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Studies on the effect of Plant spacing and Different Doses Nitrogen on Growth and Yield of Chilli (*Capsicum annum* L.) under the Open Field Conditions in Kabul, Afghanistan

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ABSTRACT

The investigation into the impact of nitrogen doses and spacing on the growth and yield-related parameters of chili was conducted during the Spring season of 2022 at the Experimental Farm of the Department of Horticulture Science, Kabul University. The study explored the effects of varying nitrogen doses (0 kg/ha, 100 kg/ha, 140 kg/ha, and 180 kg/ha) and different spacings (40cm × 45cm, 50cm × 45cm, and 60cm × 45cm) on key parameters including days to fifty percent flowering, number of primary branches, plant height, plant spread, fruit dimensions, average fruit weight, fruit yield per plant, fruit yield per plot, and days to maturity.

In general, an increase in nitrogen dose was associated with higher values for the number of primary branches, days to 50% flowering, plant height, number of fruits per plant, fruit yield per plant, fruit yield per plot, plant spread, and days to fruit maturity. However, nitrogen doses did not significantly influence fruit traits such as length, width, and average weight. Meanwhile, different spacing had a notable impact on the number of primary branches, plant height, number of fruits per plant, fruit yield per plant, fruit yield per plot, plant spread, and days to maturity. Wider plant spacing correlated with increased primary branches, fruits per plant, fruit yield per plant and per plot, and greater plant spread. Conversely, reduced plant spacing resulted in increased plant height.

The interaction between spacing and nitrogen doses significantly affected only the number of branches, with non-significant interaction effects observed for all other yield and yield-related parameters. Increased nitrogen application, particularly at a rate of 180 kg N per hectare, led to improved chili fruit yield. Similarly, wider plant spacing, specifically at 60 cm × 45 cm, demonstrated the highest increase in chili yield.

Keywords- Pepper, Growth, yield, Doses Nitrogen, Plant spacing.

I. INTRODUCTION

Hot pepper, scientifically known as Capsicum annuum L. and commonly referred to as chili in South East Asia, is cultivated globally in temperate and tropical regions (Islam et al., 2011). Ranking as the third most significant crop in the Solanaceae family, following tomato and potato (Dubey et al., 2017), chili is grown in diverse countries, including Afghanistan (Gulab et al., 2019). With 100 grams of green chili containing 564 mg potassium (K), 25-49 mg phosphorus (P), 10 mg magnesium (Mg), 10-16 mg calcium (Ca), and 0.7-1.4 mg ferrous (Fe) absorbed from the soil, it is highly nutritious (Agheli, 2005).

In Afghan horticulture, chili pepper holds particular importance due to its adaptability to hot, arid

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environments and lower postharvest losses compared to other fleshy-fruited crops. It is consumed as fresh fruits or in the form of red dry powder as spices in Afghanistan (Alan Walters). Chilies thrive in well-drained silt or clay loam soil (Khan et al., 2014). The profitability of using commercial fertilizer has been demonstrated in various experiments worldwide, underscoring the importance of selecting the right fertilizer for optimal crop growth and development. The correct proportion of fertilizer enhances crop performance and ensures essential nutrient availability.

In recent years, both inorganic and organic fertilizers have become indispensable in vegetable production, driven by the necessity for increased production and per-hectare yield of chili, as evidenced by experiments in different countries. Nitrogen, a crucial element for vegetable production, plays a pivotal role in chili cultivation, influencing fruit quality, flower development, and overall yield. Nevertheless, excessive nitrogen application can lead to uneconomical practices, physiological disorders, and environmental pollution (Islam et al., 2018).

The cultivated soils in Afghanistan, often low in fertility and deficient in nutrients, especially nitrogen, necessitate supplementation through nitrogenous fertilizers. Urea, applied through various methods, stands as the predominant nitrogen source, but challenges such as low efficiency and water scarcity impact crop yield. Achieving the optimal plant population through appropriate spacing is critical for chili's growth and development, affecting morphological characteristics and competition for water, nutrients, and light. Information on improved nutrition, particularly fertilizer use, is limited in Afghanistan concerning chili crops, highlighting the need for research and practices tailored to the region's soil fertility and climate (Gulab et al., 2019). While excessive fertilizer rates enhance fruit yields, careful management is essential to avoid negative effects on nutrient use efficiency and financial returns (Ayodele et al., 2015).

II. MATERIAL AND METHODS

The research titled "Investigations on the impact of varying nitrogen doses and plant spacing on the growth and yield of chili" was conducted at the Experimental Farm of Kabul University's Department of Horticulture Science from March 30, 2021, to August 30, 2021. The experimental site, situated at 34.51834’N latitude and 69.13968’E longitude, boasts an elevation of 1782.0 m. Kabul experiences a continental, cold semi-arid climate, characterized by winter and spring precipitation, mostly in the form of snow, and an annual mean temperature of 12.1°C, with spring being the wettest season. The study employed a Factorial Randomized Block Design (FRBD) with three replications, incorporating three levels of plant spacing (40×45 cm, 50×45 cm, and 60×55 cm) and four nitrogen fertilizer doses (control, 100 kg/ha, 140 kg/ha, and 180 kg/ha) as treatments.

Soil analysis at the experimental site, conducted at the Badam Bagh agriculture research center, revealed soil properties including a pH of 8.04, electrical conductivity (Ec) of 0.359, loam texture, nitrogen content of 0.0336%, phosphorus (P) at 14.84 ppm, and potassium (K) at 582 ppm. Some sections of the land were fallow the previous year, while others had an onion crop during winter. The field was plowed a day before transplanting.

Each block received four different nitrogen doses and was further divided into three replications. Each plot measured 5 m × 4 m. For each nitrogen dose, three-unit plots were established, with plot spacing of 40 cm × 45 cm, 50 cm × 45 cm, and 60 cm × 45 cm, resulting in 36-unit plots in the entire experiment. The same pattern was followed for each nitrogen dose.

The Hybrid hot pepper seed variety used in the experiment, named (MASTAN F1), had been treated with Thiram and was available in Kabul markets. Data were collected for 10 growth attributes and yield-contributing characteristics, including the number of primary branches, plant height, plant spread, days to 50% flowering, and fruit characteristics such as length, width, and average fresh fruit weight, along with yield characters such as fruit yield per plant, fruit yield per plot, and days to maturity for harvesting. Data collection involved six randomly selected middle tagged plants per plot of each treatment. Standard statistical techniques developed by Steel and Torrie (1980) for factorial experiments in Randomized Block Design (RBD) were employed for statistical analysis, with Analysis of Variance performed on all numerical data using the oppstat online (2007) package with the split plot design. The Least Significant Difference (LSD) at a 5% significance level was used for comparing treatment means.

III. RESULTS

The research study, entitled "Impact of Varied Nitrogen Doses and Spacing on Chili Growth and Yield," was conducted at Kabul University's Experimental Farm within the spring seasons of 2022. Following the experiment, the collected data underwent thorough statistical analysis, and the outcomes for each specific characteristic are detailed in this chapter.

3.1 Growth Attributes

3.1.1 Plant Height (cm)

Various nitrogen doses exerted a noticeable impact on plant height, exhibiting an elevation with increasing nitrogen levels. The plots with 180 kg N/ha boasted the tallest plants at 52.1 cm, in stark contrast to the comparatively lower height of 46.89 cm in control plots. Furthermore, plant spacing wielded a significant influence on plant height, with the narrowest spacing (40 cm x 45 cm) resulting in consistently taller plants (51.50 cm) across all stages of plant growth compared to wider spacings. Conversely, the widest spacing (60 cm x 45 cm) yielded the shortest plants at 47.662 cm during the final harvesting stage.

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3.1.2 Number of Primary branches

Significant variations were observed in the number of primary branches based on nitrogen impact. The control group, receiving the minimum nitrogen dose (0 kg/ha), demonstrated a noteworthy maximum average number of branches (19.464). Notably, the primary branches per plant displayed significant differences across various spacing levels. Plants with the widest spacing (60×45 cm) exhibited the highest average number of primary branches (17.483) per plant, while those with the closest spacing (40×45 cm) recorded the lowest number (16.403). This difference was statistically distinct from other treatments. The observed contrast may be attributed to the fact that plants with wider spacing received enhanced exposure to light, nutrients, and other resources compared to those with closer spacing.

3.1.3 Plant Spread (cm)

Among the growth attributes, plant spread stands out as a pivotal characteristic, exhibiting noteworthy distinctions among plants exposed to different nitrogen doses and spacing. The maximum nitrogen dosage (180 kg/ha) resulted in the most extensive plant spread per plant (50.139 cm), while the absence of nitrogen (0 kg/ha) led to the shortest spread (43.696 cm) per plant.

Significant variances in plant spread were evident across distinct spacing configurations. The widest plant spread per plant (50.598 cm) occurred with the broadest spacing (60 cm×45 cm), surpassing spreads in other spacings (40 cm×44 cm and 50 cm×45 cm). Conversely, the narrowest plant spread per plant (42.632 cm) was documented with the closest spacing (40 cm×44 cm).

Table 3.1: Growth attributes, Effect of Nitrogen doses and spacing on Number of primary branches, Plant spread and plant height.

Treatments	No. of branches per vine (Average)	Number of leaves per plant (Average)	Vine length (Average) (cm)
Nitrogen Dose (factor A)			
0 kg/ha	46.889a	14.668a	43.696a
100 kg/ha	47.051b	16.501b	47.051b
140 kg/ha	50.110c	17.256c	47.732b
180 kg/ha	52.086d	19.464d	50.139c
C.D at 5%	1.272	0.662	2.028
Spacing (Factor B)			
S1- 40 x 45 cm	51.500a	16.403a	42.632
S2- 50 x 45 cm	47.940b	17.032b	47.355
S3 - 60 x 45 cm	47.662b	17.483b	50.598
C.D at 5%	1.102	0.573	1.756
CV%	9.54	11.44	9.66
Interaction (C.D at 5%)			
Factor(B)at same level of A	N/A	0.971	N/A
Factor(A)at same level of B	N/	1.367	N/A

The interaction between spacing and various nitrogen doses did not result in significant alterations in plant height and plant spread; however, it had a notable impact on the number of primary branches.

3.1.4 Flower Behavior

3.1.4.1 Days to 50% Flowering

The duration required for 50% flowering showed a significant correlation with varying nitrogen doses, progressively extending as nitrogen doses increased. Specifically, the time for 50% flowering surpassed 66.88 days with the application of 180 kg N/ha, while control plots exhibited a shorter duration of 64.29 days. The heightened nitrogen application stimulated vegetative growth, potentially contributing to the delay in flowering. Interestingly, plant spacing did not exhibit a notable impact on the time to reach 50% flowering. Nevertheless, different plant spacings did influence this duration, with medium spacing (40cm x 45cm) resulting in a duration of 65.96 days and the widest spacing (60cm x 45cm) yielding the shortest duration of 65.568 days.

Table 3.2: Effect of Nitrogen doses and spacing on Days to 50% Flowering.

Treatments	Days to 50% Flowering
0 kg/ha	64.291 a
100 kg/ha	65.261 ab
140 kg/ha	66.411 bc

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180 kg/ha	66.881 c
C.D at 5%	1.410
S1- 40 x 45 cm	65.605
S2- 50 x 45 cm	65.960
S3 - 60 x 45 cm	65.568
C.D at 5%	N/A
CV%	12.68
Interaction (C.D at 5%)	
Factor(B)at same level of A	N/A
Factor(A)at same level of B	N/A

Similarly, the interaction of spacing and different doses of nitrogen did not bring about any significant change on Days to 50% Flowering.

3.2 Fruit characters Measure

3.2.1 Fruit Length (cm)

The influence of different nitrogen doses and spacing on fruit length did not show statistically significant outcomes. The most extended fruits, measuring 6.111 cm, were noted with a nitrogen dose of 100 kg/ha, while the shortest fruit length (6.022 cm) was observed in control conditions. In terms of varying spacing, the greatest fruit length (6.106 cm) occurred at a spacing of 50 cm × 45 cm, whereas the minimum fruit length (6.017 cm) was documented at a spacing of 40 cm × 45 cm.

3.2.2 Fruit width (mm)

The influence of different nitrogen doses on both fruit width and length demonstrated non-significant outcomes. A 100 kg/ha nitrogen application was associated with a greater fruit diameter (7.554 mm), whereas a thinner diameter (7.368 mm) was observed at 180 kg/ha. Notably, increased fruit thickness (7.539 mm) occurred with a reduced spacing of 40 cm x 45 cm, while wider spacing (60 cm x 45 cm) led to thinner fruits.

3.2.3 Average Fruit weight (gm)

There were no significant differences observed in the average fruit weight concerning various nitrogen doses and spacing. Specifically, at a nitrogen dose of 100 kg/ha, the average fruit weight was elevated at 2.972 grams, whereas it decreased to 2.904 grams at 180 kg/ha. In terms of spacing, the configuration of 40cm×45 cm yielded a lower average fruit weight of 2.907 grams, whereas 60cm×45 cm resulted in a higher average weight of 2.959 grams.

Table 3.3: Fruit Characters Measures, Effect of Nitrogen doses and spacing on Fruit Length (cm), Fruit width (mm) and Average Fruit weight (g).

Treatments	**Fruit Length (cm)**	**Fruit width (mm)**	**Average Fruit weight (g)**
Nitrogen Dose (factor A)			
0 kg/ha	6.022	7.517	2.942
100 kg/ha	6.111	7.554	2.972
140 kg/ha	6.057	7.493	2.929
180 kg/ha	6.062	7.368	2.904
C.D at 5%	N/A	N/A	N/A
Spacing (Factor B)			
S1- 40 x 45 cm	6.017	7.539	2.907
S2- 50 x 45 cm	6.106	7.478	2.945
S3 - 60 x 45 cm	6.067	7.432	2.959
C.D at 5%	N/A	N/A	N/A
CV%	7.19	9.03	10.85
Interaction (C.D at 5%)			
Factor(B)at same level of A	N/A	N/A	N/A
Factor(A)at same level of B	N/A	N/A	N/A

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Interaction of spacing and different doses of nitrogen did not bring about any significant change in fruit length, fruit width and average fruit weight.

3.3 Yield Characters

3.3.1 Number of fruits per plant

Among the factors influencing yield, the number of fruits per plant emerges as a critical parameter. This attribute demonstrated significant variations among the plants, attributed to distinct nitrogen doses and varying spacing. The highest yield, averaging 66.326 fruits per plant, was observed with a higher nitrogen dose of 180 kg/ha, whereas the lowest yield (50.692 fruits per plant) was associated with a lower dose of 100 kg/ha.

It is noteworthy that the number of fruits per plant exhibited notable differences under different plant spacings. The largest spacing, 60 cm x 45 cm, resulted in the highest average number of fruits per plant (61.99), surpassing the yields of other spacings (40 cm x 44 cm and 50 cm x 45 cm). In contrast, the smallest spacing (40 cm x 44 cm) led to the lowest number of fruits per plant (53.138).

3.3.2 Fruit Yield per Plot

Plants subjected to a higher dose of nitrogen (180 kg/ha) exhibited a greater fruit yield per plant, in contrast to control plots (0 kg/ha), which showed a lower number of fruits per plant. Additionally, significant variations in fruit yield per plant were observed across different plant spacings. The widest spacing of 60 cm x 45 cm demonstrated the highest fruit yield per plant (277.383 g), surpassing yields associated with other spacings such as 40 cm x 45 cm and 50 cm x 45 cm. Conversely, the narrowest spacing of 40 cm x 45 cm recorded the smallest fruit yield per plant at 198.309 g.

3.3.3 Days to maturity

Significant variations in days to maturity were noted with varying nitrogen doses. An escalation in nitrogen doses correlated with an extended time to maturity. The control plots, receiving 0 kg nitrogen/ha, demonstrated the briefest period (113.111 days), whereas those subjected to the highest nitrogen dose (180 kg/ha) exhibited the lengthiest duration (117.444 days).

The spacing factor also wielded a discernible impact on days to maturity. The most abbreviated duration (115.583 days) was evident in the intermediate spacing (50 cm x 45 cm), while the widest spacing (60 cm x 45 cm) resulted in the lengthiest time to maturity (115.917 days).

Table 3.4: Yield Characters, Effect of Nitrogen doses and spacing on Number of fruits per plant, Fruit Yield per Plot(kg), Fruit Yield per plant (g) and Days to maturity.

Treatments	**Number of fruits per plant**	**Fruit Yield per Plot (kg)**	**Days to maturity**	**Fruit yield per plant (g)**
Nitrogen Dose (factor A)				
0 kg/ha	53.677 a	20.816 a	113.111	164.938
100 kg/ha	50.692 a	25.551 b	115.333	204.297 b
140 kg/ha	59.492 b	28.012 c	117.222	280.744 c
180 kg/ha	66.326 c	29.019 d	117.444	297.036 d
C.D at 5%	6.602	6.602	1.304	16.718
Spacing (Factor B)				
S1- 40 x 45 cm	53.138 a	17.675 a	115.833	198.309 a
S2- 50 x 45 cm	57.512 ab	27.474 b	115.583	234.569 b
S3 - 60 x 45 cm	61.991 b	32.399 c	115.917	277.383 c
C.D at 5%	5.718	2.028	N/A	14.478
CV%	18.65	28.56	11.87	27.45
Interaction (C.D at 5%)				
Factor(B)at same level of A	12.383	N/A	N/A	N/A
Factor(A)at same level of B	12.354	N/A	N/A	N/A

Interaction of spacing and different doses of nitrogen did not bring about any significant change in fruit yield per plot, fruit yield per plant and Days to maturity except for number of fruits per plant.

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IV. DISCUSSION

The research, titled "Impact of Varied Nitrogen Doses and Spacing on Chilli Growth and Yield-Related Parameters," took place at the Experimental Farm of Kabul University's Department of Horticulture Science from March 30, 2022, to August 30, 2022. Efficient fertilizer application is pivotal for maximizing yields in large-scale commercial chilli cultivation. The investigation revealed that while fertilizer significantly boosts fruit yields, excessive rates can adversely affect crop nutrient use efficiency, leading to reduced financial returns. Therefore, determining the optimal nitrogen dose and plant density for chilli cultivation in Kabul province, Afghanistan, becomes imperative.

Against this background, the study aimed to achieve the following objectives:

i. Examine the impact of diverse nitrogen doses on chilli growth and yield-related parameters.

ii. Investigate the effect of spacing on chilli growth and yield-related parameters.

iii. Explore the combined response of nitrogen and spacing on chilli growth and yield.

The experiment involved twelve treatment combinations derived from four nitrogen doses: (i) 0 kg/ha (control condition, A1); (ii) 100 kg/ha (A2); (iii) 140 kg/ha (A3); and (iv) 180 kg/ha (A4), with urea as the nitrogen source. Three spacing options were studied: (i) 40cm × 45cm (S1) (5.55 plants per sqm); (ii) 50cm × 45cm (S2) (4.44 plants per sqm); and (iii) 60cm × 45cm (S3) (3.70 plants per sqm). In addition to assessing the effects of nitrogen doses and spacings on chilli growth and yield, the study aimed to understand the interaction between nitrogen dose and plant spacing.

The study's findings are discussed under the following sections:

4.1 Impact of Varied Nitrogen Doses on Chilli Growth and Yield.

4.2 Effect of Plant Spacing on Chilli Growth and Yield.

4.3 Combined Response of Nitrogen and Plant Spacing on Chilli Growth and Yield.

4.1 Impact of Varied Nitrogen Doses on Chilli Growth and Yield

Nitrogen fosters vegetative growth, augments chlorophyll content, and enhances fruit size. It influences the utilization of potassium and phosphorus, playing a pivotal role in protein synthesis in plants. Ensuring an adequate nitrogen supply is crucial for optimal vegetative growth and, consequently, a desirable chilli yield.

4.1.1 Nitrogen Application's Impact on Plant Height

In this study, varied nitrogen doses exhibited a substantial influence on plant height, displaying a proportional increase with the nitrogen dosage. Gasim (2001) proposed that heightened plant growth resulting from nitrogen fertilization is linked to its promotion of growth, augmentation of internode count, and extension of internode length, ultimately leading to a progressive rise in plant height. The presence of nitrogen is closely associated with carbohydrate utilization. Under favorable conditions and sufficient nitrogen supply, heightened photosynthetic activity occurs, fostering more robust growth. Studies by Ayodele et al. (2015), Dubey et al. (2017), Islam et al. (2018), and Khalid et al. (2020) observed an elevation in chili plant height with nitrogen application compared to control conditions, corroborating our findings.

4.1.2 Nitrogen Application's Effect on Number of Primary Branches

The current study observed significant variations in the number of primary branches at different nitrogen doses. The quantity of primary branches exhibited an upward trend with increasing nitrogen levels. The impact of nitrogen on the number of branches per plant is noteworthy as it stimulates vegetative growth. These findings are consistent with the research conducted by Manchanda and Singh (1991). Similarly, Khan and Suryanarayana (1977) noted a proportional increase in the number of branches per plant in chili peppers with rising nitrogen levels. Studies by Khan et al. (2014), Ayodele et al. (2015), Islam et al. (2018), and Khalid et al. (2020) consistently concluded that an elevated nitrogen rate led to an increase in branches per plant. Thus, the outcomes of this study align with prior research in this domain.

4.1.3 Nitrogen Application's Influence on Plant Spread

Several studies have highlighted the significant impact of nitrogen fertilizer doses on the chili plant canopy. Higher values in plant canopy were observed with increased nitrogen doses, while lower values were recorded under control conditions in the study. The findings indicated that elevated nitrogen treatment resulted in increased plant canopy width. This study aligns with Essilfie et al.'s (2017) research, which similarly reported an augmentation in plant canopy with higher nitrogen doses. Elevated nitrogen supply enhances the photosynthetic capacity of plants, leading to increased vegetative growth in the form of branches and plant height, ultimately contributing to the expansion of plant canopy width. Plants with wider canopies tend to exhibit higher photosynthetic potential (NAR).

4.1.4 Nitrogen Application's Impact on Days to 50% Flowering

Days to 50% flowering were significantly influenced by varying nitrogen doses. In this study, a gradual increase in days to 50% flowering was observed with higher nitrogen doses. Previous research by Islam et al. (2018) and Khan et al. (2014) similarly reported that increased nitrogen doses delayed flowering in various genotypes. The delay in flowering was attributed to elevated nitrogen fertilization, leading to the diversion of photosynthates for the plant's vegetative growth. Consequently, heightened vegetative growth postponed the plants' entry into the reproductive phase.

4.1.5 Nitrogen Application's Effect on Fruit Length

The present study found no significant effects of various nitrogen doses on fruit length. This contrasts with

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earlier research where treatments with different nitrogen doses showed significant variation in the average fruit length of chili. Studies by Lal and Pundrik (1971), Khan et al. (2014), Islam et al. (2018), and Mahmud et al. (2020) demonstrated an increase in fruit length with higher nitrogen doses. This lack of significance in the present study may be attributed to the non-significant increase in nitrogen availability with the rise in nitrogen dose, which does not significantly alter the fruit length. Fruit length, being a genotypic character, is not significantly influenced by an increase in nitrogen dose.

4.1.6 Effect of Nitrogen Application on Fruit Width

Similar to the observation regarding fruit length, our study found that varying nitrogen doses did not significantly affect fruit width. This aligns with the understanding that fruit width, being a characteristic influenced by genotype, remained unchanged despite nitrogen variations. In contrast to our findings, prior research by Lal and Pundrik (1971), Khan et al. (2014), Islam et al. (2018), and Mahmud et al. (2020) documented an increase in fruit width with higher nitrogen doses. However, our study diverges from these findings, which contradicts earlier research where significant variation in average fruit weight was noticed with increased nitrogen doses. Other studies similarly highlighted an increase in fruit length and width with elevated nitrogen levels, which contrasts with our present study's outcomes.

4.1.7 Effect of Nitrogen Application on Average Fruit Weight

Similar to the observations in fruit length and width, variations in average fruit weight due to different nitrogen doses were found to be non-significant. This can be explained by the lack of substantial changes in fruit dimensions with increased nitrogen levels. For a noticeable alteration in average fruit weight, substantial changes in fruit length and width are required.

4.1.8 Effect of Nitrogen Application on Number of Fruits per Plant

Among yield-related characteristics, the number of fruits per plant stands as a critical determinant. The significant variation in this parameter across varied nitrogen doses and spacing emphasizes its importance. Past studies consistently show an upsurge in fruit yield with increased nitrogen application. Works by Roychaudhury (1990), Guohua et al. (2001), Shrivastava (2003), Khan et al. (2014), and Mahmud et al. (2020) align with our findings, indicating an increase in fruits per plant with escalating nitrogen doses. Hence, optimal nitrogen levels foster higher yields per plant, evident in the increased number of fruits per plant.

4.1.9 Effect of Nitrogen Application on Total Fruit Yield

Our study demonstrated a higher fruit yield per plant with a higher nitrogen dose (180 kg/ha) compared to control plots (0 kg/ha), which recorded a lower fruit count. Similar to the number of fruits per plant, both the total fruit yield per plant and per plot increased with higher nitrogen doses. These results align with various studies, including those by Kulvinder (1990), Tumbare and Niikam (2004), Law-Ogbomo and Jilani et al. (2008), Egharevba (2009), Bahuguna et al. (2014), Khan et al. (2014), Ayodele et al. (2015), and Mahmud et al. (2020), where increased nitrogen led to amplified vegetative growth, more branches, enhanced flowering, better fruit set, and ultimately, higher total fruit yield.

4.2 Effect of Plant Spacing on Growth and Yield of Chili

4.2.1 Effect of Plant Spacing on Plant Height

Plant spacing exerted a significant influence on plant height in this investigation, showcasing a noticeable increase with closer spacing. This aligns with findings from Islam et al. (2011), Alabi et al. (2014), Sharma and Kumar (2017), Edgar et al. (2017), and Thakur et al. (2018), collectively indicating a consistent trend of increased height in chili plants with narrower spacing. The observed outcome may be attributed to heightened competition for space and light, prompting plants to grow taller. In contrast, wider spacing resulted in the development of shorter and stouter plants, benefiting from increased growth space and enhanced nutrient and light utilization from the soil. The higher population density at closer spacing restricted light penetration, potentially leading to increased endogenous auxin formation and accelerated bud growth as plants vied for limited resources.

4.2.2 Effect of Plant Spacing on Number of Primary Branches

Significant differences were noted in the number of primary branches at various spacings in the study. Wider spacing correlated with an increased number of branches per plant. Consistent findings from studies by Islam et al. (2011), Sharma and Kumar (2017), Edgar et al. (2017), and Thakur et al. (2018) supported the observation that the lowest plant density, resulting from wider spacing, led to the highest number of branches per plant. This phenomenon suggests that plants in wider spacing receive more light, nutrients, and resources, contributing to a higher number of branches per plant per unit area.

4.2.3 Effect of Plant Spacing on Plant Spread

The plant spread exhibited significant variation under different plant spacings, showing a general increase with wider spacing. These results, in line with Essilfie et al. (2017), indicate a correlation between plant morphology and spacing. The widening of the canopy with increased spacing may account for higher photosynthetic potential. Plant density's impact on canopy architecture, light conversion efficiency, and the duration of vegetative growth may contribute to the observed variations.

4.2.4 Effect of Plant Spacing on Days to 50% Flowering

No significant effect of plant spacing on days to fifty per cent flowering was observed in the present experiment. This aligns with the findings of Barik et al. (2017). However, contrasting results were reported by Islam et al. (2011) and Thakur et al. (2018), indicating that

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plant spacing could influence flowering time. The variation may be attributed to factors such as sunlight availability and nutrient levels affecting photosynthesis, ultimately influencing the timing of flowering.

4.2.5 Effect of Plant Spacing on Fruit Length

The impact of spacing on fruit length yielded non-significant results in this study. In contrast, Islam et al. (2011) documented significant variability in sweet pepper fruit length attributed to plant spacing. The disparity may be due to specific genotypic characteristics and the interaction between spacing and the genetic makeup of the chili plants.

4.2.6 Impact of Plant Spacing on Fruit Width

The examination of spacing's effect on fruit width in our study revealed a lack of significance, mirroring the findings for fruit length. Wider plant spacing resulted in the highest fruit width, while narrower spacing led to the smallest fruit width (Islam et al., 2011).

4.2.7 Influence of Plant Spacing on Average Fruit Weight

The impact of varied spacing on average fruit weight was found to be non-significant in this study. This lack of significance can be attributed to the observation that neither fruit length nor fruit width showed significant changes with increasing plant spacing. Consequently, average fruit weight remained unaffected, as alterations in both fruit length and width contributed to the overall stability of this parameter.

4.2.8 Effect of Plant Spacing on Number of Fruits per Plant

Among the factors contributing to yield, the number of fruits per plant emerges as crucial. Notably, the number of fruits per plant exhibited significant variation influenced by different spacing conditions. Our investigation revealed a positive correlation, indicating that a wider spacing resulted in an increased number of fruits per plant. Various studies, including those by Islam et al. (2011), Sharma and Kumar (2017), Edgar et al. (2017), and Essilfie et al. (2017), consistently reported significant differences in the number of fruits per plant under various plant spacing conditions. These studies consistently highlighted that the widest spacing led to the highest average number of fruits per plant, surpassing those observed in closer spacings. The reduced plant density under wider spacing minimized both inter and intra-plant competition, contributing to an augmented number of fruits per plant.

4.2.9 Effect of plant spacing on total fruit yield

Similarly, the study observed significant variations in fruit yield per plant across different plant spacings. Increased spacing was associated with a corresponding rise in fruit yield per plant. The wider spacing facilitated optimal plant development, mitigating both inter and intra-plant competition for available resources, ultimately resulting in a higher yield per plant. Conversely, higher population density at narrower spacing contributed to a diminished yield per plant, likely attributed to a lower fruit yield. Plants situated at wider spacing experienced reduced inter-plant competition, leading to an increased number of fruits per plant. In contrast, Islam et al. (2011) reported that closer spacing resulted in higher fruit yield, while wider spacing led to a lower yield per plot. They observed an inverse relationship between plant spacing and fruit yield per unit area, where closer spacing produced a higher yield per plot and per hectare. The study noted a positive correlation between the increase in plant population and the total and marketable yield of capsicum, consistent with findings reported by Srinivas (1982), Manchanda and Bhopal Singh (1988), Pandey et al. (1997) in tomato, Joshi et al. (1980), and Harminder Singh (1997) in brinjal.

4.3 Interaction of different doses of nitrogen and plant spacing:

The concurrent influence of spacing and varying nitrogen doses did not yield significant alterations in plant height, days to 50% flowering, fruit length, fruit width, average fruit weight, fruit yield per plant, and fruit yield per plot. However, a notable impact was observed on the number of branches and the number of fruits per plant. The maximum count of fruits per plant and fruit yield per plot was evident in cases of closer spacing combined with a high dose of nitrogen. Chougule and Mahajan (1979) highlighted a significant influence of increasing nitrogen levels and spacing on the growth and yield parameters of chilli cv. Jwala. Ramchandran and Subbiah (1981) observed a notable effect of the nitrogen x spacing interaction on the number of fruits per plant when nitrogen levels were increased under wider spacing. Shrivastava's studies (1993) revealed that the interaction of spacing with fertilizer led to a higher number of branches in sweet pepper cv. Hybrid Bharat. Anez and Travira (1993) reported that plant height and the number of primary as well as secondary shoots were affected by the interaction of nitrogen level x row spacing x within-row spacing in chilli. Banerjee et al. (1997) observed that the combination of spacing and nitrogen dose resulted in the highest yield per plant.

V. CONCLUSION

Hot pepper (Capsicum annuum L.), commonly referred to as chili in South East Asia, is a globally cultivated crop thriving in temperate and tropical regions (Islam et al., 2011). Within the Solanaceae family, it stands as the third most crucial crop, following tomato and potato (Dubey et al., 2017). Chili cultivation is widespread, including in countries like Afghanistan. The experiment conducted by Gulab et al. (2019) aimed to optimize the combination of plant spacing and nitrogen doses to enhance the yield of the Mastan-F1 hot pepper variety at the Experimental Farm of the Department of Horticulture Science, Kabul University. The investigation focused on the impact of varying nitrogen doses (0 kg/ha, 100 kg/ha, 140 kg/ha, and 180 kg/ha) and spacings (40 cm × 45 cm, 50 cm × 45 cm, and 60 cm × 45 cm) on

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parameters such as days to fifty percent flowering, number of primary branches, plant height, plant spread, fruit length, fruit width, average fruit weight, fruit yield per plant, fruit yield per plot, and days to maturity. Overall, an increase in nitrogen dose correlated with elevated numbers of primary branches, days to 50% flowering, plant height, number of fruits per plant, fruit yield per plant, fruit yield per plot, plant spread, and days to fruit maturity. The application of 180 kg N per hectare resulted in the highest chili yield in the experiment. Furthermore, an expansion in plant spacing, particularly with a spacing of 60 cm × 45 cm, contributed to a higher chili yield.

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