



## Enhancing Growth and Yield of Chia (*Salvia hispanica*) by Nitrogen Application

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### Abstract

A field experiment was conducted in Panchagarh, Bangladesh, during Rabi season of 2022–2023 to assess the impact of nitrogen fertilization rates (0, 30, 60, 90, 120, and 150 kg N ha<sup>-1</sup>) on the yield attributes of chia (*Salvia hispanica*) and soil nutrients in a Randomized Complete Block Design (RCBD) with 4 replications. Results of the study significantly ( $P \leq 0.05$ ) revealed that T<sub>4</sub> treatment (120 kg ha<sup>-1</sup> N) showed highest plant height (112.8 cm), leaf number plant<sup>-1</sup> (42.50), number of branches plant<sup>-1</sup> (20.92), number of inflorescence plant<sup>-1</sup> (18.92), effective length of inflorescence (12.68 cm), number of seed inflorescence<sup>-1</sup> (574.7), fresh shoot weight (3.91 t ha<sup>-1</sup>), dry shoot weight (2.82 t ha<sup>-1</sup>), 1000-seed weight (1.27 g), seed yield of chia (0.37 t ha<sup>-1</sup>) and biological yield (3.19 t ha<sup>-1</sup>) followed by T<sub>5</sub>. In the case of harvest index, the highest (14.86%) was observed at T<sub>4</sub> treatment. Addition of N fertilizer @ 120 kg ha<sup>-1</sup> resulted in a considerable influence on the post-harvest soil properties such as available P (75.25 ppm), exchangeable K (0.65 m.e. 100 g<sup>-1</sup> soil) and available S (7.35 ppm), which were maximal in T<sub>4</sub> treatment, while 150 kg N ha<sup>-1</sup> (T<sub>5</sub>) recorded the highest total nitrogen (0.035%). However, excessive N (T<sub>5</sub>) did not further boost yield. The study recommends 120 kg N ha<sup>-1</sup> as the most efficient nitrogen rate for enhancing chia growth, yield, and soil nutrient availability in similar agro-climatic conditions.

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## 1. Introduction

Chia (*Salvia hispanica*) belongs to Lamiaceae family, cultivated for its seeds and leaves [1]. Recently, chia seeds have become one of the world's most recognizable foods based on their nutritional properties and medicinal values [2, 3]. Chia is an excellent ingredient since it contains the highest known amount of  $\alpha$ -linolenic acid and  $\omega$ -3 fatty acid [4, 5] can be easily added to commercial food. Due to the presence of high percentage of fats, carbohydrates, dietary fiber, proteins, vitamins (A, B, K, E, D), minerals, antioxidants and antimicrobial activity chia seeds can be crucial for health [2, 6]. Regular intake of chia seed helps control diabetes prevent the incidence of cardiovascular disease and maintain the integrity of cell membranes [7, 8].

Chia is a high valued crop. In 2017 per kilograms of chia a seed costs about tk 2700 in Dhaka market [9] the cultivation of chia is still not very expressive in Bangladesh due to lack of information regarding the growth, phenology, nutritional requirement and management strategies. Grown in both tropical and subtropical climates, chia is a short-day plant. Bangladesh's environmental circumstances are favourable for the growth of this novel crop. Prior to the new crop being recommended for mass production, various agronomic utilizing management techniques is essential to get the highest possible yield.

Fertilization is highly advised to boost the growth and productivity of chia plants, especially if it contains nitrogen. Moreover, N is the most spectacular of all essential nutrients in its effect on plant growth and a yield of this crop. N fertilization can significantly affect soil properties and plant height, branches plant<sup>-1</sup>, and other growth factors and yield of chia. N increases the vegetative growth and delayed maturity of plants. On the other hand, over application of N may cause soil acidification and deteriorate the soil environment, which may ultimately harm crop development and yield [10, 11]. According to Cui, et al. [12] and Zhu, et al. [13] excessive N fertilization has resulted in low N use efficiency and major environmental issues. Yield reductions in crops with high N fertilization are primarily caused by physiological disorders associated with excessive uptake of N and soil degradation [14]. In addition, the N fertilizer requirement for maximum growth and yield of newly developed chia is not much investigated.

Considering the increasing international demand for Chia, the information on agronomic management and the importance of nitrogen fertilization on crops, the study intends to investigate the impact of N on the growth and yield performance of chia and determine the optimal dose of N for better chia growth and yield.

## 2. Materials and Methods

### 2.1. Experimental Site and Duration

The research work was conducted at the Boda upazila of Panchagarh district during the Rabi season of 2022-2023. The experimental site was located at 26° 11'55" N latitude and 88° 22'20" E longitudes with an elevation of 63 m from sea level. The land belongs to the Old Himalayan Piedmont plain (AEZ-1) having non-calcareous flood plain general soil type with alluvial deposit of parent material. The soil of the experimental plot was loam with pH 5.42, organic matter 1.56%, total N 0.014%, available P 67.89 ppm, exchangeable K 0.27 m.e.100 g<sup>-1</sup> soil and available S 2.12 ppm.

### 2.2. Experimental Design and Treatments

The experiment was conducted to investigate the effect of N on the growth and yield of chia. The experiment consists of 6 treatments with 4 replications. The treatments were as follows; T<sub>0</sub>: control, T<sub>1</sub>: 30 kg N ha<sup>-1</sup>, T<sub>2</sub>: 60 kg N ha<sup>-1</sup>, T<sub>3</sub>: 90 kg N ha<sup>-1</sup>, T<sub>4</sub>: 120 kg N ha<sup>-1</sup>, T<sub>5</sub>: 150 kg N ha<sup>-1</sup>. Here urea fertilizer is applied as the source of nitrogen. TSP and MoP were applied @ 400 and 150 kg ha<sup>-1</sup>, respectively. Per unit plot size was 2m × 1m (2m<sup>2</sup>). The distance maintained between two blocks and two plots were 1.0 m and 0.5 m respectively. Medium yielding and short duration variety of chia seeds were collected from Bangladesh Agricultural University, Mymensingh and used as planting material.

### 2.3. Land Preparation and Cultural Practices

The land was prepared to a fine tilth by repeated ploughing and harrowing. The soil was treated with Cinocarb 3G @ 4 kg ha<sup>-1</sup> during final land preparation to protect against the insects such as cutworms and mole cricket to young plants. After preparing a proper layout of the experimental field entire dose of phosphorus, potassium, and half dose of nitrogen as per treatment combination per plot were applied at the time of sowing as basal dose. The remaining half dose of nitrogen was applied after 4 weeks of sowing and at the flowering period. In this experiment chia (*Salvia hispanica*) was used as the test crop. Chia seeds were sown in line sowing method @ 1.25 kg ha<sup>-1</sup>. Intensive care was taken as per need to ensure adequate growth and development.

### 2.4. Collection of Data

#### 2.4.1. Plant Parameters

Ten (10) plants from each plot were selected randomly and were tagged for data collection of the following parameters: plant height, number of leaves plant<sup>-1</sup>, number of primary branches plant<sup>-1</sup>, number of inflorescence plant<sup>-1</sup>, length of effective inflorescence, number of seed inflorescence<sup>-1</sup>, fresh shoot weight, 1000-seed weight, seed yield, dry shoot weight, biological yield, harvest Index.

#### 2.4.2. Soil Parameters

An extensive examination of soil samples was carried out at the Department of Soil Science, HSTU, Dinajpur. Soil samples were taken from the field both before sowing seeds and after harvest. The physical and chemical characteristics of the soil were examined using standard techniques on both pre-harvest and post-harvest soil samples.

### 2.4.3. Harvest Index (%)

The harvest index was calculated from the ratio of seed yield to biological yield (Seed yield + Stover yield) and expressed in terms of percentage. The following formula was used for calculating the harvest index-

$$\text{Harvest index (\%)} = (\text{Grain yield} / \text{Biological yield}) \times 100$$

### 2.4.4. Agronomic Efficiency (AE) of Fertilizers

Agronomic efficiency (AE) is a key indicator that measures the effect of individual inputs per unit of output. The increase in yield relative to the control group for each unit of input, in this case fertilizers, is used to determine this yield-dependent metric. The AE was determined by following the equation suggested by Shah, et al. [15].

$$\text{AE of Nitrogen} = (\text{SYNA} - \text{SYNO}) / \text{NR}$$

Where,

SYNA = Seed yield (kg ha<sup>-1</sup>) after fertilizer addition

SYNO = Seed yield (kg ha<sup>-1</sup>) without fertilizer and

NR = rate of fertilizer addition (kg ha<sup>-1</sup>).

### 2.5. Collection of Soil Samples

The initial and post-harvest soil samples were collected for physical and chemical analyses. Different soil properties were analyzed i.e. Soil pH by glass electrode pH meter [16] available phosphorus (P) by olsen method [17] total nitrogen (N) by Kjeldahl method [18] exchangeable potassium (K) by ammonium acetate extraction method [19] available sulphur (S) by spectrophotometer, organic matter content (OM) by wet oxidation method [20] textural class by hydrometer method.

### 2.6. Statistical Analysis

The data were presented as the mean value. Statistix 10 software was applied to perform statistical analysis. One-way analysis of variance (ANOVA), followed by Fisher's Least Significant Difference (LSD) test ( $p < 0.05$ ) was performed to determine significant differences among treatments. Values were observed as statistically significant with  $p < 0.05$  [21].

## 3. Results

The results on different parameters, such as growth parameters, yield contributing parameters and yield parameters after harvest of chia are presented below:

**Table 1.** Effect of different levels of N on plant height, number of leaves plant<sup>-1</sup>, number of branches plant<sup>-1</sup>, number of inflorescence plant<sup>-1</sup>, effective length of inflorescence, number of seed inflorescence<sup>-1</sup> of chia

| Treatments     | Plant height (cm) | Leaf no. plant <sup>-1</sup> | No. of branches plant <sup>-1</sup> | No. of inflorescence plant <sup>-1</sup> | Effective length of inflorescence (cm) | No. of seeds inflorescence <sup>-1</sup> |
|----------------|-------------------|------------------------------|-------------------------------------|------------------------------------------|----------------------------------------|------------------------------------------|
| T <sub>0</sub> | 81.75 d           | 23.25 d                      | 8.17 e                              | 10.75 e                                  | 6.13 d                                 | 358.80 e                                 |
| T <sub>1</sub> | 92.09 c           | 30.00 c                      | 11.42 d                             | 13.42 d                                  | 7.16 cd                                | 385.20 e                                 |
| T <sub>2</sub> | 103.40 b          | 34.17 b                      | 14.33 cd                            | 17.25 c                                  | 8.72 c                                 | 421.70 d                                 |
| T <sub>3</sub> | 105.07 b          | 36.25 b                      | 17.08 c                             | 20.42 b                                  | 11.16 b                                | 468.20 c                                 |
| T <sub>4</sub> | 112.83 a          | 42.50 a                      | 24.92 a                             | 25.92 a                                  | 13.68 a                                | 574.70 a                                 |
| T <sub>5</sub> | 111.80 a          | 41.50 a                      | 20.75 b                             | 21.25 b                                  | 12.15 ab                               | 519.40 b                                 |
| LSD            | 1.018             | 1.333                        | 1.413                               | 1.13                                     | 0.817                                  | 13.565                                   |
| CV %           | 1.23              | 4.72                         | 8.74                                | 7.62                                     | 9.17                                   | 3.65                                     |

**Note:** In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level probability. CV%= Coefficient of Variance and LSD = Least Significant Difference. Here, T<sub>0</sub>=Control, T<sub>1</sub>=30 kg N ha<sup>-1</sup>, T<sub>2</sub>=60 kg N ha<sup>-1</sup>, T<sub>3</sub>=90 kg N ha<sup>-1</sup>, T<sub>4</sub>=120 kg N ha<sup>-1</sup>, T<sub>5</sub>=150 kg N ha<sup>-1</sup>.

**Table 2.** Effects of different levels of N on fresh shoot weight, dry shoot weight, 1000-seed weight, seed yield, biological yield and harvest index of chia

| Treatments     | 1000-seed weight (g) | Fresh shoot weight (t ha <sup>-1</sup> ) | Dry shoot weight (t ha <sup>-1</sup> ) | Seed yield (t ha <sup>-1</sup> ) | Biological yield (t ha <sup>-1</sup> ) | Harvest index (%) |
|----------------|----------------------|------------------------------------------|----------------------------------------|----------------------------------|----------------------------------------|-------------------|
| T <sub>0</sub> | 1.18 a               | 1.82 d                                   | 1.32 d                                 | 0.19 e                           | 1.51 d                                 | 12.57 d           |
| T <sub>1</sub> | 1.21 a               | 2.49 c                                   | 1.56 c                                 | 0.23 d                           | 1.79 c                                 | 12.84 cd          |
| T <sub>2</sub> | 1.22 a               | 3.06 b                                   | 1.67 c                                 | 0.25 d                           | 1.92 c                                 | 13.01c            |
| T <sub>3</sub> | 1.24 a               | 3.13 b                                   | 1.86 b                                 | 0.29 c                           | 2.15 b                                 | 13.48 b           |
| T <sub>4</sub> | 1.28 a               | 3.61 a                                   | 2.12a                                  | 0.37 a                           | 2.49 a                                 | 14.86 a           |
| T <sub>5</sub> | 1.25 a               | 3.54 a                                   | 2.06 a                                 | 0.33 b                           | 2.39 a                                 | 13.80 b           |
| LSD            | 0.082                | 0.0903                                   | 0.0816                                 | 0.0163                           | 0.098                                  | 0.1781            |
| CV %           | 8.13                 | 3.76                                     | 5.67                                   | 7.23                             | 5.88                                   | 1.62              |

**Note:** In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level probability. CV%= Coefficient of Variance and LSD = Least Significant Difference. Here, T<sub>0</sub>=Control, T<sub>1</sub>=30 kg N ha<sup>-1</sup>, T<sub>2</sub>=60 kg N ha<sup>-1</sup>, T<sub>3</sub>=90 kg N ha<sup>-1</sup>, T<sub>4</sub>=120 kg N ha<sup>-1</sup>, T<sub>5</sub>=150 kg N ha<sup>-1</sup>.

**Table 3.** Effects of different levels of N on agronomic efficiency (AE)

| Treatments     | SYNA (Kg ha <sup>-1</sup> ) | SYNO (Kg ha <sup>-1</sup> ) | NR (Nitrogen Kg ha <sup>-1</sup> ) | AE of nitrogen fertilizer (Kg ha <sup>-1</sup> ) |
|----------------|-----------------------------|-----------------------------|------------------------------------|--------------------------------------------------|
| T <sub>0</sub> | 190                         | 190                         | 0                                  | 0 e                                              |
| T <sub>1</sub> | 230                         |                             | 30                                 | 1.33 b                                           |
| T <sub>2</sub> | 250                         |                             | 60                                 | 0.99 cd                                          |
| T <sub>3</sub> | 290                         |                             | 90                                 | 1.11 c                                           |
| T <sub>4</sub> | 370                         |                             | 120                                | 1.5 a                                            |
| T <sub>5</sub> | 330                         |                             | 150                                | 0.93 d                                           |
| LSD            |                             |                             |                                    | 0.1633                                           |
| CV%            |                             |                             |                                    | 9.18                                             |

**Note:** SYNA= Seed yield with the addition of fertilizer, SYNO= Seed yield without fertilizer, NR= rate of fertilizer addition (kg ha<sup>-1</sup>), CV= Coefficient of Variance and LSD = Least Significant Difference.

**Table 4.** Effects of different levels of N on the available P, S, total N and exchangeable K of the post-harvest soil

| Treatments     | Total N (%) | Available P (ppm) | Exchangeable K (m.e.100 g <sup>-1</sup> soil) | Available S (ppm) |
|----------------|-------------|-------------------|-----------------------------------------------|-------------------|
| T <sub>0</sub> | 0.012       | 60.67 d           | 0.32 c                                        | 1.75 e            |
| T <sub>1</sub> | 0.021       | 63.45 cd          | 0.32 c                                        | 4.75 d            |
| T <sub>2</sub> | 0.028       | 66.11 cd          | 0.32 c                                        | 5.77 c            |
| T <sub>3</sub> | 0.021       | 67.15 bc          | 0.48 b                                        | 4.52 d            |
| T <sub>4</sub> | 0.021       | 75.25 a           | 0.65 a                                        | 7.35 a            |
| T <sub>5</sub> | 0.035       | 72.12 ab          | 0.48 b                                        | 6.54 b            |
| LSD            | 0.048       | 5.42              | 2.56                                          | 0.396             |
| CV%            | 7.75        | 5.61              | 10.16                                         | 5.13              |

**Note:** In a column means having similar letter(s) are statistically similar and those having dissimilar letter(s) differ significantly at 0.05 level probability. CV%= Coefficient of Variation, LSD = Least Significant Difference. Here, T<sub>0</sub>=Control, T<sub>1</sub>=30 kg N ha<sup>-1</sup>, T<sub>2</sub>=60 kg N ha<sup>-1</sup>, T<sub>3</sub>=90 kg N ha<sup>-1</sup>, T<sub>4</sub>=120 kg N ha<sup>-1</sup>, T<sub>5</sub>=150 kg N ha<sup>-1</sup>.

## 4. Discussion

### 4.1. Agronomic Growth Parameters

Application of different doses of nitrogen responded significantly ( $P \leq 0.05$ ) on different yield attributes of chia (Table 1). The highest plant height (112.83 cm), leaf number plant<sup>-1</sup> (42.50) and number of branches plant<sup>-1</sup> (24.92) were found in T<sub>4</sub> treatment followed by T<sub>5</sub>. Rasha, et al. [22] found that vegetative growth of chia increased by 23-28 % supplied with 120 kg N ha<sup>-1</sup> than in plants that were not supplied with N. These findings are consistent with those of Souza and Chaves [23] who found that nitrogen's stimulating effect on metabolic activity led to an increase in the total amount of metabolites, which in turn caused internode elongation and increased plant height in chia plants with elevated nitrogen levels.

Regarding the number of inflorescence plant<sup>-1</sup>, effective length of inflorescence and number of seed inflorescence<sup>-1</sup> the findings revealed that the nitrogen fertilization had significant effect on these parameters (Table 1). The highest number of inflorescence plant<sup>-1</sup> (18.92), effective length of inflorescence (12.68 cm) and number of seed inflorescence<sup>-1</sup> (574.7) were recorded in T<sub>4</sub> (120 kg N ha<sup>-1</sup>). The data revealed that nitrogen application exhibited significant effect on the plant growth and development. Every increase in rate of N application increased the growth parameters significantly at all the growth stages Njoka, et al. [24]. Mohanty, et al. [25] concluded that during the vegetative stage, nitrogen application large extent controls

the growth of plant and higher performance of growth at higher fertility levels with wider spacing could be ascribed to the luxuriant growth of crop as reflected by higher dry matter production.

The results indicated that there was no significant impact of nitrogen fertilizer on the 1000-seed weight (Table 2). The application of 120 kg N ha<sup>-1</sup> (T<sub>4</sub>) treatment, however, resulted in the maximum 1000-seed weight (1.28 g), which was then followed by T<sub>5</sub> and T<sub>3</sub> treatments (1.25 g and 1.24 g, respectively). Bechini, et al. [26] found that nitrogen fertilizer had little effect on the 1000-kernel weights of chia, even when yields increased. Numerous elements, including variety, growing conditions, climatic factors, and soil qualities, generally affect the 1000-seed weight [27].

According to the result (Table 2), the fresh and dry shoot weight of chia were significantly influenced by different level of nitrogen fertilization. The maximum fresh shoot weight (3.61 t ha<sup>-1</sup>) and dry shoot weight (2.12 t ha<sup>-1</sup>) were resulted in T<sub>4</sub> treatment and the minimum weight were found in T<sub>0</sub> treatment. Bechini, et al. [26] and Souza and Chaves [23] had demonstrated a positive impact of nitrogen fertilization on the plant dry matter of chia. The improved growth development of the plant's above ground parts, particularly the leaf area, combined with the higher nitrogen levels resulted in higher rates of photosynthesis and thus the highest dry weight.

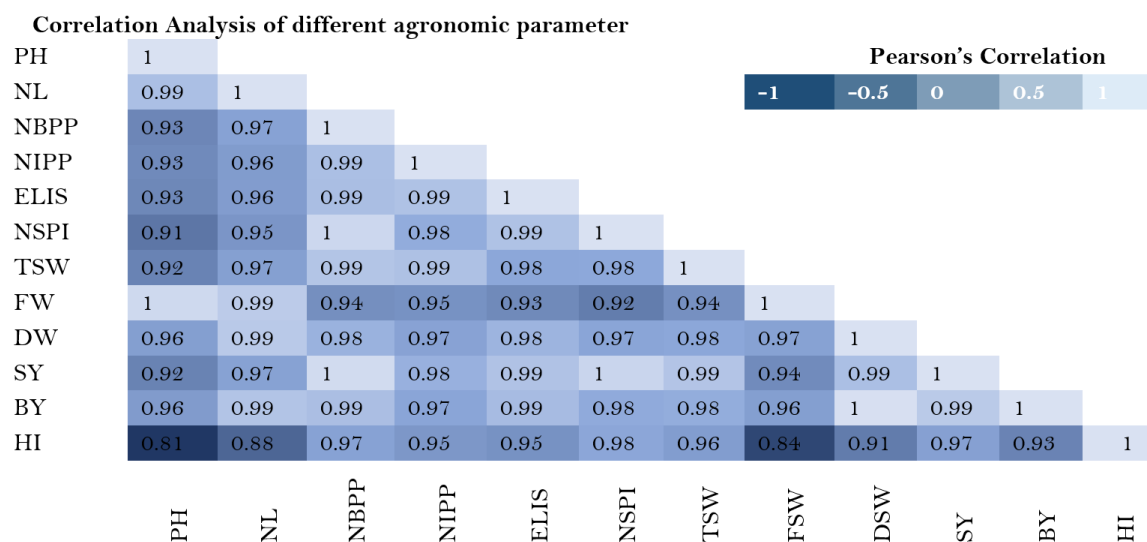
Concerning seed yield, biological yield and harvest index, the influence of the different rates of nitrogen fertilization was found to be statistically significant (Table 2). The highest seed yield of chia (0.37 t ha<sup>-1</sup>), biological yield (2.49 t ha<sup>-1</sup>) and harvest index of 14.86 % were recorded from T<sub>4</sub> (120 kg N ha<sup>-1</sup>) treatment. The increased seed yield, biological yield and harvest index may be due to the favorable effects of nitrogen on the vegetative growth that helped proper growth and development of the chia seed. According to Sosa-Baldivia and Ibarra [28] and Mary, et al. [29] the highest fertilizers (90 and 100 kg N ha<sup>-1</sup>, respectively) led to noticeably higher yields of chia seeds. The plant's dry weight and seed output both improved as a result of increased photosynthesis, which raised the amount of photosynthetic products Kakabouki, et al. [1]. Singh, et al. [30] stated that N at 120 kg ha<sup>-1</sup> produced 2.55 q higher seed yield. Mohanty, et al. [25] and Njoka, et al. [24] also confirmed that optimum seed yield and dry matter of chia was recorded with high nitrogen dose (120 kg N ha<sup>-1</sup>).

#### 4.2. Agronomic Efficiency of Nitrogen

Agronomic efficiency (AE) is crucial for assessing how well fertilizers enhance crop yield. In this study, treatment T<sub>4</sub> (120 kg N ha<sup>-1</sup>) achieved the highest nutrient use efficiency, with a seed yield of 0.37 t/ha and AE values of 1.5 kg ha<sup>-1</sup> for nitrogen fertilizer (Table 3). This highlights the effectiveness of nitrogen fertilizer to boost nutrient efficiency. All the other treatments also showed significant improvements in AE over the control group (T<sub>0</sub>). While T<sub>4</sub> was the most efficient, T<sub>1</sub> and T<sub>3</sub> also provided notable benefits in nutrient use efficiency. The control group (T<sub>0</sub>), which received no fertilizers, exhibited no measurable AE. These results suggest that nitrogen fertilizer enhances nutrient use efficiency by improving soil nitrate retention and reducing nitrate losses, consistent with the findings of Zhao, et al. [31]; Govindasamy, et al. [32] and Golla [33].

#### 4.3. Chemical Properties of Post-Harvest Soil

Application of N fertilizers resulted in a considerable influence on the properties of the post-harvest soils (Table 4). Total N content in the post-harvest soil insignificantly affected by various treatments under this study. Soil N of the post-harvest soil was higher than the initial soil (0.014 %). The total N content of the post-harvest soil ranged between 0.012% and 0.035 %. The highest (0.035%) soil N was found in T<sub>5</sub> treatment which was closely followed by T<sub>2</sub> treatment. The maximum available P (75.25 ppm), exchangeable K (0.65 m.e.100 g<sup>-1</sup> soil) and available sulphur (7.35 ppm) were found in the treatment T<sub>4</sub> (Table 4). These findings were consistent with the previous research by Zhong, et al. [34] which demonstrated the different doses of nitrogen significantly affect the soil properties. Zhang, et al. [35] also suggested that available nitrogen, available potassium and available phosphorus are increased with increasing level of nitrogen.



**Figure 1.** Heatmap showing the Pearson correlation coefficients between various agronomic traits

The color intensity indicates the strength of the correlation, with lighter colors representing stronger positive correlations. PH= Plant height, NL= Number of Leaf, NBPP= Number of branches plant<sup>-1</sup>, NIPP= Number of inflorescence plant<sup>-1</sup>, ELIS= Effective length of inflorescence, NSPI= Number of seeds per inflorescence, FW=Fresh shoot weight, DW= Dry shoot, TSW=1000-seed weight, SY= Seed yield, StY= Straw yield, BY= Biological yield, HI= Harvest index

The heatmap illustrates the Pearson correlation coefficients between various agronomic traits, providing a visual summary of their interrelationships (Figure 1). This correlation matrix indicates the strength and direction of relationships among various plant traits, with the color intensity reflecting the strength of the correlation. A strong positive correlation (values close to 1) is observed across most parameters, indicating that increases in one parameter are generally associated with increases in others. For instance, plant height strongly correlates with fresh shoot weight (1.00), suggesting that taller plants tend to produce more biomass. Similarly, the number of seeds per inflorescence and seed yield are highly correlated (1.00), emphasizing the direct relationship between seed count and yield. Biological yield shows strong associations with most parameters, including dry shoot weight (0.99) and seed yield (0.99), highlighting its integral role in plant productivity. Interestingly, harvest index, which reflects the efficiency of converting biomass into yield, shows slightly lower correlations with other parameters like plant height (0.81) and fresh shoot weight (0.84), indicating that factors other than biomass may influence yield efficiency. Overall, the data underscores interconnected relationships among morphological, reproductive, and yield traits in plants.

## 5. Conclusion

The study indicated that applying 120 kg N ha<sup>-1</sup> significantly increased the vegetative growth of chia. Similarly it increased the seed yield also. The plants performed better in respect of plant growth and seed yield in T<sub>4</sub> treatment than the control treatment (T<sub>0</sub>) which showed the least performance. It can be therefore, concluded from the above study that the treatment T<sub>4</sub> (application of 120 kg N ha<sup>-1</sup>) was found to be the most suitable dose of N fertilizer for the highest yield of chia in non-calcareous brown floodplain soil in Bangladesh.

## References

- [1] I. P. Kakabouki, I. Roussis, D. Hela, P. Papastylianou, A. Folina, and D. Bilalis, "Root growth dynamics and productivity of quinoa (*Chenopodium quinoa* Willd.) in response to fertilization and soil tillage," *Folia Horticulturae*, vol. 31, no. 2, pp. 285-299, 2019. <https://doi.org/10.2478/fhort-2019-0023>
- [2] R. Ullah *et al.*, "Nutritional and therapeutic perspectives of Chia (*Salvia hispanica* L.): A review," *Journal of Food Science and Technology*, vol. 53, pp. 1750-1758, 2016. <https://doi.org/10.1007/s13197-015-1967-0>
- [3] R. Deka and A. Das, "Advances in chia seed research," *Advances in Biotechnology & Microbiology*, vol. 5, no. 2, p. 555661, 2017. <https://doi.org/10.19080/AIBM.2017.05.555662>
- [4] R. Coorey, A. Grant, and V. Jayasena, "Effects of chia flour incorporation on the nutritive quality and consumer acceptance of chips," *Journal of Food Research*, vol. 1, no. 4, pp. 85-98, 2012. <https://doi.org/10.5539/jfr.v1n4p85>
- [5] V. Vuksan *et al.*, "Reduction in postprandial glucose excursion and prolongation of satiety: Possible explanation of the long-term effects of whole grain Salba (*Salvia Hispanica* L.)," *European Journal of Clinical Nutrition*, vol. 64, no. 4, pp. 436-438, 2010. <https://doi.org/10.1038/ejcn.2009.159>
- [6] C. Silva, V. Garcia, and C. Zanette, "Chia (*Salvia hispanica* L.) oil extraction using different organic solvents: Oil yield, fatty acids profile and technological analysis of defatted meal," *International Food Research Journal*, vol. 23, no. 3, p. 998, 2016.

- [7] W. Yao *et al.*, "Effects of dietary ratio of n-6 to n-3 polyunsaturated fatty acids on immunoglobulins, cytokines, fatty acid composition, and performance of lactating sows and suckling piglets," *Journal of Animal Science and Biotechnology*, vol. 3, p. 43, 2012. <https://doi.org/10.1186/2049-1891-3-43>
- [8] T. Ludwig, S. Worsch, M. Heikenwalder, H. Daniel, H. Hauner, and B. L. Bader, "Metabolic and immunomodulatory effects of n-3 fatty acids are different in mesenteric and epididymal adipose tissue of diet-induced obese mice," *American Journal of Physiology-Endocrinology and Metabolism*, vol. 304, no. 11, pp. E1140-E1156, 2013. <https://doi.org/10.1152/ajpendo.00171.2012>
- [9] Prothom Alo, "Chia cultivation gives new hopes to farmers," 2020. <https://en.prothomalo.com/Bangladesh/Chia-cultivation-gives-new-hopes-to-farmers>
- [10] J. H. Guo *et al.*, "Significant acidification in major Chinese croplands," *Science*, vol. 327, no. 5968, pp. 1008-1010, 2010. <https://doi.org/10.1126/science.1182570>
- [11] J. L. Schroder, H. Zhang, K. Girma, W. R. Raun, C. J. Penn, and M. E. Payton, "Soil acidification from long-term use of nitrogen fertilizers on winter wheat," *Soil Science Society of America Journal*, vol. 75, no. 3, pp. 957-964, 2011. <https://doi.org/10.2136/sssaj2010.0187>
- [12] P. Cui *et al.*, "Long-term organic and inorganic fertilization alters temperature sensitivity of potential N<sub>2</sub>O emissions and associated microbes," *Soil Biology and Biochemistry*, vol. 93, pp. 131-141, 2016. <https://doi.org/10.1016/j.soilbio.2015.11.005>
- [13] G. Zhu, S. Peng, J. Huang, K. Cui, L. Nie, and F. Wang, "Genetic improvements in rice yield and concomitant increases in radiation-and nitrogen-use efficiency in middle reaches of Yangtze river," *Scientific Reports*, vol. 6, p. 21049, 2016. <https://doi.org/10.1038/srep21049>
- [14] J. Qiao, L. Yang, T. Yan, F. Xue, and D. Zhao, "Nitrogen fertilizer reduction in rice production for two consecutive years in the Taihu Lake area," *Agriculture, Ecosystems & Environment*, vol. 146, no. 1, pp. 103-112, 2012. <https://doi.org/10.1016/j.agee.2011.10.014>
- [15] K. Shah, M. Memon, S. Siddiqui, and M. Aslam, "Response of wheat to broadcast and fertigation technique or P application," *Pakistan Journal of Biological Sciences*, vol. 4, no. 5, pp. 543-545, 2001.
- [16] M. L. Jackson, *Soil chemical analysis*. Englewood Cliffs, New Jersey, USA: Prentice-Hall, 1967.
- [17] S. R. Olsen, C. V. Cole, F. S. Watanabe, and L. A. Dean, *Estimation of available phosphorus in soils by extraction with sodium bicarbonate (U.S. Department of Agriculture Circular No. 939)*. Washington, D.C: U.S. Department of Agriculture, 1954.
- [18] C. A. Black, *Methods of soil analysis: Part 1, Physical and mineralogical properties, including statistics of measurement and sampling; Part 2, Chemical and microbiological properties*. Madison, WI: American Society of Agronomy, 1965.
- [19] A. L. Page, R. H. Miller, and D. R. Keeney, *Methods of soil analysis: Part 2. Chemical and microbiological properties*, 2nd ed. Madison, WI: American Society of Agronomy, 1989.
- [20] A. Walkley and I. A. Black, "An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29-38, 1934. <https://doi.org/10.1097/00010694-193401000-00003>
- [21] K. H. Gomez and A. A. Gomez, *Statistical procedures for agricultural research*, 2nd ed. New York: John Wiley & Sons, 1984.
- [22] S. Rasha, A. El-Sheshtawy, and H. Ali, "Phenology, architecture, yield and fatty acid content of chia in response to sowing date and plant spacing," *Fayoum Journal of Agricultural Research and Development*, vol. 34, no. 1, pp. 314-331, 2020.
- [23] R. S. Souza and L. H. G. Chaves, "Initial growth of chia (*Salvia hispanica* L.) submitted to nitrogen, phosphorus and potassium fertilization," *Australian Journal of Crop Science*, vol. 11, no. 5, pp. 610-615, 2017.
- [24] M. Njoka, P. Masinde, and C. M. Mwenda, "Influence of nitrogen and spacing on growth and yield of chia (*Salvia hispanica* L.) in Meru County, Kenya," *International Journal of Agricultural Education and Extension*, vol. 8, no. 1, pp. 442-451, 2022.
- [25] P. Mohanty, C. Umesh, S. Ranjan, and K. Lalit, "Impact of spacing and nitrogen levels on growth and yield of Chia (*Salvia hispanica* L.)," *Biological Forum-An International Journal*, vol. 13, no. 1, pp. 148-153, 2021.
- [26] L. Bechini, C. Costamagna, L. Zavattaro, C. Grignani, J. Bijttebier, and G. Ruysschaert, "Barriers and drivers towards the incorporation of crop residue in the soil. Analysis of Italian farmers' opinion with the theory of planned behaviour," *Italian Journal of Agronomy*, vol. 10, no. 4, p. 663, 2015. <https://doi.org/10.4081/ija.2015.663>
- [27] I. Roussis, A. Mavroudis, I. Kakabouki, A. Efthimiadou, N. Katsenios, and D. Bilalis, "Influence of nitrogen fertilization on root growth dynamics and yield of chia (*Salvia hispanica* L.) in greenhouse pots," *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca: Horticulture*, vol. 78, no. 2, pp. 140-146, 2021.
- [28] A. Sosa-Baldivia and G. R. Ibarra, "Inadequate nitrogen fertilization: Main Cause of the low seed yield on the chia crop (*Salvia hispanica* L.)," *Papeles de Población*, vol. 23, no. 93, pp. 20-230, 2018. <https://doi.org/10.26717/BJSTR.2018.02.000670>
- [29] J. Mary, H. Veeranna, G. Girijesh, B. Dhananjaya, and S. Gangaprasad, "Effect of different spacings and fertilizer levels on growth parameters and yield of chia (*Salvia hispanica* L.)," *International Journal of Pure & Applied Bioscience*, vol. 6, no. 2, pp. 259-263, 2018.
- [30] G. K. Singh, K. Prasad, and K. Prasad, "Effect of row spacing, nitrogen levels and basis of N application on yield attributes and yield of mustard," *Crop Research Hisar*, vol. 25, no. 3, pp. 427-430, 2003.
- [31] J. Zhao, Y. Qi, C. Yin, and X. Liu, "Effects of nitrogen reduction at different growth stages on maize water and nitrogen utilization under shallow buried drip fertigated irrigation," *Agronomy*, vol. 14, no. 1, p. 63, 2023. <https://doi.org/10.3390/agronomy14010063>

- [32] P. Govindasamy *et al.*, "Nitrogen use efficiency—a key to enhance crop productivity under a changing climate," *Frontiers in Plant Science*, vol. 14, p. 1121073, 2023. <https://doi.org/10.3389/fpls.2023.1121073>
- [33] B. Golla, "Nitrogen response and agronomic use efficiency of N fertilizer in diverse commercial maize hybrids at Bako, Western Ethiopia," *International Journal of Agricultural Science and Food Technology*, vol. 7, no. 2, pp. 245-248, 2021. <https://doi.org/10.17352/2455-815X.000114>
- [34] H. Zhong *et al.*, "Effects of different nitrogen applications on soil physical, chemical properties and yield in maize (*Zea mays* L.)," *Agricultural Sciences*, vol. 5, no. 14, pp. 1440-1447, 2014. <https://doi.org/10.4236/as.2014.514155>
- [35] J. Zhang, J. Huang, Z. Wang, and X. Wang, "Effects of nitrogen fertilizer on soil chemical property in citrus orchard," in *IOP Conference Series: Earth and Environmental Science (Vol. 310, No. 4, p. 042066)*. IOP Publishing, 2019.