Research Article

Phytopharmacology Research Journal (PRJ) Open Access

Received: 01 December 2024 | Revised: 14 January 2025 | Accepted: 26 January 2025 | Published online: 30 January 2025 | ISSN : 2959-9687

Quantitative assessment of vegetative and rhizhospheric responses of maize cultivar “Swabi White” under varying plant densities and nitrogen regimes

Abdul Basir[1]*, Muhammad Adnan[1], Afaq Hussain[1], Muhammad Ibrahim[1], Sayab Khan[1], Inzamam Hussain[2], Mohammed Afaq Khan[1], Abdullah Shahid[1], Adeel Ahmad[1], Hamza Zaman[1]

[1]Department of Agriculture, The University of Swabi, Khyber Pakhtunkhwa, Pakistan
[2]College of Agronomy and biotechnology, China Agricultural University, Beijing 100193, China

Correspondence email
a.basir@uoswabi.edu.pk
Funding information
“NA

Abstract

Optimizing agronomic practices such as nitrogen (N) management and planting density is crucial for enhancing maize (Zea mays L.) productivity, particularly in regions with distinct environmental constraints. A field study was conducted to evaluate the vegetative and rhizhosp\\heric responses of the open-pollinated maize variety 'Swabi White' to different plant densities and nitrogen application rates in Swabi, Pakistan. The experiment used a split-plot design with three replications. The main plots consisted of three plant densities (P1: 100,000; P2: 66,666; and P3: 50,000 plants ha^{-1}), and the sub-plots included three nitrogen rates (N1: 100; N2: 150; and N3: 200 kg N ha^{-1}). Results indicated that increasing nitrogen application significantly enhanced stem diameter, leaf number, leaf area, root length, and biological yield, with the 200 kg N ha^{-1} rate yielding the most vigorous growth. Conversely, individual plant morphology was negatively affected by higher plant densities; lower densities resulted in taller plants with thicker stems and larger leaves. However, total biological yield per unit area was optimized at an intermediate density. A significant interaction between nitrogen and plant density was observed for biological yield, with the highest yield (8,875.6 kg ha^{-1}) achieved at a density of 66,666 plants ha^{-1} combined with 200 kg N ha^{-1}. These findings suggest that a balanced approach, integrating moderate plant densities with optimal nitrogen inputs, is a viable strategy for maximizing maize yield and resource-use efficiency in similar agroecological zones.

KEYWORDS

Zea mays L., Plant Population, Nitrogen Fertilization, Sustainable Agriculture, Yield Optimization.

1. Introduction

Maize (Zea mays L.) is a cornerstone of global food security, contributing significantly to the caloric intake of millions worldwide and serving as a primary component in livestock feed and bio-energy production [1,2]. Although maize (Zea mays ssp. mays) is a major economic and nutritional crop, the agricultural performance is limited by inadequate agronomic management strategies, in particular the use of nutrients and inter-row spacing.

Nitrogen (N) is the most common-limiting nutrient that affects the maize production because it is essential in the synthesis of protein, nucleic acids, and chlorophyll and therefore, plant growth and development [3]. Despite the fact that augmented N fertilization usually increases yields, over usage leads to reduced NUE, increased cost of production, and the poor environmental impact, consisting of greenhouse gas emissions and water pollution [4,5]. That is why NUE is one of the main aims of sustainable agriculture [6].

Plant density is an another factors regulating maize yield since it affects the ability of the canopy to capture light and the ability of roots to acquire water and nutrients. Higher plant densities increase intra specific competition over resources which consequently leads to stress and reduced individual plant growths. However, there are certain range of the densities, where crop productivity increases per unit area and reaches the peak, then starts to decrease [7,8]. In low-density planting however, the use of resources is not exhaustive, and this may limit the potential of yield in general [9].The increased planting densities often require higher amounts of nitrogen to support a higher population but such an approach cannot always lead into improved yields and may significantly reduce NUE [10]. The optimum level of nitrogen rates and planting density depends on the maize variety, weather pattern, and soil type and there is no prescription that can be used everywhere [11,12].

Maize productivity varies across different agro-climatic zones, necessitating location-specific research to develop tailored management strategies in pakistan. This study was designed to investigate the effects of varying plant densities and nitrogen rates on the vegetative and rhizhospheric characteristics of 'Swabi White,' a local open-pollinated maize variety. The primary objectives were to: (1) determine the optimal plant density for morphological growth, (2) evaluate the impact of nitrogen rates on root development, and (3) identify the plant density and nitrogen rate combination that maximizes biological yield under the agro-climatic conditions of Swabi, Khyber Pakhtunkhwa.

2. Materials and Methods

The field experiment was conducted during the 2024 Kharif season at the Agriculture Research Station in Swabi, Pakistan (34°07' N, 72°30' E; 370 m elevation). The study was laid out in a split-plot arrangement within a Randomized Complete Block Design (RCBD), replicated three times. The main plot factor was plant population, with three levels: P1 (100,000 plants ha^{-1}; 50 cm x 20 cm spacing), P2 (66,666 plants ha^{-1}; 75 cm x 20 cm spacing), and P3 (50,000 plants ha^{-1}; 100 cm x 20 cm spacing). The sub-plot factor was nitrogen level, with three rates: N1 (100 kg ha^{-1}), N2 (150 kg ha^{-1}), and N3 (200 kg ha^{-1}).

2.1. Crop Management

The experimental field was prepared by conventional plowing and leveling. The maize variety used was 'Swabi White,' a local open-pollinated variety. Sowing was completed on July 18, 2024, using a seed drill. Phosphorus (as DAP) and potassium (as SOP) were applied as a basal dose to all plots. Nitrogen (as Urea) was applied in two split doses: 50% at sowing and 50% as a top-dressing at the knee-high stage. Standard agronomic practices, including manual weeding and flood irrigation at 10-day intervals, were followed uniformly for all treatments.

2.2. Data Collection

Data were collected at crop maturity from randomly selected plants within each sub-plot.

- **Plant Height (cm):** Measured from the soil surface to the tip of the tassel.
- **Stem Diameter (mm):** Measured at the second internode from the base using a vernier caliper.

- **Number of Leaves per Plant:** Total number of fully expanded leaves were counted.
- **Leaf Area (cm²):** Calculated for the last fully expanded leaf using the formula: LA = Leaf Length × Leaf Width × 0.75 (correction factor).
- **Root Parameters:** Roots were carefully excavated, washed, and blotted dry. Root length (cm) was measured with a scale. Root fresh weight (g) was recorded using a digital balance. For root dry weight (g), samples were oven-dried at 80°C until a constant weight was achieved.
- **Biological Yield (kg ha⁻¹):** Plants from a central area in each plot were harvested, sun-dried, and weighed to determine total above-ground biomass, which was then converted to kg ha⁻¹.

2.3. Statistical Analysis

The collected data were subjected to Analysis of Variance (ANOVA) using Statistix 8.1 software. Treatment means were compared using the Least Significant Difference (LSD) test at a 5% probability level ($p \leq 0.05$).

3. Results

3.1 Plant height

Nitrogen application and plant population had significant but distinct effects on maize vegetative growth. While nitrogen did not significantly affect plant height, a clear trend of increased height with higher N rates was observed. Plant population, however, had a highly significant effect ($p<0.01$), with the highest density (P1) producing the tallest plants (206.46 cm) due to increased competition for light (Table 1).

Table 1: Effect of Plant Population and Nitrogen on Maize Plant Height (cm) and Stem Diameter (mm)

Nitrogen	Population			MEAN
	P1 100000 plant / ha	**P2** 66666 plant / ha	**P3** 50000 plant / ha	
N1*(100 Kg/ha)*	178.90 NS	192.37	205.03	**192.10 NS**
N2*(150 Kg/ha)*	180.67	194.00	206.37	**193.68**
N3*(200 Kg/ha)*	179.77	194.37	207.97	**194.03**
MEAN	**179.78 c**	**193.58 b**	**206.46 a**	

LSD ($p<0.05$) for plant density=1.69
LSD ($p<0.05$) for nitrogen = NS
LSD ($p<0.05$) for PxN=NS

3.2 Stem diameter

Stem diameter was significantly influenced by both factors ($p<0.001$). The highest nitrogen rate (N3) produced the thickest stems (21.72 mm), whereas the lowest plant density (P3) resulted in the thickest stems (21.53 mm), indicating that while N promotes structural growth, high density constrains it (Table 2).

Table 2: Stem diameter of maize as affected by plant population and nitrogen levels

Nitrogen	Population			MEAN
	P1 100000 plant / ha	**P2** 66666 plant / ha	**P3** 50000 plant / ha	
N1*(100 Kg/ha)*	17.96 NS	19.13	20.09	**19.06 c**
N2*(150 Kg/ha)*	19.32	20.80	21.62	**20.58 b**
N3*(200 Kg/ha)*	20.68	21.60	22.89	**21.72 a**
MEAN	**19.32 c**	**20.51 b**	**21.53 a**	

LSD ($p<0.05$) for plant density=0.655
LSD ($p<0.05$) for nitrogen =0.360
LSD ($p<0.05$) for PxN=NS

3.3 Leaf area

The number of leaves per plant and leaf area responded similarly. Both parameters increased significantly ($p<0.001$) with higher nitrogen rates but decreased with higher plant densities. The N3 treatment produced the most leaves (10.77) and the largest leaf area (287.71 cm²), while the P3 density supported the highest number of leaves (10.77) and largest leaf area (285.59 cm²) on a per-plant basis (Table 3).

Table 3: Leaf Area of maize as affected by plant population and nitrogen levels

Nitrogen	Population			MEAN
	P1 100000 plant ha^{-1}	**P2** 66666 plant ha^{-1}	**P3** 50000 plant / ha	
N1*(100 Kg/ha)*	246.97 NS	257.20	268.77	**257.64 c**
N2*(150 Kg/ha)*	266.70	274.37	284.30	**275.12 b**
N3*(200 Kg/ha)*	275.63	283.80	303.70	**287.71 a**
MEAN	**263.10 c**	**271.79 b**	**285.59 a**	

LSD ($p<0.05$) for plant density=7.3386
LSD ($p<0.05$) for nitrogen =4.9090
LSD ($p<0.05$) for PxN=NS

3.4. Rhizospheric and Yield Parameters

Root length was significantly affected by both treatments ($p<0.01$), increasing with higher nitrogen rates but decreasing with higher plant densities (Table 4). The longest roots (30.00 cm) were observed under the N3 treatment. In contrast, root fresh and dry weights were not significantly affected by either nitrogen or plant density, though numerical trends suggested that higher N rates tended to increase root biomass.

Table 4: Root length of maize as affected by plant population and nitrogen levels

Nitrogen	Population			MEAN
	P1 100000 plantsha^{-1}	**P2** 66666 plantha^{-1}	**P3** 50000 plant / ha	
N1*(100 Kg/ha)*	26.33 NS	27.66	28.66	**27.55 c**
N2*(150 Kg/ha)*	28.00	29.00	30.00	**29.00 b**
N3*(200 Kg/ha)*	29.00	30.00	31.00	**30.00 a**
MEAN	**27.77 c**	**28.88 b**	**29.88 a**	

LSD ($p<0.05$) for plant density=0.503, LSD ($p<0.05$) for nitrogen =0.342,
LSD ($p<0.05$) for PxN=NS

3.5 Biological yield

Biological yield was significantly influenced by both factors and their interaction ($p<0.05$). Yield increased linearly with nitrogen application, with N3 producing the highest biomass (8875.6 kg ha^{-1}). The effect of plant population was not linear; the intermediate density (P2) produced a slightly higher yield than the highest density (P1), and both were significantly higher than the lowest density (P3). The significant interaction revealed that the highest biological yield (9425.3 kg ha^{-1}) was achieved with the combination of intermediate plant density (P2: 66,666 plants ha^{-1}) and the highest nitrogen rate (N3: 200 kg ha^{-1}) (Table 5).

Table 5: Biological yield of maize as affected by plant population and nitrogen levels

Nitrogen	Population			MEAN
	P1 100000 plant ha^{-1}	**P2** 66666 plant ha^{-1}	**P3** 50000 plant ha^{-1}	
N1	7304.7E	7130.0E	6246.0G	**6893.6 c**
N2	8508.7C	8211.7D	6849.0F	**7856.4 b**
N3	8802.3B	9425.3A	8399.0CD	**8875.6 a**
MEAN	**8205.2 a**	**8255.7 a**	**7164.7 b**	

LSD ($p<0.05$) for plant density=214.86
LSD ($p<0.05$) for nitrogen =90.862,
LSD ($p<0.05$) for PxN=157.38

3.6 Root Fresh Weight:

Root biomass measurements showed more complex responses *(table 6).* Neither nitrogen nor population effects reached statistical significance ($p>0.05$), though numerical trends were apparent. The N2 treatment (150 kg ha^{-1}) produced the heaviest fresh roots (61.88 g), suggesting a possible optimal nitrogen level for root growth. Similarly, P1 plants (100,000 ha^{-1}) showed slightly higher fresh weights (61.77 g) than lower densities. These non-significant trends indicating root biomass may be less sensitive to these treatments than other parameters [21].

Table 6: Root fresh weight of maize as affected by plant population and nitrogen levels

Nitrogen	Population			MEAN
	P1 100000 plant ha^{-1}	**P2** 66666 $plantsha^{-1}$	**P3** 50000 plant / ha	
N1(*100 Kg/ha)*	58.33	59.66	60.66	**59.55**
N2(*150 Kg/ha)*	63.00	61.00	61.66	**61.88**
N3(*200 Kg/ha)*	61.00	61.33	63.00	**61.77**
MEAN	**60.77**	**60.66**	**61.77**	

LSD ($p<0.05$) for plant density= NS
LSD ($p<0.05$) for nitrogen = NS, LSD ($p<0.05$) for PxN=NS

3.7 Root Dry Weight:

Similar to fresh weight, root dry matter accumulation showed non-significant treatment effects *(table 6).* However, numerical patterns mirrored nitrogen inputs, with N3 (21.77 g) and N2 (21.88 g) exceeding N1 (19.55 g). The P3 population also showed slightly higher dry weights (21.77 g) than lower densities. These observations suggesting root dry matter responds differently than other growth parameters [22] (Table 7).

Table 7: Root dry weight of maize as affected by plant population and nitrogen levels

Nitrogen	Population			MEAN
	P1 100000 plant ha^{-1}	**P2** 66666 plant ha^{-1}	**P3** 50000 plant / ha	
N1(*100 Kg/ha)*	18.33	19.66	20.66	**19.55**
N2(*150 Kg/ha)*	23.00	21.00	21.66	**21.88**
N3(*200 Kg/ha)*	21.00	21.33	23.00	**21.77**
MEAN	**20.77**	**20.66**	**21.77**	

LSD ($p<0.05$) for plant density= NS
LSD ($p<0.05$) for nitrogen = NS
LSD ($p<0.05$) for PxN=NS

4. Discussion

The results of this study highlight the intricate relationship between nitrogen fertilization, plant density, and maize productivity. The observed increase in vegetative parameters such as stem diameter, leaf number, and leaf area with higher nitrogen rates is consistent with the established role of N in promoting cell division and expansion, leading to greater photosynthetic capacity [13, 14]. Similarly, the enhancement of root length with increased N suggests that adequate nitrogen supply encourages deeper root exploration to access water and other nutrients, a finding supported by research in other cereal crops [15].

Plant population density explains a canonical trade off between stand productivity and individual plant performance. When grown at low-density level of 50 000 plant ha^{-1}, individuals had more elevated stems, broader leaves, and leaf area, which can be related to less inter-plant competition in these areas, resulting in many more resources to be devoted to individuals [9, 19]. In contrast, the height of the plant was bigger at increasing densities due to the shade-avoidance response that is well documented, where plants extend their stems to be aggressive towards those looking to attract light very often to the slight of strength [16, 20].

In the study, the main finding is that about the interaction of nitrogen input and plant density with biological yield. Despite the obvious effects of increased N rates to increase biomass consistently, the highest density where this effect was maximized was not the highest but an intermediate density. Maximum biological production was reached by 66,666 plants ha^{-1} alongside with 200 kg N ha^{-1}. This finding suggests that when the plants were at the maximum population (100 000 plants ha^{-1}) the strong competition over the resources that are not nitrogen (i.e., light or water) could have constrained the use of nitrogen showing how the high planting density can generate diminishing returns despite high planting input [10,17,24]. The intermediate density is probably an optimum helping in achieving optimal interception of light and the use of resources at the canopy level and kept such that the plants are not too stressed individually and thus the most effective conversion of nitrogen into biomass. This can be summed up with the fact that using ideal combinations of density-nitrogen is key to maximizing biomass [18, 25].

5. Conclusion

This study demonstrates that both nitrogen application and plant population density are critical drivers of maize growth and yield, but their effects are interdependent. It is concluded that Increasing nitrogen fertilization up to 200 kg ha^{-1} robustly enhanced key vegetative and rhizospheric traits of maize variety Swabi White, leading to higher biological yield in the agro-climatic conditions of Swabi, Pakistan. Lower plant densities (50,000 plants ha^{-1}) promoted superior individual plant growth, but intermediate densities (66,666 plants ha^{-1}) are more effective for maximizing biomass production per unit area. A significant synergistic interaction exists, where the highest biological yield is achieved by combining an intermediate plant density (66,666 plants ha^{-1}) with a high rate of nitrogen (200 kg ha^{-1}). Based on these findings, a management strategy integrating a plant population of approximately 66,000 plants ha^{-1} with a nitrogen application of 200 kg ha^{-1} is recommended for farmers in this region to sustainably maximize maize productivity.

Acknowledgment

We acknowledge the services and facilitations in terms of field and labour provided by the Agriculture Research Station Gulu Dheri, Swabi for this experiment.

Conflict of Interest

The authors declare that there is no conflict of interest among authors

References

1. M. Kaushal, R. Sharma, D. Vaidya, A. Gupta, HK. Saini, and A. Anand, (2023). Maize: an underexploited golden cereal crop. Cereal Research Communication 51(1): 3-14.
2. Y. Ai, and JL. Jane, (2016). Macronutrients in corn and human nutrition. Comprehensive Reviews in Food Science and Food Safty 15(3): 581-598.
3. AA. Correndo, JL. Rotundo, N. Tremblay, S. Archontoulis, JA. Coulter, D. Ruiz-Diaz, and IA. Ciampitti. (2021). Assessing the uncertainty of maize yield without nitrogen fertilization. Field Crops Research 260: 107985.
4. L. Lassaletta, G. Billen, B. Grizzetti, J. Anglade, and J. Garnier, (2014). 50 year trends in nitrogen use efficiency of world cropping systems: the relationship between yield and nitrogen input to cropland. Environmental Research Letter 9(10): 105011.
5. X. Zhang, R. Bol, C. Rahn, G. Xiao, F. Meng, and W. Wu, (2017). Agricultural sustainable intensification improved nitrogen use efficiency and maintained high crop yield during 1980–2014 in Northern China. Science of the Total Environment 596: 61-68.
6. X. Du, Z. Wan, W. Lei, and L. Kong, (2021). Increased planting density combined with reduced nitrogen rate to achieve high yield in maize. Scientific Report 11(1): 358.
7. LC. Zhai, RZ. Xie, B. Ming, and SK. Li (2018). Evaluation and analysis of intraspecific competition in maize: A case study on plant density experiment. Jounal of Integrated Agriculture 17(10): 2235-2244.
8. V. Mandić, S. Đorđević, M. Brankov, V. Živković, M. Lazarević, T. Keškić, and V. Krnjaja, (2024). Response of yield formation of maize hybrids to different planting densities. Agriculture, 14(3): 351.
9. Q. Jia, L. Sun, H. Mou, S. Ali, D. Liu, Y. Zhang, and Z. Jia, (2018). Effects of planting patterns and sowing densities on grain-filling, radiation use efficiency and yield of maize (Zea mays L.) in semi-arid regions. Agriculture Water Management 201*:* 287-298.
10. P. Yan, J. Pan, W. Zhan, J. Sh, X. Chen, and Z. Cui, (2017). A high plant density reduces the ability of maize to use soil nitrogen. PLoS ONE, 12(2): e0172717.

11. IS. Tokatlidis, (2013). Adapting maize crop to climate change. Agronomy for Sustainable Development 33*:* 63-79.
12. Y. Jiang, H. Li, W. Ma, W. Yu, J. Chen, Y. Gao, and L. Xu, (2025). A meta-analysis of the effects of nitrogen fertilizer application on maize (Zea mays L.) yield in Northwest China. Frontier in Plant Sciences 15: 1485237.
13. MA. Cheema, W. Farhad, MF. Saleem, HZ. Khan, A. Munir, and MA. Wahid, (2010). Nitrogen management strategies for sustainable maize production. Crop & Environment 1(1): 49-52.
14. FS. Ferrari, GB. da Rosa, ED. dos Santos, ACR. Marques, EC. Monteiro, and DN. Follmann, (2025). Morphological changes in maize subjected to different nitrogen rates in a low-altitude subtropical environment. Observatorio de la Economia Latinoamiricana 23(4): 165.
15. X. Zhang, S. Du, Y. Xu, C. Cao, and H. Chen, (2021). Reducing N application by increasing plant density based on evaluation of root, photosynthesis, N accumulation and yield of wheat. Agronomy, 11(6): 1080.
16. BJ. Bernhard, and FE. Below, (2020). Plant population and row spacing effects on corn: Plant growth, phenology, and grain yield. Agronomy Journal 112(4): 2456-2465.
17. I. Djalovic, PV. Prasad, D. Dunđerski, S. Katanski, D. Latković, and L. Kolarić (2024). Optimal plant density is key for maximizing maize yield in calcareous soil of the south Pannonian Basin. Plants 13(13): 1799.
18. H. Akbar, MJ. Khan, S. Akhtar, and S. Ahmad (2008). Effect of plant population and nitrogen levels on maize. Sarhad Journal of Agriculture 24(2): 223–227.
19. M. Haroon, M. Alam, M. Saeed, A. Basir, Y. Jamal, M. Adnan, and M.Z. Majeed, (2022). Parthenium derived extract: a sustainable weed management approach in maize crop. Pakistan Journal of Weed Science Research, 28(1).
20. Z. Xing, G. Bi, T. Li, Q. Zhang, & P.R. Knight, (2024). Effect of Plant Density on Growth and Bioactive Compounds in Salvia miltiorrhiza. Agronomy, 14(6), 1157.
21. F.M.F. Abdel Motagally and K.K. Attia, (2009). Response of Sugar Beet Plants to Nitrogen and Potassium Fertilization in Sandy Calcareous Soil. International Jouranal of Agriculture and Biology: 11(6) 695–700
22. M. Bilal, M.Tayyab, I. Aziz, A. Basir, Bilal Ahmad, Umair Khan, Muhammad Zahid, and Naveed Ali. 2017. Impact of Integrated Fertilization (Organic and In-Organic) on Grain Yield of Maize Crop. Agriculture, Forestry and Fisheries.6,(5), 173-178.
23. S.R. Jalal, A. Basir, J. Alam, A. Ali, G.R. Khan, A. Aziz, M.M. Anjum, Sunila and I. Khan. (2018). Evaluation of eight maize genotypes for yield and yield contributing traits. Pure and Applied Biology. Pure Applied Biology, 7(2): 620-624
24. A. Basir, A. Aziz, M.A. Khan, I. Khan, M. Adnan, S. Fahad, A.S. Shah, I. Rehman, M. Noor and A. Rahman. (2018). Phenology and growth traits response of maize (Zea mays L.) genotypes to semi-arid conditions. Pure and Applied Biology. 7(1)-169-173