1. Plant parameters

4.1.1.1. Plant height

Plant height for wheat, okra and green gram are presented in Table 4.1. The analysis of variance (ANOVA) indicated significant (p ≤ 0.05) effect of treatment and year (except vegetative stage of wheat and flowering stage of okra and green gram) on plant height. The interaction effect of treatment × year was only significant for flowering of wheat and vegetative and maturity stage of okra and green gram (Table 4.1).

Treatments T2 and T3 recorded the highest plant height during vegetative stage of all the crops in both the years (Year 1 and Year 2). During flowering stage treatments T4, T2 and T3 recorded the highest plant height in wheat, okra and green gram respectively in year 1 while in year 2 the same was recorded under treatments T3, T2 and T4. In maturity stage, T4 recorded the highest plant height of wheat and green gram during first year while in year 2 the same was found in treatments T2 and T3 respectively. In okra, T2 recorded the highest plant height for both the years during the maturity stage.

4.1.1.2. Root biomass

Root biomass was significantly affected by treatment and year (except flowering of wheat) in all the three crops irrespective of the growth stages (Table 4.2). The interaction effect of treatment × year was significant (p ≤ 0.05) for all the growth stages of okra, vegetative stage of wheat and maturity stage of green gram.

In wheat, treatment T3 (vegetative) and T4 (flowering and maturity) recorded the highest root biomass in both the years. In green gram, treatment T2, T3 and T4 documented the highest root biomass in vegetative, flowering and maturity stage respectively. In okra, treatment T3 (flowering) and T4 (vegetative and maturity) showed the highest root biomass.
Table 4.1: Plant height (cm plant\(^{-1}\)) of the test crops under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments within a stage of crop growth period at p ≤ 0.05)

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Treatment</th>
<th>Wheat Year 1</th>
<th>Wheat Year 2</th>
<th>Okra Year 1</th>
<th>Okra Year 2</th>
<th>Green gram Year 1</th>
<th>Green gram Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetative</td>
<td>T1</td>
<td>22.2±1.3c</td>
<td>23.7±1.4d</td>
<td>16.7±1.9c</td>
<td>27.2±1.9d</td>
<td>12.6±0.9b</td>
<td>11.9±0.9b</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>29.2±1.7a</td>
<td>28.1±1.4a</td>
<td>27.9±1.6a</td>
<td>33.3±2.2a</td>
<td>15.3±0.7a</td>
<td>12.2±1.1a</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>26.2±1.1b</td>
<td>29.6±1.9a</td>
<td>26.2±2.1a</td>
<td>35.9±2.5a</td>
<td>11.2±0.5b</td>
<td>13.3±2.1a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>22.19±1.4c</td>
<td>26.0±1.6b</td>
<td>26.0±1.3a</td>
<td>33.0±1.9a</td>
<td>11.9±0.7b</td>
<td>12.9±1.0a</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>21.3±0.7c</td>
<td>24.9±1.7cd</td>
<td>24.9±1.6b</td>
<td>29.4±2.2c</td>
<td>9.7±0.8d</td>
<td>10.2±0.9c</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>21.67±1.1c</td>
<td>25.0±1.3c</td>
<td>27.9±2.2a</td>
<td>31.9±1.8b</td>
<td>10.3±0.8c</td>
<td>11.9±1.4b</td>
</tr>
<tr>
<td>Flowering</td>
<td>T1</td>
<td>51.3±1.1b</td>
<td>55.7±1.0d</td>
<td>48.4±2.1c</td>
<td>47.4±2.3d</td>
<td>27.8±1.1c</td>
<td>27.8±2.1c</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>59.3±1.0a</td>
<td>68.7±1.2ab</td>
<td>68.5±2.3a</td>
<td>67.3±2.6a</td>
<td>32.2±1.6b</td>
<td>33.2±2.7b</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>58.3±1.1a</td>
<td>71.3±1.3a</td>
<td>58.3±2.0b</td>
<td>60.1±1.8b</td>
<td>36.4±1.9a</td>
<td>37.3±1.9a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>62.3±1.4a</td>
<td>66.7±1.9b</td>
<td>52.4±2.1c</td>
<td>58.5±2.6b</td>
<td>36.1±2.1a</td>
<td>39.2±1.1a</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>54.8±1.8b</td>
<td>59.3±1.6c</td>
<td>50.2±1.2c</td>
<td>54.4±2.9c</td>
<td>30.3±2.1b</td>
<td>31.1±2.4b</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>52.1±0.9b</td>
<td>58.3±1.5cd</td>
<td>51.8±2.0c</td>
<td>56.3±2.1b</td>
<td>28.4±1.4c</td>
<td>29.1±1.2c</td>
</tr>
<tr>
<td>Maturity</td>
<td>T1</td>
<td>67.3±1.9c</td>
<td>70.3±2.1b</td>
<td>54.9±1.2c</td>
<td>56.3±2.6e</td>
<td>51.2±2.7d</td>
<td>47.2±2.2c</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>78.8±2.1a</td>
<td>84.6±2.1a</td>
<td>69.8±1.9a</td>
<td>73.3±2.6a</td>
<td>62.9±2.3b</td>
<td>64.9±1.1a</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>78.9±1.6a</td>
<td>82.1±1.7a</td>
<td>60.5±1.9b</td>
<td>69.4±1.9b</td>
<td>60.7±2.3b</td>
<td>65.4±1.1a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>81.3±2.1a</td>
<td>82.7±2.2a</td>
<td>58.7±2.1b</td>
<td>63.4±1.5c</td>
<td>66.3±1.1a</td>
<td>64.4±1.7a</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>72.9±1.6b</td>
<td>72.4±1.6b</td>
<td>50.8±2.2d</td>
<td>59.4±2.1d</td>
<td>59.4±3.1b</td>
<td>60.2±2.4b</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>66.2±1.3c</td>
<td>71.7±2.3b</td>
<td>52.2±2.4cd</td>
<td>60.7±3.1d</td>
<td>55.0±1.9c</td>
<td>58.9±2.4b</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Vegetative</th>
<th>Flowering</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>T - *; Y - ns; T×Y - ns</td>
<td>T - *; Y - *; T×Y - *</td>
<td>T - ; Y - *; T×Y - *</td>
</tr>
<tr>
<td>Year</td>
<td>T - *; Y - *; T×Y - *</td>
<td>T - *; Y - *; T×Y - *</td>
<td>T - ; Y - *; T×Y - *</td>
</tr>
</tbody>
</table>

T- Treatment, Y- Year

** significant at p≤0.01
* significant at p≤0.05
ns – non-significant
### Table 4.2: Root biomass (g plant⁻¹) of the test crops under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments within a stage of crop growth period at p ≤ 0.05)

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Treatment</th>
<th>Wheat Year 1</th>
<th>Wheat Year 2</th>
<th>Okra Year 1</th>
<th>Okra Year 2</th>
<th>Green gram Year 1</th>
<th>Green gram Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetative</td>
<td>T1</td>
<td>0.075±0.003c</td>
<td>0.095±0.008a</td>
<td>0.456±0.050c</td>
<td>0.378±0.031c</td>
<td>0.064±0.003e</td>
<td>0.056±0.008e</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>0.081±0.004b</td>
<td>0.078±0.009b</td>
<td>0.756±0.080a</td>
<td>0.650±0.021a</td>
<td>0.119±0.012b</td>
<td>0.096±0.007c</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>0.089±0.006a</td>
<td>0.086±0.010a</td>
<td>0.521±0.054b</td>
<td>0.485±0.031b</td>
<td>0.106±0.011c</td>
<td>0.102±0.010b</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>0.077±0.006c</td>
<td>0.067±0.004c</td>
<td>0.325±0.051d</td>
<td>0.356±0.042d</td>
<td>0.124±0.015a</td>
<td>0.125±0.009a</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>0.081±0.008b</td>
<td>0.087±0.008b</td>
<td>0.258±0.045e</td>
<td>0.374±0.025e</td>
<td>0.072±0.015d</td>
<td>0.056±0.007e</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>0.083±0.009b</td>
<td>0.089±0.008d</td>
<td>0.382±0.038d</td>
<td>0.365±0.045d</td>
<td>0.073±0.012d</td>
<td>0.075±0.005d</td>
</tr>
<tr>
<td>Flowering</td>
<td>T1</td>
<td>0.323±0.023b</td>
<td>0.271±0.012c</td>
<td>1.268±0.015e</td>
<td>1.604±0.051d</td>
<td>0.120±0.018e</td>
<td>0.180±0.009e</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>0.345±0.012a</td>
<td>0.325±0.021b</td>
<td>2.654±0.032b</td>
<td>2.510±0.057b</td>
<td>0.296±0.027c</td>
<td>0.253±0.021a</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>0.312±0.021b</td>
<td>0.304±0.023b</td>
<td>3.125±0.041a</td>
<td>2.912±0.061a</td>
<td>0.354±0.021a</td>
<td>0.300±0.018a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>0.345±0.032a</td>
<td>0.368±0.034a</td>
<td>1.956±0.035c</td>
<td>2.048±0.045c</td>
<td>0.258±0.021c</td>
<td>0.263±0.014b</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>0.231±0.041d</td>
<td>0.184±0.015e</td>
<td>1.965±0.041c</td>
<td>1.848±0.043d</td>
<td>0.198±0.017d</td>
<td>0.210±0.012d</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>0.262±0.023c</td>
<td>0.288±0.018d</td>
<td>1.624±0.031d</td>
<td>1.824±0.051d</td>
<td>0.244±0.019b</td>
<td>0.241±0.011c</td>
</tr>
<tr>
<td>Maturity</td>
<td>T1</td>
<td>0.498±0.023c</td>
<td>0.503±0.076d</td>
<td>1.985±0.031e</td>
<td>2.012±0.087d</td>
<td>0.198±0.015e</td>
<td>0.225±0.013e</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>0.875±0.023b</td>
<td>0.721±0.071c</td>
<td>4.123±0.023a</td>
<td>3.719±0.087ab</td>
<td>0.465±0.024c</td>
<td>0.463±0.021b</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>0.954±0.035a</td>
<td>0.871±0.064b</td>
<td>3.560±0.074b</td>
<td>3.529±0.091b</td>
<td>0.532±0.023ab</td>
<td>0.492±0.024a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>0.963±0.024a</td>
<td>1.102±0.094a</td>
<td>4.125±0.084a</td>
<td>3.961±0.078a</td>
<td>0.542±0.021a</td>
<td>0.538±0.031c</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>0.865±0.032b</td>
<td>0.871±0.084c</td>
<td>2.536±0.064d</td>
<td>3.151±0.087c</td>
<td>0.521±0.032b</td>
<td>0.535±0.027c</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>0.845±0.031b</td>
<td>0.835±0.085c</td>
<td>2.654±0.058d</td>
<td>3.142±0.079c</td>
<td>0.312±0.024d</td>
<td>0.461±0.024d</td>
</tr>
</tbody>
</table>

**ANOVA**

- **Vegetative**
  - T - *; Y - *; T×Y - *
  - T - *; Y - *; T×Y - *
  - T - *; Y - *; T×Y - ns

- **Flowering**
  - T - *; Y - ns; T×Y - ns
  - T - *; Y - *; T×Y - *
  - T - *; Y - *; T×Y – ns

- **Maturity**
  - T - **; Y - *; T×Y - ns
  - T - **; Y - *; T×Y - *
  - T - **; Y - *; T×Y - *

**T- Treatment, Y- Year**

* **significant at p<0.01**

* * significant at p<0.05**

**ns – non-significant**
Table 4.3: Shoot biomass (g plant\(^{-1}\)) of the test crops under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments within a stage of crop growth period at p ≤ 0.05)

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Treatment</th>
<th>Wheat</th>
<th>Okra</th>
<th>Green gram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 1</td>
</tr>
<tr>
<td>Vegetative</td>
<td>T1</td>
<td>0.112±0.05d</td>
<td>0.128±0.02d</td>
<td>1.256±0.09e</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>0.245±0.02b</td>
<td>0.279±0.021b</td>
<td>5.231±0.21b</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>0.302±0.04a</td>
<td>0.331±0.023a</td>
<td>5.501±0.11a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>0.298±0.01b</td>
<td>0.299±0.019b</td>
<td>4.023±0.12c</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>0.156±0.01c</td>
<td>0.158±0.011c</td>
<td>2.354±0.18d</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>0.145±0.03c</td>
<td>0.186±0.018c</td>
<td>2.245±0.11d</td>
</tr>
<tr>
<td>Flowering</td>
<td>T1</td>
<td>3.30±0.021</td>
<td>2.380±0.12c</td>
<td>16.25±1.20d</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>2.568±0.21b</td>
<td>2.668±0.21a</td>
<td>26.23±1.22b</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>2.625±0.24a</td>
<td>2.526±0.18b</td>
<td>33.21±2.41a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>2.598±0.32b</td>
<td>2.517±0.15b</td>
<td>24.25±2.11b</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>2.478±0.61c</td>
<td>2.541±0.14b</td>
<td>18.23±2.10d</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>2.321±0.51d</td>
<td>2.211±0.21d</td>
<td>21.26±2.01c</td>
</tr>
<tr>
<td>Maturity</td>
<td>T1</td>
<td>3.256±0.32c</td>
<td>4.150±0.32c</td>
<td>15.23±1.21c</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>6.892±0.51a</td>
<td>7.16±0.45a</td>
<td>32.45±1.32a</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>6.235±0.45a</td>
<td>6.928±0.51b</td>
<td>36.12±1.24a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>4.12±0.52b</td>
<td>6.973±0.29b</td>
<td>25.16±1.19b</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>3.23±0.012c</td>
<td>4.07±0.34c</td>
<td>22.98±1.09b</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>3.035±0.54c</td>
<td>4.73±0.38c</td>
<td>24.23±2.01b</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Treatment</th>
<th>Wheat</th>
<th>Okra</th>
<th>Green gram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 1</td>
</tr>
<tr>
<td>Vegetative</td>
<td>T - **; Y - ns; T×Y - ns</td>
<td>T - *; Y - *; T×Y - ns</td>
<td>T - *; Y - ns; T×Y - ns</td>
<td></td>
</tr>
<tr>
<td>Flowering</td>
<td>T - *; Y - ns; T×Y - ns</td>
<td>T - *; Y - *; T×Y - ns</td>
<td>T - *; Y - ns; T×Y - ns</td>
<td></td>
</tr>
</tbody>
</table>

T - Treatment, Y - Year ** significant at p≤0.01 * significant at p≤0.05 ns – non-significant
4.1.1.3. Shoot biomass
Table 4.3 represents the results of shoot biomass for all the crops grown under different fertilizer treatments. Analysis of the data revealed that the effects of treatment was significant (p ≤ 0.01) for all the crops and growth stages, effect of year was significant only for okra and maturity stage of wheat and green gram while the interaction effect of treatment × year was only significant for maturity stage of the crops.

Application of N fertilizer increased shoot biomass with the highest value in treatment T3 at vegetative stage of all the crops in both the years. During flowering stage, treatment T3 noted the highest shoot biomass of okra while treatments T2 (year 1) and T4 (year 2) noted the highest values of shoot biomass of green gram. During maturity stage, the highest wheat shoot biomass was noted in treatment T2 and that of okra and green gram in treatment T4.

4.1.1.4. Leaf number
The results of leaf number are presented in Table 4.4. Results of ANOVA showed that except treatment effect on leaf number during vegetative stage of wheat and maturity stage of green gram, the other effects were non-significant (Table 4).

Treatments T3 (year 1) and T4 (year 2) during vegetative, T4 during flowering and T3 during maturity stage recorded the highest values for wheat. In okra, treatments T2, T3 and T5 noted the highest leaf number in vegetative, flowering and maturity stage respectively. While for green gram, treatment T3 recorded the highest value irrespective of growth stages and year. However, the highest recorded values were not significantly different from other treatments.
Table 4.4: Leaf number (plant\(^1\)) of the test crops under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments within a stage of crop growth period at \(p \leq 0.05\))

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Treatment</th>
<th>Wheat Year 1</th>
<th>Wheat Year 2</th>
<th>Okra Year 1</th>
<th>Okra Year 2</th>
<th>Green gram Year 1</th>
<th>Green gram Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetative</td>
<td>T1</td>
<td>9±2c</td>
<td>8±2c</td>
<td>6±2a</td>
<td>5±1a</td>
<td>17±2a</td>
<td>18±2a</td>
</tr>
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<td></td>
<td>T2</td>
<td>12±2b</td>
<td>13±2b</td>
<td>7±1a</td>
<td>7±1a</td>
<td>18±1a</td>
<td>19±3a</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>15±2a</td>
<td>13±3b</td>
<td>6±2a</td>
<td>6±2a</td>
<td>19±1a</td>
<td>19±3a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>14±1a</td>
<td>16±2a</td>
<td>5±2a</td>
<td>6±1a</td>
<td>18±3a</td>
<td>17±2ab</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>10±3c</td>
<td>12±3b</td>
<td>6±2a</td>
<td>6±2a</td>
<td>16±3a</td>
<td>16±3b</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>11±2bc</td>
<td>12±3b</td>
<td>6±2a</td>
<td>5±1a</td>
<td>17±2a</td>
<td>15±3b</td>
</tr>
<tr>
<td>Flowering</td>
<td>T1</td>
<td>14±2b</td>
<td>18±3b</td>
<td>13±3a</td>
<td>11±2b</td>
<td>21±2b</td>
<td>24±3b</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>17±3a</td>
<td>22±3a</td>
<td>14±2a</td>
<td>13±2b</td>
<td>25±2a</td>
<td>27±2a</td>
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<tr>
<td></td>
<td>T3</td>
<td>18±2a</td>
<td>20±2a</td>
<td>15±3a</td>
<td>16±3a</td>
<td>26±1a</td>
<td>27±3a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>20±2a</td>
<td>21±3a</td>
<td>14±2a</td>
<td>13±2b</td>
<td>25±1a</td>
<td>27±2a</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>19±3a</td>
<td>20±3a</td>
<td>13±2a</td>
<td>12±2b</td>
<td>22±2b</td>
<td>23±4b</td>
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<tr>
<td></td>
<td>T6</td>
<td>17±2a</td>
<td>20±2a</td>
<td>13±2a</td>
<td>12±3b</td>
<td>23±2b</td>
<td>25±3b</td>
</tr>
<tr>
<td>Maturity</td>
<td>T1</td>
<td>19±3b</td>
<td>20±3b</td>
<td>13±2a</td>
<td>14±2a</td>
<td>26±3c</td>
<td>27±3c</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>21±3a</td>
<td>22±2a</td>
<td>13±2a</td>
<td>15±3a</td>
<td>32±4ab</td>
<td>31±4b</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>22±3a</td>
<td>22±2a</td>
<td>13±3a</td>
<td>15±3a</td>
<td>36±3a</td>
<td>34±2a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>20±2ab</td>
<td>19±3c</td>
<td>14±4a</td>
<td>16±3a</td>
<td>34±3a</td>
<td>30±4b</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>20±2ab</td>
<td>20±3b</td>
<td>15±4a</td>
<td>14±3a</td>
<td>31±2bc</td>
<td>29±3bc</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>19±3b</td>
<td>21±3c</td>
<td>14±3a</td>
<td>13±2a</td>
<td>28±3c</td>
<td>29±2bc</td>
</tr>
</tbody>
</table>

ANOVA: Vegetative T - *; Y - ns; T×Y - ns  
         Flowering T - ns; Y - ns; T×Y - ns  
         Maturity T - ns; Y - ns; T×Y - ns

T - Treatment, Y - Year  
** significant at \(p\leq0.01\)  
* significant at \(p\leq0.05\)  
ns – non-significant
Figure 4.1: Leaf area index of wheat (a), okra (b) and green gram (c) under different N fertilizers (Mean ± SE)
Figure 4.2: Leaf photosynthesis ($P_N \cdot \mu$mol CO$_2$ m$^{-2}$ s$^{-1}$) of wheat (a), okra (b) and green gram (c) under different N fertilizers (Mean ± SE)
4.1.1.5. Leaf area index (LAI)

Figure 4.1 represents LAI of the tested crops. Results of ANOVA showed that the effects of treatment was significant (p ≤ 0.01) for all the crops at all the growth stages. The effect of year was significant for flowering stage of wheat and green gram and vegetative stage of okra. The interaction effect of treatment × year was non-significant for all the crops and growth stages.

Irrespective of the years, both wheat and okra recorded the highest LAI in treatment T3 during vegetative and maturity stage while during flowering stage, the same was noted in treatments T2 and T4 for wheat and okra respectively. For green gram, the highest LAI during vegetative stage was recorded in treatment T4 in both the years. Treatments T2 (year 1) and T3 (year 2) recorded the highest LAI at flowering stage while, during maturity stage treatments T3 (year 1) and T4 (year 2) noted the highest LAI.

4.1.1.6. Leaf photosynthesis rate (PN)

Figure 4.2 depicts the PN of the three test crops under different fertilizer treatments measured at different growth stages. Results of ANOVA for PN showed that the effects of treatment and year (except for okra at maturity) were significant (p ≤ 0.01) for all the three tested crops. The interactions of treatment × year were non-significant for vegetative stage of all the three tested crops.

Application of N fertilizer significantly increased the PN (p ≤ 0.01) of all the tested crops. Irrespective of the years, maximum PN was noted in treatment T3 with the highest N fertilizer during vegetative stage. The highest PN during flowering and maturity stage of okra was noted in treatment T3 while in green gram the same was noted in treatments T4 and T3 during flowering and maturity stages respectively. In wheat, treatments T4 (year 1) and T3 (year 2) noted the highest PN during flowering stage while during maturity, treatment T4 documented the highest.
Table 4.5: Yield component of wheat under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grains panicle(^{-1})</th>
<th>1000 Grain weight (g)</th>
<th>High density grain (%)</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 1</td>
<td>Year 2</td>
</tr>
<tr>
<td>T1</td>
<td>28±2b</td>
<td>25±3d</td>
<td>37.23±0.9d</td>
<td>38.27±0.8b</td>
</tr>
<tr>
<td>T2</td>
<td>34±2a</td>
<td>32±2b</td>
<td>41.29±1.1a</td>
<td>42.19±1.1a</td>
</tr>
<tr>
<td>T3</td>
<td>34±3a</td>
<td>35±2a</td>
<td>40.49±1.1b</td>
<td>41.42±1.3a</td>
</tr>
<tr>
<td>T4</td>
<td>34±3a</td>
<td>33±3ab</td>
<td>40.45±1.2b</td>
<td>42.45±1.2a</td>
</tr>
<tr>
<td>T5</td>
<td>31±2ab</td>
<td>28±2c</td>
<td>38.98±0.9c</td>
<td>40.22±0.9a</td>
</tr>
<tr>
<td>T6</td>
<td>27±2b</td>
<td>29±1c</td>
<td>39.09±0.8c</td>
<td>41.21±1.2a</td>
</tr>
</tbody>
</table>

ANOVA: T - *; Y - ns; T×Y - ns  
** significant at p≤0.01  
* significant at p≤0.05  
ns – non-significant

Figure 4.3: Seed yield of wheat under different N fertilizers (Mean ± SE, Different letters indicate significant differences among the treatments for each year)
Table 4.6: Yield attributing parameters and harvest index of okra under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pod plant$^{-1}$</th>
<th>Pod length (cm)</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 1</td>
</tr>
<tr>
<td>T1</td>
<td>6±2a</td>
<td>6±2a</td>
<td>12.1±0.9b</td>
</tr>
<tr>
<td>T2</td>
<td>7±3a</td>
<td>8±1a</td>
<td>13.2±1.0ab</td>
</tr>
<tr>
<td>T3</td>
<td>8±2a</td>
<td>8±2a</td>
<td>14.1±0.7a</td>
</tr>
<tr>
<td>T4</td>
<td>8±2a</td>
<td>7±2a</td>
<td>14.6±0.9a</td>
</tr>
<tr>
<td>T5</td>
<td>6±2a</td>
<td>6±3a</td>
<td>11.8±1.2b</td>
</tr>
<tr>
<td>T6</td>
<td>5±3a</td>
<td>6±1a</td>
<td>10.3±1.1c</td>
</tr>
</tbody>
</table>

ANOVA

T - Treatment, Y - Year

** significant at p≤0.01  * significant at p≤0.05  ns – non-significant

Figure 4.4: Cumulative okra yield (q ha$^{-1}$) under different N fertilizers (Mean ± SE, Different letters indicate significant differences among the treatments for each year)
4.1.1.7. Yield of wheat

Application of N fertilizer had significant impact on yield (Figure 4.3) and yield attributing parameters (Table 4.5) of wheat. Results of ANOVA showed that treatment had significant (p ≤ 0.05) impact on yield and yield components while year (except yield) and the interaction effect of treatment × year was non-significant for the yield components.

In both the years, treatments T2, T3 and T4 noted the higher yield, grains per panicle, 1000 grain weight, high density grains and harvest index compared to control (T1), T5 and T6. However, no significant differences were observed among treatment T2, T3 and T4.

4.1.1.8. Yield of okra

Table 4.6 and Figure 4.4 represent the results of yield and yield components of okra under application of N fertilizers. Results of ANOVA showed that treatment had significant (p ≤ 0.01) impact on yield, pod length and harvest index while was non-significant for pod per plant. The effect of year (except cumulative yield) and the interaction effect of treatment × year were non-significant for the studied yield components of okra.

Compared to other treatments, higher pod per plant, pod length, harvest index and cumulative okra yield were recorded in treatments T2, T3 and T4 irrespective of years. No significant differences were noted among the treatments T2, T3 and T4.

4.1.1.9. Yield of green gram

The results of yield and yield components of green gram are presented in Figure 4.5 and Table 4.7. Results of ANOVA showed that treatment had significant (p ≤ 0.01) impact on yield and yield components while year was only significant for number of seeds per pod and yield and the interaction of treatment × year effects were non-significant for all the yield attributing parameters of green gram.

Similar to wheat and okra, higher values of seed yield and yield attributing parameters were noted in treatments T2, T3 and T4 with no significant differences among these treatments.
Table 4.7: Yield attributing parameters and harvest index of green gram under different N fertilizers (Mean ± SE, different letters indicate significant differences among the treatments)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of pod plant⁻¹</th>
<th>Number of seed pod⁻¹</th>
<th>1000 Grain weight (g)</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 1</td>
<td>Year 2</td>
</tr>
<tr>
<td>T1</td>
<td>13±2b</td>
<td>12±1b</td>
<td>4±2d</td>
<td>6±2b</td>
</tr>
<tr>
<td>T2</td>
<td>16±1a</td>
<td>17±2a</td>
<td>9±3ab</td>
<td>13±3a</td>
</tr>
<tr>
<td>T3</td>
<td>16±3a</td>
<td>18±2a</td>
<td>11±2a</td>
<td>13±2a</td>
</tr>
<tr>
<td>T4</td>
<td>17±2a</td>
<td>18±2a</td>
<td>9±3ab</td>
<td>12±2a</td>
</tr>
<tr>
<td>T5</td>
<td>16±1a</td>
<td>16±3a</td>
<td>7±2c</td>
<td>8±2b</td>
</tr>
<tr>
<td>T6</td>
<td>13±2b</td>
<td>15±2a</td>
<td>8±3bc</td>
<td>8±2b</td>
</tr>
</tbody>
</table>

ANOVA

<table>
<thead>
<tr>
<th>T - ns; Y - ns;</th>
<th>T - ns; Y - ns;</th>
<th>T - *; Y - *;</th>
<th>T - *; Y - ns;</th>
<th>T - *; Y - ns;</th>
</tr>
</thead>
<tbody>
<tr>
<td>T×Y - ns</td>
<td>T×Y - ns</td>
<td>T×Y - ns</td>
<td>T×Y - ns</td>
<td>T×Y - ns</td>
</tr>
</tbody>
</table>

** significant at p≤0.01  * significant at p≤0.05  ns – non-significant

Figure 4.5: Yield (q ha⁻¹) of green gram under different N fertilizers (Mean ± SE, Different letters indicate significant differences among the treatments for each year)
Figure 4.6: Soil organic carbon in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)

Figure 4.7: Particulate organic carbon in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)
4.1.2. Soil organic carbon and its fractions

4.1.2.1. Soil organic carbon (SOC)

Soil organic carbon increased as a function of increasing dose of N fertilizers with the more prominent changes in top soil than sub soil (Figure 4.60). Irrespective of depths at the end of two years, T3 (1.38% in top and 0.88% in sub) documented the highest values SOC content followed by T2 (1.37% in top and 0.83% in sub) and T4 (1.35% in top and 0.85% in sub) while SOC decreased (1.25%) in control plots (T1) over the experimental period. Compared to the basic soil, the highest increase in SOC (7.0%) was noted in T3 compared to the basic soil while over the years highest increase was noted in T4 (3.1% increase in year 2 over year 1). Results of ANOVA indicated that treatment, year and interaction of treatment × year had significant impacts on SOC in both the soil layers (top and sub).

4.1.2.2. Particulate organic carbon (POC)

Irrespective of soil depths, fertilizer treatments and cultivation over years have significant effect on POC while the interaction effect of treatment × year was significant only for top soil. With increased application of N fertilizers, POC also increased especially in the top soil. With continuous cultivation, POC increased with the highest value in treatment T2 (1.08% in top and 0.44% in sub) followed by T3 (1.00% in top and 0.44% in sub) at the end of two years. In control plots also, significant increase (15% in top and 6.7% in sub) in POC was noted at the end of two years. In treatment T5, a decrease in POC was noted during second year of cultivation.
Table 4.8: Microbial biomass carbon (mg kg\(^{-1}\)) in top and sub soil under different N fertilizers (Mean ± SE, different letters in a column indicate significant differences among the treatments in each soil depth at p \(\leq 0.05\))

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Treatment</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wheat</td>
<td>Okra</td>
<td>Green grain</td>
</tr>
<tr>
<td>Top soil</td>
<td>T1</td>
<td>164±12c</td>
<td>186±14b</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>184±11b</td>
<td>207±11c</td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>192±17a</td>
<td>174±15a</td>
</tr>
<tr>
<td></td>
<td>T4</td>
<td>221±13a</td>
<td>215±14a</td>
</tr>
<tr>
<td></td>
<td>T5</td>
<td>175±17bc</td>
<td>198±19b</td>
</tr>
<tr>
<td></td>
<td>T6</td>
<td>184±13b</td>
<td>195±15b</td>
</tr>
</tbody>
</table>

ANOVA T-***; Y-**; T×Y-**

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Treatment</th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub soil</td>
<td>T1</td>
<td>121±9c</td>
<td>135±11c</td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>158±14a</td>
<td>148±13b</td>
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<tr>
<td></td>
<td>T3</td>
<td>145±12b</td>
<td>147±11a</td>
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<tr>
<td></td>
<td>T4</td>
<td>162±11a</td>
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</tr>
<tr>
<td></td>
<td>T6</td>
<td>128±11c</td>
<td>142±12bc</td>
</tr>
</tbody>
</table>

ANOVA T-ns; Y- ns; T×Y-ns

T- Treatment  Y- Year

** significant at p≤0.01  * significant at p≤0.05  ns – non-significant

4.1.2.3. Microbial biomass carbon (MBC)

The results of MBC are presented in Table 4.8. Microbial biomass carbon was higher in treatments T2 and T4 compared to T5, T6 and control plots (T1) in both top and sub soil. However, no consistency was observed in increase or decrease of MBC with the applied N doses. Significantly higher MBC was recorded in top soil than that of sub soil. At the end of the experimental period, significantly higher MBC was recorded in all the treatments (16-67% in top soil and 3-33% in sub soil) with the highest increase recorded in treatment T2 (67%) in top soil and T4 (33%) in sub soil. Results of ANOVA indicated that treatment, year and interaction of treatment × year were significant for MBC in top soil while the same non-significant for sub soil.
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Figure 4.8: Humic acid carbon in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)

Figure 4.9: Fulvic acid carbon in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)
4.1.2.4. Humic acid carbon (HAC)
The data of HAC are presented in Figure 4.8. Results of ANOVA showed that treatments have significant affect in both the soil depths, while year and the interaction of treatment × year were significant only in top soil. Treatment T3 followed by T2 and T4 noted the highest HAC values at the end of two years. Significant increase in HAC was noted at the end of two years in all the treatments including control. The highest increase was recorded in treatment T2 (approximately doubled) while control noted the lowest increase (57%) in top soil. In the sub soil, the highest increase was noted in treatment T2 (22%) while in control and T6 no increase was recorded compared to the basic soil.

4.1.2.5. Fulvic acid carbon (FAC)
The results of FAC are presented in Figure 4.9. For FAC, ANOVA results showed that only treatment and year had significant affect in top soil while, in sub soil all the effects were non-significant. In both the soil depths, the highest values were recorded in T3 (0.86% in top soil and 0.92% in sub soil) while control plots noted the lowest. Continuous application of inorganic fertilizers significantly increased (51-100%) the FAC in top soil while in sub soil, the increase (1.4-31.2%) was less pronounced.
4.1.2.5. Degree of humification (E4/E6)

Figure 4.10 shows the results of E4/E6. The results of ANOVA showed that only treatment had significant effect on E4/E6 in both the soil depths. Treatments T2 and T3 noted the highest value of E4/E6 in both the soil depths. Control (T1) noted the lowest value while treatment T4 showed significantly lower value than the treatments T2 and T3.
Figure 4.11: Sensitivity index of different carbon fractions in top (a and c) and sub (b and d) soil in year 1 (a and b) and year 2 (c and d) (Mean ± SE)
4.1.2.6. Sensitivity index (SI) of different soil organic carbon fractions

The results of SI of different SOC fractions are presented in Figure 4.11. The SI was higher in top soil than that of sub soil and SI also increased with the continuous cultivation and addition of inorganic N fertilizers at different doses. Among the studied SOC fractions, POC and MBC noted the highest sensitivity to the application of inorganic fertilizer while SOC and E4/E6 showed the lowest sensitivity to fertilizer application.

4.1.2.7. Correlation study

Correlations among the different SOC fractions and the studied parameters are presented in Table 4.9 (top soil) and Table 4.10 (sub soil). Significant positive correlation among the C fractions was noted and these relations were more positive in top soil than sub soil. The E4/E6 showed a significant positive correlation with the SOC. Soil C fractions showed a significant positive correlation with the concentration of soil available N while a negative correlation was noted with soil pH.
4.1.3. Soil chemical properties

4.1.3.1. Soil available N

The results of soil available N are presented in Figure 4.12. The ANOVA results showed that effects of fertilizer treatments and year were significant for both the soil depths while the interaction effect of treatment × year was significant only for top soil. Continuous application of fertilizers over a period of two years significantly increased soil available N with the highest increase noted in treatment T3 (78% in top soil and 48% in sub soil) followed by T2 (73% in top soil and 60% in sub soil) compared to the basic soil. Control plots recorded significant decrease (9% in top soil and 11% in sub soil) in soil available N. The increase in soil available N was more pronounced in top soil than sub soil. Soil available N showed a positive correlation with yield of all three tested crop (Table 4.9 and Table 4.10).

4.1.3.2. Soil available P

Figure 4.13 represents the results of soil available P. Soil available P was higher in top soil than that of sub soil. The ANOVA results showed that effects of fertilizer treatments, year and interaction of treatment × year were significant for top soil while, in sub soil the effects were non-significant. Continuous application of fertilizers over a period of two years noted significant accumulation of available P with the highest value noted in treatment T4 (82 kg ha⁻¹) while control plots noted the lowest (32 kg ha⁻¹) value in top soil. No significant differences among the treatments were recorded in sub soil at the end of two years.
Figure 4.12: Soil available nitrogen (N) (kg ha\(^{-1}\)) in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)

Figure 4.13: Soil available phosphorous (P) (kg ha\(^{-1}\)) in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)
Figure 4.14: Soil available potassium (K) (kg ha\(^{-1}\)) in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)

Figure 4.15: Soil pH in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)
4.1.3.3. Soil available K
The results of soil available K are presented in Figure 4.14. ANOVA showed that only the effect of year on soil available K was significant in top soil while the other effects were non-significant. Fertilizer application over a period of two years significantly enhanced the available K concentration with pronounced accumulation in top soil (29-39%) than that of sub soil (19-23%). No significant differences were observed at the end of two years among the fertilizer treatments.

4.1.3.4. Soil pH
The results of soil pH are presented in Figure 4.15. Results of ANOVA documented significant effect of fertilizer treatments, cultivation over years and the interaction effect of treatment × year on soil pH in both the soil depths. Continuous application of inorganic fertilizers for a period of two years significantly decreased soil pH in both the soil depths with higher decrease in top soil (0.9-5.1%) than sub soil (0.2-2.0%). Soil pH decreased with the increasing dose of N fertilizers. The lowest soil pH was noted in treatment T3 followed by T2 and T4 in both the soil depths. A decrease of 5.1% and 2.0% in T3, 4.0% and 1.6% in T2, 2.6% and 1.2% in T4 was observed for pH in top and sub soil respectively. Soil pH documented a negative correlation with SOC and crop yield of the tested crops (Table 4.9 and Table 4.10).

4.1.4. Soil physical properties (BD and WHC)
The results of BD and WHC are presented in Figure 4.16 and Figure 4.17. Application of only inorganic fertilizers reduced the BD and increased WHC and this trend was more prominent in top soil than sub soil. ANOVA results of top soil showed a significant effect of fertilizer treatment on BD and year on BD and WHC while the other effects were non-significant in both the soil depths. A decrease in BD (0.9-3.6% in top and 0.8-2.5% in sub soil) was recorded while WHC increased (9-20% in top and 5-15% in sub soil). The highest WHC was recorded in treatment T2 but no significant differences were noted among the treatments. The lowest BD was noted in T2 (1.07 Mg m⁻³ in top and 1.16 Mg m⁻³ in sub soil) and the highest (1.10 Mg m⁻³ in top and 1.18Mg m⁻³ in sub soil) values were recorded from control (T1) plots.
Figure 4.16: Bulk density (Mg m\(^{-3}\)) in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)

Figure 4.17: Water holding capacity (%) in top (a) and sub (b) soil under different N fertilizers (Mean ± SE)
Table 4.9: Pearson’s correlation coefficients (r values) of top soil at the end of two years for association among soil organic carbon (SOC), particulate organic carbon (POC), microbial biomass carbon (MBC), humic acid carbon (HAC), fulvic acid carbon (FAC), E4/E6, available N, P, K, soil pH and yield of wheat, okra and green gram

<table>
<thead>
<tr>
<th></th>
<th>SOC</th>
<th>POC</th>
<th>MBC</th>
<th>HAC</th>
<th>FAC</th>
<th>E4/E6</th>
<th>Available N</th>
<th>Available P</th>
<th>Available K</th>
<th>pH</th>
<th>Wheat Yield</th>
<th>Okra Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>POC</td>
<td>0.732</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>MBC</td>
<td>0.844*</td>
<td>0.768</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAC</td>
<td>0.839*</td>
<td>0.762</td>
<td>0.919**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>FAC</td>
<td>0.890*</td>
<td>0.915*</td>
<td>0.893*</td>
<td>0.922**</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E4/E6</td>
<td>0.986**</td>
<td>0.707</td>
<td>0.783</td>
<td>0.763</td>
<td>0.865*</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Available N</td>
<td>0.920**</td>
<td>0.922**</td>
<td>0.836*</td>
<td>0.873*</td>
<td>0.984**</td>
<td>0.907*</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Available P</td>
<td>0.913*</td>
<td>0.407</td>
<td>0.702</td>
<td>0.709</td>
<td>0.653</td>
<td>0.888*</td>
<td>0.691</td>
<td></td>
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</tr>
<tr>
<td>Available K</td>
<td>0.880*</td>
<td>0.403</td>
<td>0.597</td>
<td>0.547</td>
<td>0.569</td>
<td>0.878*</td>
<td>0.648</td>
<td>0.955**</td>
<td></td>
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</tr>
<tr>
<td>pH</td>
<td>-0.807</td>
<td>-0.962**</td>
<td>-0.804</td>
<td>-0.759</td>
<td>-0.947**</td>
<td>-0.814*</td>
<td>-0.951**</td>
<td>-0.497</td>
<td>-0.490</td>
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<td></td>
</tr>
<tr>
<td>Wheat Yield</td>
<td>0.963**</td>
<td>0.714</td>
<td>0.825*</td>
<td>0.914*</td>
<td>0.909*</td>
<td>0.933**</td>
<td>0.920**</td>
<td>0.880*</td>
<td>0.782</td>
<td>-0.767</td>
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</tr>
<tr>
<td>Okra Yield</td>
<td>0.943**</td>
<td>0.678</td>
<td>0.797</td>
<td>0.905*</td>
<td>0.896*</td>
<td>0.919**</td>
<td>0.902*</td>
<td>0.865*</td>
<td>0.751</td>
<td>-0.744</td>
<td>0.996**</td>
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<tr>
<td>Green gram Yield</td>
<td>0.965**</td>
<td>0.752</td>
<td>0.828*</td>
<td>0.914*</td>
<td>0.909*</td>
<td>0.924**</td>
<td>0.930**</td>
<td>0.874*</td>
<td>0.795</td>
<td>-0.777</td>
<td>0.992**</td>
<td>0.977**</td>
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</table>

**. Correlation is significant at the 0.01 level
*. Correlation is significant at the 0.05 level
**Table 4.10:** Pearson’s correlation coefficients (r values) of sub soil at the end of two years for association among soil organic carbon (SOC), particulate organic carbon (POC), microbial biomass carbon (MBC), humic acid carbon (HAC), fulvic acid carbon (FAC), E4/E6, available N, P, K, soil pH and yield of wheat, okra and green gram

<table>
<thead>
<tr>
<th></th>
<th>SOC</th>
<th>POC</th>
<th>MBC</th>
<th>HAC</th>
<th>FAC</th>
<th>E4/E6</th>
<th>Available N</th>
<th>Available P</th>
<th>Available K</th>
<th>pH</th>
<th>Wheat Yield</th>
<th>Okra Yield</th>
<th>Green gram Yield</th>
</tr>
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<tbody>
<tr>
<td>POC</td>
<td>0.617</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>MBC</td>
<td>0.690</td>
<td>0.625</td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>HAC</td>
<td>0.695</td>
<td>0.565</td>
<td>0.665</td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>FAC</td>
<td>0.967**</td>
<td>0.637</td>
<td>0.0832*</td>
<td>0.707</td>
<td></td>
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<tr>
<td>E4/E6</td>
<td>0.886*</td>
<td>0.812*</td>
<td>0.592</td>
<td>0.793</td>
<td>0.814*</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Available N</td>
<td>0.772</td>
<td>0.771</td>
<td>0.551</td>
<td>0.904*</td>
<td>0.736</td>
<td>0.921**</td>
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<tr>
<td>Available P</td>
<td>0.613</td>
<td>0.926**</td>
<td>0.613</td>
<td>0.795</td>
<td>0.613</td>
<td>0.869*</td>
<td>0.904*</td>
<td></td>
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<tr>
<td>Available K</td>
<td>0.681</td>
<td>0.589</td>
<td>0.313</td>
<td>0.47</td>
<td>0.532</td>
<td>0.835*</td>
<td>0.594</td>
<td>0.617</td>
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<tr>
<td>pH</td>
<td>-0.913*</td>
<td>-0.559</td>
<td>-0.658</td>
<td>-0.868*</td>
<td>-0.905*</td>
<td>-0.840*</td>
<td>-0.887*</td>
<td>-0.665</td>
<td>-0.480</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Wheat Yield</td>
<td>0.927**</td>
<td>0.715</td>
<td>0.756</td>
<td>0.896*</td>
<td>0.911*</td>
<td>0.948**</td>
<td>0.909*</td>
<td>0.812*</td>
<td>0.703</td>
<td>-0.932**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Okra Yield</td>
<td>0.925**</td>
<td>0.718</td>
<td>0.654</td>
<td>0.715</td>
<td>0.857*</td>
<td>0.959**</td>
<td>0.793</td>
<td>0.746</td>
<td>0.887*</td>
<td>-0.796</td>
<td>0.937**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green gram Yield</td>
<td>0.922**</td>
<td>0.727</td>
<td>0.718</td>
<td>0.836*</td>
<td>0.880*</td>
<td>0.968**</td>
<td>0.868*</td>
<td>0.805</td>
<td>0.813*</td>
<td>-0.867*</td>
<td>0.984**</td>
<td>0.981**</td>
<td></td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level  *. Correlation is significant at the 0.05 level
Table 4.11: Carbon pool index (CPI), humic: fulvic acid ratio (HAC:FAC) of top and sub soil and agronomic efficiency (AE) of the fertilizer treatments at the end of two years (Different letters in a row indicate significant differences among the treatments for each parameter at p ≤ 0.05)

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPI Top soil</td>
<td>1.00d</td>
<td>1.10a</td>
<td>1.10a</td>
<td>1.08b</td>
<td>1.06c</td>
<td>1.06c</td>
</tr>
<tr>
<td>CPI Sub soil</td>
<td>1.00e</td>
<td>1.11bc</td>
<td>1.17a</td>
<td>1.13b</td>
<td>1.09c</td>
<td>1.05d</td>
</tr>
<tr>
<td>HAC:FAC Top soil</td>
<td>0.843a</td>
<td>0.765b</td>
<td>0.767b</td>
<td>0.844a</td>
<td>0.676c</td>
<td>0.754b</td>
</tr>
<tr>
<td>HAC:FAC Sub soil</td>
<td>0.913a</td>
<td>0.961a</td>
<td>0.937a</td>
<td>0.892b</td>
<td>0.871b</td>
<td>0.869b</td>
</tr>
<tr>
<td>AE Wheat (kg kg⁻¹)</td>
<td>.</td>
<td>18.8b</td>
<td>15.3c</td>
<td>19.7b</td>
<td>21.1b</td>
<td>26.3a</td>
</tr>
<tr>
<td>AE Okra (kg kg⁻¹)</td>
<td>.</td>
<td>34.1a</td>
<td>28.0b</td>
<td>35.7a</td>
<td>35.0a</td>
<td>22.3c</td>
</tr>
<tr>
<td>AE Green gram (kg kg⁻¹)</td>
<td>-</td>
<td>4.8ab</td>
<td>3.7c</td>
<td>5.1a</td>
<td>3.9c</td>
<td>4.3bc</td>
</tr>
</tbody>
</table>

4.1.5. Agronomic evaluation and soil organic carbon indices

At the end of two years of continuous application of inorganic fertilizers, treatment T3 noted the highest CPI in both the soil depths and HAC:FAC in sub soil while the HAC:FAC ratio of top soil was highest in treatment T4 (Table 4.11). The results of agronomic efficiency for the applied fertilizer treatments noted significantly higher values in treatment T4 for okra and green gram while for wheat the same was noted in T6 (Table 4.11). Treatment T3 with 120% of recommended N fertilizers noted significantly lower values of agronomic efficiency for all the three tested crops.
4.2. DISCUSSION

Amongst the essential nutritional elements, plants require a higher quantity of nitrogen (N) for their growth and development. Therefore, the availability of soil N and its plant uptake determine the concomitant N metabolism, partitioning of plant biomass and finally crop yield. Being highly mobile nutrient, the quantity and timing of N application significantly affect nutrient availability, photosynthesis, plant growth and yield [1]. However, excessive application of N fertilizers also causes environmental pollution.

4.2.1. Effect of N fertilization on plant height, root and shoot biomass

Both plant height and biomass (Table 4.1, 4.2 and 4.3) increased with the advancement of plant growth stages which directly represents the sigmoid S-shaped growth curve (the highest increase during vegetative and flowering stage and steady growth towards maturity). The observed increased plant height in higher N fertilized plots (T2, T3 and T4) in both the years is due the higher absorption of N by the plants under increased availability of N which increase the tissue N concentration. This condition triggers the production of growth-promoting hormone cytokinin [2] which subsequently improve the cell wall elasticity, number of meristematic cells and cell growth [3] enhancing plant elongation or increased plant height. This also justifies the lesser plant height of wheat, okra and green gram in the treatments with 75% (T5), 50% (T6) and 0% (T1) N fertilizer (Table 4.1). Similar results of increased plant height due to application of higher N fertilizer dose (150 kg ha⁻¹) in wheat-soybean and maize-soybean crop sequence has been reported by Divito et al. [4]. Andivia et al. [5] also reported increase seedling height and root collar diameter of oak (Quercus ilex L.) seedlings with the application of N fertilizer.

N fertilization has positive effect on shoot biomass production [6]. Root absorbs N (mostly as nitrate) from soil by means of specific high and low affinity transporters located in the root cell membrane. Nitrates are then reduced to nitrite by the enzyme nitrate reductase in root cytosols and the newly formed nitrites are then transported to chloroplast for reduction to ammonia by the enzyme nitrite reductase and then assimilated into the cellular system to form amino acids [7]. The amino acids formed, stimulate the storage and transport of proteins, RNA and DNA replication [8] which subsequently enhance cell replication and biomass production. This mechanism of
biomass production explains the observed increase in shoot biomass under application N fertilizers. However, application of higher N doses increases the N availability and fastens the growth process, which justifies the production of higher shoot biomass under the treatments T2, T3 and T4 of the present study (Table 4.3). Increased shoot biomass of rice and wheat under inorganic N fertilizer application has been demonstrated by Purakayastha et al. [9] and Hati et al. [10] from the Indo-Gangetic plains of India.

Optimum N fertilization have a positive effect on root growth, which is supported by previous findings where the N availability has documented significant effect on root biomass production, mortality, root elongation and higher root development and branching [11,12]. In the present study, higher N applied plots (T2, T3 and T4) documented higher root biomass compared to control (T1), 75% (T5) and 50% (T6) N applied plots (Table 4.2) which is in confirmation with the previous findings of Razaq et al. [13] on maple (Acer mono L.) plants. One interesting finding of the present study is that the production of root biomass decreased in the second year of cultivation in higher N fertilized plots (T2 and T3) for all the tested crops. This can be attributed to the prolonged metaphase under higher N availability during mitosis division of root meristematic cells [14] as in the present experiment we documented higher availability of soil N in the second year of cultivation. Similar result of decreased root biomass production in winter wheat cultivars at higher N levels (above 150 kg ha$^{-1}$) has been reported by Rasmussen et al. [15].

4.2.2. Effect of N fertilization on leaf number, leaf area index and photosynthesis

The recorded highest increase in leaf number during vegetative to flowering stage can be attributed to the fact that vegetative stage is the most active growth period for the development of plant parts which ceases towards maturity. Nitrogen fertilization affected the number of leaves to a very lesser extent whereas a significant enhancing effect on the leaf area development was noted. It might be due to the reason that leaf number is an attribute of the genetic make-up of the crops rather than controlled by the environmental or external factors [16].

Leaf area index is the ratio of total leaf area (m$^2$) of a plant per m$^2$ of ground area and provides information about the adequate crop canopy cover for maximum light
interception. Thus, LAI is directly proportional to the expansion of leaves or increased leaf area. Addition of N fertilizer activates the elongation of the leaf epidermal and mesophyll cells [17] by inducing the activity of endogenous cytokinin level and thus increase the cell number at the leaf base [16]. This fact justifies the increased LAI under 120%, 100% and 90% of recommended N applied plots compared to the reduced (0%, 75% and 50%) N applied plots. However, the degree of increased LAI is a function of plant growth stage and in the present investigation, increased LAI was noted during vegetative and flowering stage of wheat and okra but creases during maturity. While in green gram, LAI continued to increase till maturity stage. Increased LAI in loblolly pine (Pinus taeda L.) stands under higher N fertilization has been recorded by Maggard et al. [18].

N fertilization stimulates the division of leaf mesophyll cells at a higher rate than the epidermal cells [17], which are the major site for photosynthesis in plant as it contains large populations of chloroplast organelles. Thus, the increased mesophyll cells and leaf area provide surface for higher plant photosynthesis. Increased leaf area (Figure 4.1) and soil N availability (Figure 4.12) under the application of higher N fertilizer enhance the light interception, gas exchange in the internal airspaces [19] and N uptake that triggers higher photosynthesis in treatments with higher N levels (T2 and T3) (Figure 4.2). Studies also reported that N deficiency either reduce the activity or the concentration of enzyme Rubisco (enzyme that catalyze the first reaction of photosynthesis and fixes CO₂) [20]. This might be the reason for lower $P_N$ in treatments (T1, T5 and T6) with reduced doses or without N fertilizer. However, the observed higher $P_N$ during vegetative and flowering stage than maturity stage of all the three tested crops might be attributed to the higher mobilization of N to the fruits from the leaves, as during post-anthesis stage the uptake of N decreases and demand for N to the fruit increases [16]. Increased $P_N$ under N fertilizer application has also been documented by Sivasankar et al. [16], Ma et al. [21] in Narrow-leafed Lupin (Lupinus angustifolius L.), Tranavičienė et al. [22] in winter wheat and Jiang et al. [23] in tobacco (Nicotiana tabacum L.) leaves.

4.2.3. Effect of N fertilization on yield and yield attributing parameters of wheat, okra and green gram
Crop yield is the function of several yield attributing parameters such as pods or panicle per plant, seeds per pod or panicle and the cumulative weight of the seeds in wheat and green gram and pods in case of okra. In the present study, the recorded higher number of grains per panicle, 1000 grain weight and high density grain of wheat; pod per plant of okra and number of pod per plant, number of seed per pod and 1000 grain weight of green gram under treatments T2 and T3 (Table 4.5, 4.6 and 4.7) implies that under application of higher N fertilizer, there is improvement in yield attributing parameters which in turn increased the overall crop yield. Application of N fertilizer increases soil available N as well as nutrient uptake, especially N along with efficient plant metabolism and photosynthesis which finally contributed to the higher crop yield. Reduced doses of N application delayed the flowering period due to slow emergence and development of leaves which prolonged the vegetative growth period [21]. This fact justifies the lower pod and grain weight in reduced N fertilized plots compared to treatments T2, T3 and T4.

One interesting finding of the present study is that in all the three tested crops, harvest index was higher in treatment T4 than treatments T2 and T3 and there were no significant differences among the treatments T2, T3 and T4 especially in year 2. This indicates that application of excess N fertilizer did not increase the economic yield rather it contributed to the development of the other plant parts (leaf, stem and roots) and thereby decreasing the harvest index. This finding also indicated that under continuous application of N, reducing the N application doses by 10% of the recommended would be a sustainable option to obtain higher N use efficiency and reduce the risk of nitrate accumulation and pollution in the environment.

4.2.4. Effect of N fertilization on soil organic carbon and its fractions

The increased SOC pool as a result of N fertilizer application is more pronounced in the top soil layer than that of sub soil which is due to the higher farming activities in the top soil (0-15 cm) coupled with the presence of higher root biomass and litter decomposition. Nitrogen fertilization does not have direct effect on the SOC pool rather indirectly enhances the SOC stock by increasing the residue return. Nitrogen fertilizers supply readily available plant nutrients which increase plant photosynthesis, above-ground biomass, rooting depth and root proliferation [24,25]. This increased shoot and root
biomass in turn increase the residue return to soil in the form of litter fall, sloughed off roots and also release the root exudates and secondary metabolites to the soil (both top and sub soil layer) which add to the SOC pool. In the present investigation, treatments with lower N fertilizer doses (T5 and T6) yielded lesser biomass production which is the reason for lower SOC increase in these plots. However, in control plots the decreased SOC might have been due to the extraction of organic matter by the crops in absence of external fertilizer input. Yadav [26] reported increased SOC under continuous application of different combinations of N, P and K fertilizers while it decreased in unfertilized soils. Liebig et al. [27] documented 1.0-1.4 Mg ha\(^{-1}\) greater SOC in 0–7.6 cm soil depth under application of 180 kg N ha\(^{-1}\) over a period of 16 years. Increased SOC under inorganic fertilization is documented by many researchers [9,28].

The significant increase in POC, which constitutes the partly decomposed plant material (sloughed off roots, root exudates, microbial debris, etc.) at an early stage of decomposition [29], is due to the addition of root biomass by the growing plants which is more pronounced in the top soil. Also the increased root and microbial activities under the application of higher N fertilizers 100% (T2) and 120% (T3) resulted in increased POC in both the soil layers while the reverse holds true for the lower (75% and 50%) N fertilized plots. This signifies the importance of increasing or decreasing residue return by N fertilization which in turn shifts the POC dynamics. DuPont et al. [30] also highlighted the important role of roots and belowground allocation in POC formation. Increased POC due to application of N fertilizers upto 30 cm soil layer is reported by Purakayastha et al. [9] and Divito et al. [4] while working in rice-wheat crop sequence in India and Argentinean Pampas respectively.

The MBC fraction of SOC, that constitutes the living pool of SOC, showed no linear relation with the applied N fertilizer. Such inconsistency in MBC content under different levels of N fertilizer has also been reported earlier [31]. The noted higher MBC in top soil layer is due to the higher availability of nutrient and soil moisture (23-33%) along with favorable soil temperature (18-25 °C) which provides more suitable environment for microbial growth than that of the sub soil. The recorded lower MBC in 120% N applied plots might be due to the growth inhibition of a particular microbial community in presence of higher soil available N [32]. While the increased substrate
availability (in the form of POC and other plant debris) under 100% and 90% N fertilized plots might have resulted in higher MBC. The lower nutrient content in 75%, 50% and 0% N applied plots might have led to the decreased MBC under these treatments.

Being microbially recalcitrant and relatively stable reservoir of SOC, the increased HAC and FAC in the present investigation indicates the stabilization and formation of persistent organic C under the application N fertilizer. Song et al. [33] reported increased HAC and FAC over control as a result of N fertilizer application. The E4/E6 ratio (the ratio absorbance at 465 nm and 665 nm), that indicates the degree of condensation of chain of aromatic carbons [34] was higher in treatments T2 and T3. This indicates higher extraction of aliphatic groups from N fertilized soils and thereby decreasing SOC stability. This increases the availability of humic substances for plant utilization [33]. The recorded significantly lower E4/E6 value in control plots and sub soil layer indicates the accumulation of aromatic functional group with higher stability of SOC under lesser disturbances. Also the presence of more primary/aromatic C in sub soil layer contributes to the higher E4/E6 ratio in sub soil. The E4/E6 ratio also suggests that the estimated higher HAC and FAC from 120% and 100% N applied plots are relatively less stable compared to that of 90% N applied plots.

Sensitivity index (SI) represents the relative sensitivity of different C fractions to the addition of N fertilizers. The increased SI is due to the direct role of N on crop growth and development which added organic matter to soil in various forms. The highest variation of SI was shown by POC (more labile fraction) followed by MBC which indicates that these two fractions are the most responsive fractions to N fertilizer application in sandy loam soil. However, with decreasing N dose and increasing soil depth, SI decreased for all the fractions which verified the possibility of minimum changes in SOC fractions under lower doses of inorganic N fertilizer and in sub soil layer. Yang et al. [35] also reported POC as one of the sensitive indicators of SOC in soil under nutrient management.

Correlation analyses of the studied SOC fractions showed a significant correlation indicating inter dependency of SOC and its fractions. Higher positive correlation between E4/E6, HAC and FAC with SOC showed that the rate of humification determines the
amount of SOC in soil. Similar relationship was previously observed by Yang et al. [35] and Song et al. [33].

4.2.5. Effect on soil chemical properties (pH, available N, P and K)
In the present investigation, soil pH decreased with the increasing N fertilizer dose. The main cause of decreased soil pH (soil acidification) under the application of N fertilizers is the production of H\(^+\) ions due to urea hydrolysis. Each mole of N-urea oxidized to nitrate (NO\(_3\)) produces one mole of H\(^+\) [36]. On the other hand, NO\(_3\) uptake by plants leads to the release of an equivalent amount of OH\(^-\) into the rhizosphere, resulting in the neutralization of acidity. But excess use of N fertilizers cause surplus accumulation of NO\(_3\) in soil leading to the dominance of anions that reduces soil pH. The leaching of these anions into the sub soil lowers the sub soil pH. Therefore, application of reduced the N fertilizer dose is very essential in acidic soil. The acidifying effect of N fertilizer has already been demonstrated by other researchers [10,37,38].

The relation of N fertilization with available P and K was inconsistent and non-significant which has also been reported by Ismail et al. [39]. The recorded higher P and K availability over years was apparently due to the addition of organic residues and decreased soil pH near the soil surface [37]. The observed variation in the availability of both P and K under different levels of N fertilizer might be due to the effects of N fertilizers on soil microbial population and activity leading to differences in the availability of these nutrients. However, the higher doses of N fertilizers were reported to decrease the P and K levels by Jagadamma et al. [40] during a long term trial. These results also confirm with the obtained results of greater P and K from 90% and 75% N applied plots compared to the plots with 100% and 120% N. The addition of N enhances plant growth which leads to the enhanced uptake of P and K and depleted the P and K contents in soil [41]. However, continuous application of inorganic P and K fertilizers over a period of two years has led to the accumulation of P and K in the top soil. Thus, modulating the recommended P and K fertilizer doses is also important under continuous cultivation to avoid surface accumulation of these nutrients.

N fertilization and available N concentration showed a strong relation i.e. available N increased as a function of increased N fertilizer dose. The continuous
application of N fertilizers in all the three tested crops contributed to the accumulation of N. The higher rate of N accumulation in plots with high N fertilizers indicated that only a small fraction of the applied N is being used by the crops and the remaining portion is accumulated in the soil. This availability was more pronounced in the top soil layer because of the surface application of fertilizers while the recorded increase in the sub soil layer might be due to the leaching of N to the sub soil because of its higher mobility.

4.2.5. Effect on soil physical properties (BD and WHC)
Irrespective of the applied N fertilizers, the recorded BD was lower in the top 0–15 cm soil layer compared to the 15–30 cm soil layer indicating subsurface compaction. N fertilization indirectly increases the soil organic matter inputs and production of higher amounts of undecomposed residues, which improved soil aggregation, porosity and consequently decreased the BD and increased WHC [42,38]. The inverse relation of BD and WHC under N fertilization has also been documented by Bandyopadhyay et al. [43]. However, N fertilization does not directly influence the BD and WHC which suggest that the effects of inorganic fertilization on these parameters were indirect, and were modified by the crop and soil characteristics.

4.2.6. Agronomic evaluation and indices
To evaluate the efficiency of the applied treatments to uphold SOC, the CPI and HAC:FAC was computed. The recorded higher CPI in 120% (T3) and 100% (T2) N applied plots indicate higher accumulation of SOC under these treatments. But the HAC:FAC ratio, which signifies the stability of the SOC was higher in treatment 90% N (T4) applied plots. The HAC:FAC ratio near 1 is an indicative of good quality organic material that could enhance soil physical properties and improve plant growth while lesser values indicates loss of the FAC fraction [44]. Therefore, the higher HAC:FAC ratio under T4 indicated higher stability of the SOC pool. The results of E4/E6 (Figure 4.10) also indicated higher stabilization of SOC under T4 compared to T2 and T3. Thus, reducing the N dose by 10% would have better chances to sustainably uphold the SOC pool for a longer period of time.
The agronomic efficiency, which is an indicative of the N use efficiency, was higher under treatments T4 (for okra and green gram) and T6 (wheat) which indicated that the applied N doses were more efficiently used up by the crops compared to 120% N applied plots. Thus, from these results we can conclude that application of higher doses of N fertilizers lessens the N use efficiency, thereby leading to the accumulation of N in the soil system [45].

4.3. Salient findings

- N fertilization at higher rates (100%, 120% and 90%) increased plant growth and yield which subsequently enhanced the SOC pool up to 30 cm soil layer.
- Increased (120% and 100% of the recommended) N fertilizer doses resulted in higher rate of increase in labile SOC pool such as POC than that of 90% N applied plots.
- Stable SOC fractions such as HAC, FAC and degree of humification (E4/E6) were higher in 90% N applied plots (T4) indicating higher C stabilization under this treatment compared to higher N (120% and 100%) applied plots.
- POC and MBC showed the highest sensitivity to N fertilization and can be used as indicators of SOC dynamics in experiments with N fertilization.
- Higher rate of N application (120% and 100%) caused soil acidification and accumulation of available N but reduced the concentration of P and K over continuous application in wheat-okra-green gram crop sequence.
- No significant differences in yield were recorded among the treatments with 120%, 100% and 90% N indicating that reducing N doses would not compromise the yield of wheat, okra and green gram and also uphold production of higher root biomass.
- The CPI, HAC:FAC ratio and agronomic efficiency at the end of two years indicated that reducing the N application rate by 10% can uphold SOC for longer time and also increase the N use efficiency thereby, reducing the risk of nitrate pollution.
- Therefore, from our results it is evident that reducing the application of N fertilizer by 10% of the recommended dose appears to be the most suitable management practice for increasing SOC and long term sustainability of acidic sandy loam inceptisols of northeast India under wheat-okra-green gram cultivation.
References


