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Effects of Nitrogen and Phosphorus on the Growth and Yield of Sweet Pepper (*Capsicum annuum* L.)

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Abstract
Stubble burning in Punjab and Haryana constitutes an agricultural crisis with catastrophic environmental consequences, releasing hazardous pollutants that degrade air quality, exacerbate climate change, and endanger public health. This comprehensive study quantifies environmental costs using satellite data (2002–2025), economic loss assessments, and policy evaluations. Findings reveal that 84 million tonnes (Mt) of India's annual agricultural residue is burned, emitting 3.4 Mt of CO, 91 Mt of CO_2, and 1.2 Mt of $PM_{2.5}$, with Punjab and Haryana contributing 30.5 Mt annually (Chauhan *et al.,* 2024). Post-monsoon burning peaks in November due to groundwater preservation policies compressing harvest windows, increasing Delhi's $PM_{2.5}$ by 23–26% (Singh & Kumar, 2025). Policy analysis demonstrates underutilization of Crop Residue Management (CRM) machinery despite subsidies, with only 36% adoption due to financial and technical barriers. Viable alternatives like biomass energy generation could avert USD 120 million in annual losses while restoring soil health through agroecological principles (Altieri & Nicholls, 2023). The study recommends integrated solutions combining varietal diversification, ex-situ market incentives, and stricter enforcement to transition toward zero-burn agriculture by 2030.

Keywords
Stubble burning, Air pollution, Crop residue management, Agricultural policy, Particulate matter, Punjab-Haryana, Environmental health, Biomass valorization

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INTRODUCTION
Botanically known as the genus *Capsicum*, sweet pepper (*Capsicum annuum* L.) is a member of Solanaceae family. According to Shoemaker and Teskey, (1955) it is indigenous to Brazil and tropical South America. It was brought to Spain by Columbus, and India received it from Brazil via the Portuguese. exclusively four of the approximately 20 species in the genus capsicum are grown commercially; *C. pendulum* and *C. pubescens* are exclusively found in Central and South America. The two other species *C. frutescens* and *C. annuum* are widely farmed around the globe. The majority of dry chilies and all green chilies on the market come from the most widely cultivated species, *C. annuum*. It has been chosen based on the varieties that are utilized in international trade because capsicum fruits varied greatly in size, shape, and mature color (Singh, 2000). Eleven groups make up the species, which can be split into sweet pepper and spicy peppers (Elia and Santamaria, 1995). After the tomato, sweet pepper is the second major significant vegetable crop due to its thick flesh and generally mild or mildly pungent flavor (Yoon et al. 1989). Bell pepper, green pepper and capsicum are further names for sweet pepper. It can be consumed as a raw or cooked salad. Additionally, the leaves are eaten as a salad, in soups, or with rice (Lovelook, 1973). Additionally, Knott and Deanon, (2002) found that it was a reliable source of a tome for gout, paralysis, and a pharmaceutical concoction for black vomit. There are no statistics on the production of sweet pepper, a minor vegetable in

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Bangladesh (Hasanuzzaman, 1999). In the Gazipur and Dhaka districts, small-scale agriculture is practiced to serve the city of Dhaka's market. For several large hotels in Bangladesh's capital, catering to foreigners is in high demand (Rashid, 1999). Although Bangladesh has only recently adopted this crop, it is in high demand for export and has a high nutritional value. Although sweet pepper is low in energy, it is high in nutrients, notably in terms of vitamins A and C. Fertilizer is considered as an important element in crop production. According to Uddin and Khalequzzaman (2003), nitrogen is one of these nutrients that is crucial for healthy plant establishment and anticipated growth. A sweet pepper's correct growth, development, and maximum output are all boosted by the right amount of nitrogen fertilizers. According to Demirovska et al. (1992), slow release fertilizers are also very promising for the cultivation of solanaceous plants like tomato and eggplant. They discovered that 92 tons of tomatoes may be produced per hectare using slow-release fertilizers, as opposed to only 42 tons with regular commercial fertilizers. Numerous scientists from around the world have been striving to commercially cultivate sweet pepper under diverse cultural conditions. Quantity and quality of capsicum were impacted by fertilizer rate. According to Kumar et al. (2006), fertilizer rates affected the color and capsaicin concentration of powdered pepper. The effects of phosphorus on pepper (*Capsicum annuum* L.) yield, yield components, nutritional concentration, and food value have been noted. Phosphorus levels at 125 kg per hectare considerably improved the height, leaves number, leaf area and branches of pepper plants. Early flowering, maturity period and yield of the treated plants were also markedly improved by the application of phosphorus (Alabi, 2006). The Rabi season in Bangladesh, which spans the months of October to April, is when sweet pepper is primarily farmed. The ideal amounts of phosphorus and nitrogen are related to the highest output of sweet pepper. To determine how fertilizers, affect the development and yield of sweet peppers, some studies were carried out in the BARI and Mymensingh regions. There is no doubt that various nutrient sources play a crucial role in crop production. In order to develop physiologically, morphologically, and biologically, plants use nitrogen and phosphorus, two of the key macronutrients. Fruit productivity and marketability are increased by nitrogen. The effectiveness of nitrogen fertilizer application in Bangladesh was a typical 30%. Fertilizer containing nitrogen and phosphorus is regarded as being essential for its proper development. In light of the aforementioned information, the current study has been conducted to look into how nitrogen and phosphorus affect the growth and yield of sweet pepper.

MATERIALS AND METHODS

This investigation was done from October 2018 to April 2019 at the Farm of Horticulture Department of Bangladesh Agricultural University, Mymensingh. The BARI Misti Morich-1 was employed as the planting material for this exploration and sowing materials were collected from Bangladesh Agricultural Research Institute, Joydevpur, Gazipur. Considerable two factors in the experiment were four levels of nitrogen (N) i.e., N_0: 0, N_1: 50, N_2: 100 and N_3: 150 kg N ha^{-1} respectively and four levels of phosphorus (P) fertilizer viz., P_0: 0, P_1: 30, P_2: 60 kg and P_3: 90 kg P ha^{-1}, respectively. Urea (46% nitrogen in urea) and TSP (21% P in TSP) were used as the sources of nitrogen and phosphorus according to the treatments. The experiment was embeded using a three-replication randomized block design. In addition to nitrogen and phosphorus fertilizers, other manures and fertilizers such as, cow dung 100 kg ha^{-1}, muriate of potash (MoP) 300 kg ha^{-1} were applied for normal growth and development of sweet pepper plant. During the last stage of land preparation, all fertilizers aside from urea and molybdenum were applied. At 30, 45, and 60 DAT, the remaining urea and MoP were applied in three equal portions. Manual irrigation was performed after each top dressing. Seedlings were cultivated in seedbeds, and when they were 30 days old and healthy, they were transplanted onto a 3 m × 2.25 m plot while maintaining a spacing of 50 cm x 40 cm and a distance of 30 cm and 60 cm, respectively, from plot to plot and block to block. To determine the statistical significance of the experimental results, data was acquired from five randomly chosen plants from each plot and statistical analysis was performed on the results. The means for each treatment were determined and the variance for each character was examined using the F test and LSD test was executed at 5% level of probability (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Plant height (cm)

Nitrogen was discovered to have considerable main effects on the plant's height ($P \leq 0.05$) at different days after transplanting (DAT). The best tall plant (45.40 cm) was achieved with nitrogen application at 150 kg ha^{-1} and the shortest (42.13 cm) was found in control treatment (N_0) at 125 DAT (Table 1). On the plant height at various days following transplanting, it was also discovered that the main influence of various quantities of phosphorus was substantial (Table 2). P_3 treatment had the highest plant height (44.69 cm), while P_0, the control treatment had the lowest plant height (43.18 cm), both at 125 DAT (Table 2). Regarding plant height, the cumulative effects of nitrogen and phosphorus were also substantial. However, the maximum plant height was obtained with treatment combination N_3P_3 and the minimum with N_0P_0. At 75 DAT, the tallest plant was obtained with same N_3P_3 treatment combination, while the minimum from N_0P_0 (Table 3). Result of present study was following the findings of Grazia et al. (2007) reported that the use of both nitrogen and phosphorus boosted the height of plant. Chailloux et al. (1992) also found that application of higher doses of nitrogen fertilizer raised the plant height more of sweet pepper cultivated during *Rabi* season.

Leaves plant^{-1} (no.)

Good leaf count is a sign of superior sweet pepper growth and development and is directly concerned to yield. The photosynthetic area increases with leaves count, increasing yield. The count of leaves plant^{-1} at various DAT varied significantly according to seedling age ($P \leq 0.05$). Maximum leaves plant^{-1} (124.61) was obtained when the plants were fertilized with nitrogen @ 150 kg ha^{-1} and the minimum number of leaves plant^{-1} (123.50) produced from the control treatment N_0 (Table 1). The quantity of leaves produced by a plant as the phosphorus level increased in response to different phosphorus doses. At 125 DAT the highest leaves count (125.10) was obtained from 90 kg P ha^{-1} whereas the treatment P_0 produced the least number of leaves plant^{-1} (123.09). The application of phosphorus likely increased as plant height rose, and this nutrient's effects eventually led to an increase the leaves count (Table 2). The quantity of leaves plant^{-1} was significantly impacted by the cumulative effects of nitrogen and phosphorus. Each plant's number of leaves was counted to be the highest (125.26) from 150 kg N ha^{-1} with 90 kg P ha^{-1} mimicked by 100 kg N ha^{-1} with 90 kg P h^{-1} treatment (125.21) whereas the lowest number (122.38) was found from control treatment N_0P_0 (Table 3). The findings of the Grazia et al. (2007) lend credence to the study's findings who reported that the usage of both nitrogen and phosphorus provoked the leaves count plant^{-1} in sweet pepper.

Table 1. Effects of various nitrogen fertilizer doses on growth and yield of sweet pepper

Doses of nitrogen fertilizer	Plant height at 125 DAT	Leaves at 125 DAT (no.)	Primary branch plant^{-1} at 125 DAT (no.)	Secondary branch plant^{-1} at 125 DAT (no.)	Fruits plant^{-1} (no.)	Fruit length (cm)	Fruit diameter (cm)	Wt. of individual fruit (g)	Yield plant^{-1} (g)	Yield (ton ha^{-1})
N_0	42.13	123.50	3.02	20.67	9.65	4.63	4.04	35.57	307.17	14.39
N_1	43.41	123.88	3.17	22.02	10.47	4.94	4.09	46.42	412.29	17.96
N_2	44.50	124.29	3.46	22.41	10.90	5.17	4.30	51.43	478.21	22.30
N_3	45.40	124.61	3.91	22.76	11.55	5.62	4.41	53.26	493.01	25.85
$LSD_{(0.05)}$	0.16	0.07	0.1	0.07	0.08	0.06	0.12	0.73	7.47	0.52
Level of significance	*	*	*	*	*	*	*	*	*	*

N_0, N_1, N_2 and N_3 indicate 0, 50, 100 and 150 kg N ha^{-1}, respectively;
* suggests significant at 5% probability level

Primary branches plant^{-1} (no.)

Main effects of nitrogen on primary branches for each plant were found to be significant ($P \leq 0.05$) at different days after transplanting (DAT). The highest primary branches plant^{-1} (3.91) was found in N_3 at 125 DAT and the lowest (3.02) was recorded from N_0 at 125 DAT (Table 1). The main impact of various phosphorus levels was also discovered to be substantial for the number of primary branches plant^{-1} at various days following transplanting (Table 2). The most primary branches possible on a single plant (3.72) was recorded from P_3 at 125 DAT and the bare minimum of main branches per plant (3.15) was recorded from P_0. The combined and interaction effect of nitrogen and phosphorus in the number of primary branches per plant at different DAT were statistically significant. The best count of primary branches plant^{-1} (4.55) was noticed at 125 DAT from the combination of treatment N_3P_3 (Table 3). Result of present study agreed with the results of Das and Rath, (1992) who investigated that the use of both nitrogen and phosphorus increased the quantity of primary branches plant^{-1}.

Secondary branches plant^{-1} (no.)

Main effects of nitrogen on secondary branches plant^{-1} were found to be significant ($P \leq 0.05$) at different days after transplanting (DAT). Maximum secondary branches plant^{-1} (22.76) was recorded from N_3 at 125 DAT and the minimum (20.67) was recorded from N_0 at 125 DAT (Table 1). Main effects of different dosess of phosphorus was also significant on secondary branches plant^{-1} at different DAT (Table 2). Maximum secondary branches plant^{-1} (22.71) was recorded from P_3 at 125 DAT and the minimum (21.41) was recorded from P_0. The cumulative and interactions effects of nitrogen and phosphorus in the quantity of secondary branches plant^{-1} at different DAT were statistically significant. The maximum secondary branches plant^{-1} (23.31) was obtained at 125 DAT from the treatment combination of N_3P_3 (Table 3). Result of present study aligned with the findings of Chailloux et al. (1992) also found that application of higher doses of nitrogen fertilizer increased the quantity of secondary branches plant^{-1} of sweet pepper.

Fruits plant^{-1} (no.)

At different DAT, the various nitrogen doses significantly ($P \leq 0.05$) influenced the amount of fruits produced per plant. As shown in (Table 1), N3 produced the most fruits per plant (11.55) whereas N_0 produced the fewest (9.65). The number of fruits produced by each plant was influenced significantly by different phosphorus levels. From (Table 2) P_3 produced the most fruits per plant (11.01) while P_0 produced the fewest fruits per plant (10.36). The combined and interaction effects of nitrogen and phosphorus for number of fruits plant^{-1} were significant statistically ($P \leq 0.05$). The maximum quantity of fruits plant^{-1} (12.33) was found from the combination treatment of N_3P_3 (Table 3). Result of present study is aligned with the reports of Grazia et al. (2007) reported that the application of both phosphorus and nitrogen increased the number of fruits plant^{-1} in sweet pepper.

Table 2. Effects of various phosphorus fertilizer doses on growth and yield of sweet pepper

Doses of phosphorus	Plant height at 125 DAT	Leaves at 125 DAT (no.)	Primary branch plant^{-1} at 125 DAT (no.)	Secondary branch plant^{-1} at 125 DAT (no.)	Fruits plant^{-1} (no.)	Fruit length (cm)	Fruit diameter (cm)	Wt. of individual fruit (g)	Yield plant^{-1} (g)	Yield (ton ha^{-1})
P_0	43.18	123.09	3.15	21.41	10.36	4.85	4.07	43.89	397.21	17.90
P_1	43.56	123.82	3.28	21.80	10.47	4.98	4.11	46.23	414.50	19.86
P_2	44.00	124.27	3.41	21.95	10.73	5.11	4.22	47.36	430.53	20.93

P_3	44.69	125.10	3.72	22.71	11.01	5.40	4.43	49.20	448.46	21.81
$LSD_{(0.05)}$	0.14	0.05	0.08	0.06	0.07	0.05	0.92	0.66	7.08	0.49
Level of significance	*	*	*	*	*	*	*	*	*	*

P_0, P_1, P_2 and P_3 demark 0, 30, 60 and 90 kg P ha^{-1}, respectively; * indicates significant at 5% level of probability

Fruit length (cm)

Fruit length was influenced significantly ($P \le 0.05$) by the different nitrogen doses. The maximum fruit length (5.62cm) was found from N_3 and the minimum (4.63 cm) was from N_0 (Table 1). Various phosphorus levels have substantial effects on fruit length. The maximum fruit length (5.40cm) was found from P_3 and the minimum fruit length (4.85cm) was found from P_0 (Table 2). The combined and interaction effects of phosphorus and nitrogen on fruit length at different DAT had statistical significance. The treatment combination of N_3P_3 produced the most desired fruit length (6.28 cm) (Table 3).

Fruit diameter (cm)

Fruit diameter was influenced significantly ($P \le 0.05$) by the different nitrogen doses. The maximum fruit diameter (4.41 cm) was taken from N_3 and the minimal (4.04 cm) from N_0 (Table 1). The varying quantities of phosphorus had a substantial impact on fruit diameter. P_0 produced the fruit with the smallest diameter (4.07 cm), whereas P_3 produced the fruit with the largest diameter (4.43 cm) (Table 2). The combined and interaction effects of phosphorus and nitrogen on fruit diameter were significant ($P \le 0.05$) statistically. The highest fruit diameter (4.68 cm) was attained from the combined treatment of N_3P_3 (Table 3).

Individual Fruit Weight (g)

The effects of nitrogen and phosphorus were significant in respect of individual weight of fruit ($P \le 0.05$). Different degrees of nitrogen application caused a sizable difference in the weight of each individual fruit. The maximum fruit weight (53.26 g) was attained from N_3 and the minimal fruit weight (35.57 g) was recorded from N_0 (Table 1). Single fruit weight was influenced significantly by various phosphorus doses. The maximum fruit weight (49.20 g) was attained from P_3 and the minimum fruit weight (43.89 g) from P_0 (Table 2). The cumulative and interaction effects of phosphorus and nitrogen in fruit weight were statistically significant. The maximum fruit weight (54.59 g) was obtained from the combined treatment of N_3P_3 (Table 3). Akinrinde et al. (2005) also found that application of higher doses of phosphorus fertilizer increased the individual fruit weight of sweet pepper.

Yield plant^{-1} (g)

Yield per plant was recorded at several nitrogen doses was significant. The best yield per plant (493.01 g) was recorded from N_3 and least yield per plant (307.17 g) was recorded from control treatment N_0 (Table 1). Ghoname et al. (2005) also found that application of higher doses of nitrogen fertilizer increased the individual yield per plant of sweet pepper. Yield per plant was recorded at different phosphorus levels. Maximum yield per plant (448.46 g) was recorded from P_3 and the minimum yield per plant (397.21 g) was attained from P_0 (Table 2). The combined and interaction effect of nitrogen and phosphorus in yield per plant were statistically significant ($P \le 0.05$). The highest yield plant^{-1} (495.54 g) was obtained from the treatment combination of N_3P_3 (Table 3).

Table 3. Combined effects of different levels of nitrogen and phosphorus fertilizer on growth and yield of sweet pepper

Treatment combinations	Plant height at 125 DAT	Leaves at 125 DAT (no.)	Primary branch plant^{-1}	Secondary branch plant^{-1} at 125 DAT	Fruits plant^{-1} (no.)	Fruit length (cm)	Fruit diameter (cm)	Wt. of individual fruit (g)	Yield plant^{-1} (g)	Yield (ton ha^{-1})

			at 125 DAT (no.)	(no.)						
N_0P_0	40.96	122.38	2.69	20.20	9.45	4.38	3.94	31.14	256.21	11.61
N_0P_1	41.59	123.25	2.99	20.57	9.52	4.54	3.95	34.15	289.82	14.27
N_0P_2	42.47	123.52	3.14	20.80	9.73	4.77	4.08	37.24	322.97	14.72
N_0P_3	43.48	124.84	3.27	21.13	9.89	4.82	4.17	39.75	359.69	16.94
N_1P_0	43.04	123.10	3.00	21.25	10.33	4.67	3.97	42.25	370.96	14.64
N_1P_1	43.35	123.34	3.11	21.81	10.44	4.85	3.98	46.62	402.29	16.88
N_1P_2	43.51	123.99	3.20	21.88	10.50	5.03	4.14	46.89	423.31	19.85
N_1P_3	43.74	125.08	3.37	23.13	10.59	5.20	4.28	49.93	452.61	20.47
N_2P_0	43.83	123.24	3.30	21.81	10.65	5.01	4.11	50.38	472.20	21.24
N_2P_1	43.97	124.12	3.36	22.16	10.71	5.16	4.20	51.04	473.05	22.20
N_2P_2	44.66	124.58	3.50	22.43	11.03	5.20	4.29	51.76	481.62	22.59
N_2P_3	45.53	125.21	3.68	23.25	11.21	5.30	4.59	52.52	485.98	23.18
N_3P_0	44.88	123.62	3.62	22.36	11.00	5.35	4.27	51.77	489.46	24.08
N_3P_1	45.34	124.57	3.67	22.66	11.22	5.39	4.31	53.13	492.81	26.07
N_3P_2	45.36	125.00	3.81	22.70	11.66	5.45	4.36	53.55	494.21	26.57
N_3P_3	46.00	125.26	4.55	23.31	12.33	6.28	4.68	54.59	495.54	26.67
$LSD_{(0.05)}$	0.32	0.13	0.19	0.15	0.17	0.13	0.21	1.46	14.95	1.04
Level of significance	*	*	*	*	*	*	*	*	*	*

N_0, N_1, N_2 and N_3 demark 0, 50, 100 and 150 kg N ha^{-1}, respectively; P_0, P_1, P_2 and P_3 demark 0, 30, 60 and 90 kg P ha^{-1}, respectively; * indicates significant at 5% level of probability

Yield (ton ha^{-1})

Different nitrogen doses considerably ($P \leq 0.05$) impacted the yield of sweet pepper. N_3 produced the maximum yield (25.85 ton ha^{-1}) where N_0 produced the least yield (14.39 ton ha^{-1}) (Table 1). Main effects of different doses of phosphorus was also found to be significant on the yield. The utmost yield (21.81 ton ha^{-1}) was recorded from P_3 and the least (19.90 ton ha^{-1}) was found from P_0 (Table 2). Das and Rath, (1992) also found that application of higher doses of phosphorus fertilizer increased the yield potential of sweet pepper. The cumulative and interaction effects of nitrogen and phosphorus on sweet pepper yield were significant ($P \leq 0.05$) statistically. The treatment combination of N_3P_3 produced the maximum yield (26.67 ton ha^{-1}) where the control treatment N_0P_0 gave the lowest one (11.61 ton ha^{-1}). Benefits of nitrogen and phosphorus application in sweet pepper with respect to increase in yield was recorded by Hari et al. (2006).

CONCLUSION

It was found that growth and yield of sweet pepper in the combined treatment were higher than control. In this experiment, the highest measurable yield 26.67 ton ha^{-1} was obtained from the combination of treatment of nitrogen (150 kg ha^{-1}) and phosphorus 90 kg ha^{-1}). Whereas the minimum yield 11.61 ton ha^{-1} was found from the control treatment combination of no nitrogen with no phosphorus application. The study accomplished that judicious combination strategy of (N_3P_3) using 150 kg nitrogen ha^{-1} with 90 kg phosphorus ha^{-1} may be helpful in increasing the growth and yield of sweet pepper. To recommend a technology for usage at the grower level, more research may be required on the simultaneous effects of nitrogen and phosphorus on the growth and yield of sweet pepper in different Agro Ecological Zones (AEZ) of Bangladesh.

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