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Response of maize to combined application of nitrogen and phosphorous fertilizers in semi-arid conditions of Faisalabad

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Abstract: Changes in climate, development of new hybrids and soil fertility status has influenced nutrient application rates worldwide. Shifting climate conditions may necessitate changes in crop selection and the adoption of more heat or drought tolerant varieties, which can have different nutrient requirements, further influencing nutrient application rates. Sustainable nutrient management strategies must adapt to these climate induced challenges to ensure efficient and environmentally responsible agriculture. A field experiment was carried out at Student research area, Agronomy Farm, University of Agriculture, Faisalabad, Pakistan during spring 2019 to determine the response of maize to combined application of nitrogen (N) and phosphorus (P) in the semi-arid conditions of Faisalabad. The experiment was organized according to randomized complete block design with split plot arrangement keeping a net plot size of 8 m x 3 m with three replications. The experiment was comprised of two main factors (i) Nitrogen levels (100, 200 and 300 kg ha^{-1}) and (ii) Phosphorus levels (50, 100 and 150 kg ha^{-1}). Nitrogen doses were kept in main plots, while phosphorous doses in subplots. Highest values for parameters were attained where N and P were applied with dose 200 and 150 kg ha^{-1}, respectively. Among the N and P levels, maximum grains per cob (496, 195.7), 1000 grains weight (369.04, 353.46 g), grain yield (6.20, 5.85 t ha^{-1}), biological yield (25.555, 23.51 t ha^{-1}) and harvest index (29.01, 27.34%) was observed from the N2 and P2, respectively. Whereas, NUE (2.44) was the highest in treatment N2P3 and PUE (6.45) was the highest with treatment N3P1. While, minimum values were attained with 100 and 50 kg ha^{-1} N and P, respectively.

Keywords: Changing environment; Crop nutrition; Nutrients; Crop production; Nutrient use efficiency; Nitrogen; Phosphorus

Introduction

Food demand increases in direct relation with human population, whereas intensive agricultural practices have led widespread soil degradation (Saleem et al., 2023). Provision of good quality food is among the focusses of sustainable developmental goals which can be met through higher crop production at lower cast (Iqbal et al., 2023). There are many crops sown in the world for food security out of which maize has high dietary value thus helpful in reducing the hunger of world's human (Rouf Shah, Prasad, & Kumar, 2016). Maize plays an important role in the overall progress of the national economy, feed poultry and livestock industries along with providing the domestic industry with raw marital (Hassan, 2005). In starch industry maize, provides basic raw material for different products (Hussain et al., 2011). Currently, maize was cultivate on area of 1720 thousand hectares indicating an increase of 4.1% in comparison to last year's 1653 thousand hectares with a total production of 10.183 million tons facing an increase 6.9% from last year (Govt. of Pakistan, 2024).

There are many aspects due to which maize crop yield is low (Chughtai, Hussain, HN, & Aslam, 2002). Climatic conditions, soil fertility, unbalanced nutrient applications and poor crop management are major causes effecting maize yield. Nutrients availability and crop management are necessary for successful crop production (Ahmad, Tahir, Saleem, & Zafar, 2018). Crop nutrition management is necessary for enhanced crop production (Saleem, Tahir, Ahmad, & Tahir, 2020). Crop nutrition must be managed for escalated crop yields (Fatima, Tahir, & Saleem, 2021). Nutrients are categorized as macro and micro on the basis of their requirements. All the nutrients are mostly taken up by the plants through their roots from the soil and this movement is facilitated by some transporters (Kimura et al., 2019). Every single nutrient plays its specific role in plant body and growth augmentation. Nitrogen is the most important mineral element taking part in plant physiological functions. İt is the integral part of some biomolecules in plant body such as proteins, nucleic acid, growth regulators and chlorophyll (Nguyen, Rothstein, Spangenberg, & Kant, 2015). All the plant parts require an optimum dose of N for proper functioning (Gastal & Lemaire, 2002). It help the generation of proteins by directly involving in the chlorophyll synthesis (Oliveira, Bonfim-Silva, Silveira, & Monteiro, 2010). Nitrogen plays key role in biomass production in forages but the supply of N from soil solution and organic amendments seems insufficient to meet the crop requirement, therefore additional application of N is essential to sustain crop production (Dupas, Buzetti, Sarto, Hernandez, & Bergamaschine, 2010; Hancock, Harris, Franks, Morgan, & Green, 2008; Karina et al., 2014). Phosphorus, the second most important of the macronutrients, must be present in very high concentrations for there to be successful crop production. It plays an important part in the development of plant growth, root development (Kabir et al., 2013), metabolism, and crop output (Cordell et al., 2009). In Pakistan, the majority of soils have a high pH; hence, phosphorus in these soils precipitates with calcium and magnesium ions (Alburquerque et al., 2013). Because of this, the plant only takes a relatively small percentage of phosphorus between 10 and 20 percent and the rest of it is fixed and it is possible to recover up to 80 percent of the phosphorus contained in most soils with the application of appropriate management strategies (Wang et al., 2014). The biogeochemical cycles of N and P elements are commonly acknowledged to exhibit biological interdependence, as observed in studies by Finzi et al. (2011). Consequently, when there are disproportionate inputs of nitrogen and phosphorus into terrestrial ecosystems, it is anticipated that this imbalance will perturb the cycling of these nutrients and lead to a transition in terrestrial ecosystems from being nitrogen-limited to becoming phosphorus-limited (Peng, Peng, Zeng, & Houx, 2019).

Reduction in N supply is directly related to yield (Osborne, Schepers, Francis, & Schlemmer, 2002). Nitrogen improves plant vegetative growth. Maximum crop production can be achieved using N, but excess use will reduce crop productivity (Hammad et al., 2016).

Phosphorus performs its function in cell division and photosynthesis, Phosphorus is mandatory for quality production (Maqsood, Abid, Iqbal, & Hussain, 2001) and also influences the root system (Kabir, Yeasmin, Islam, & Sarkar, 2013). Maize roots give maximum response to phosphorus (Vita et al., 2016). Nitrogen and phosphorus are the major two nutrients being used in agricultural lands to increase crop productivity throughout the world (Hu & Chu, 2020). Changing the climatic conditions, development of new hybrids and uneven distribution of nutrients in soil is affecting the crop production. Crop requirements, soil fertility and nutrient efficiencies has been changed from previously recommended. Different areas and soil conditions demand the balanced nutrient management practices. Balanced application of N and P are fundamental for maximum maize production. Therefore, current experiment was conducted to re-evaluate the concentration of N and P for better maize production.

Materials and methods

Experimental site and soil analysis

The proposed study was conducted in the semi-arid conditions at University of Agriculture, Faisalabad (Latitude: 31.4342514782 Longitude: 73.0674410574) during 2019. Soil samples were examined for their physical and chemical characters before the sowing of crop. Data obtained after soil analysis is provided in Table 1. Climate data was also observed during the experimental period which is given in Figure 1.

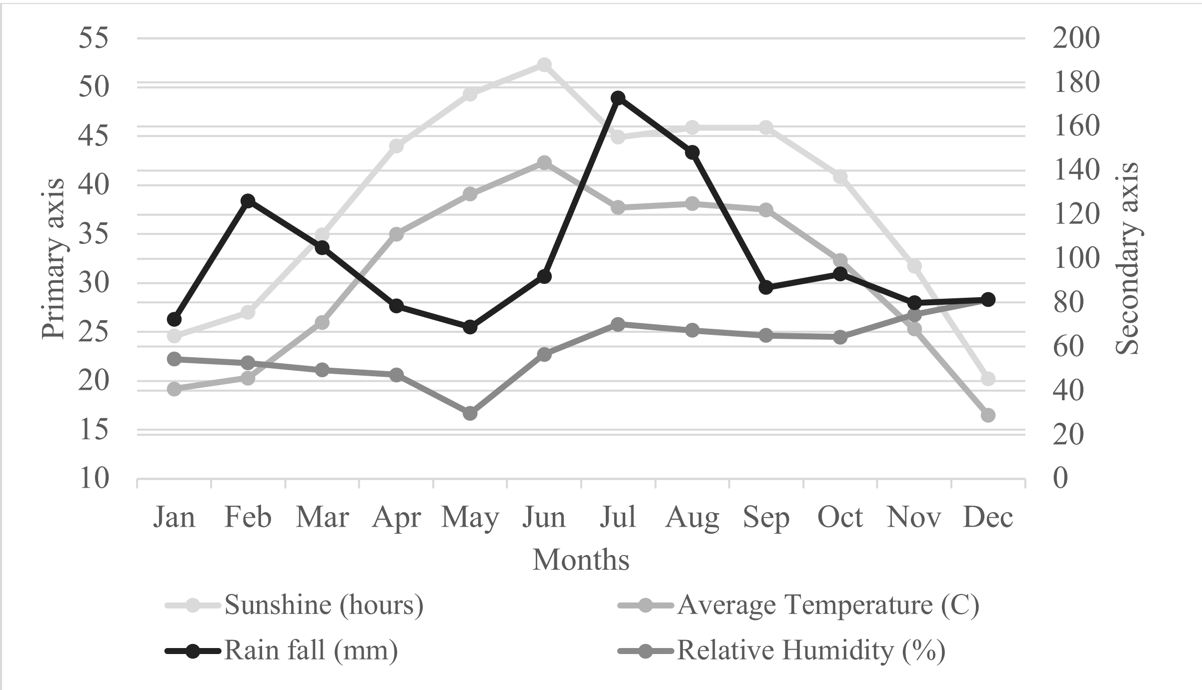

Figure 1 - Average temperature and relative humidity on primary axis while rainfall and sunshine on secondary axis

Table 1 - Experimental soil analysis

Parameter	Values		Status
	Soil depth (0-15 cm)	Soil depth (15-30 cm)	
pH	8.2	8.4	Alkaline
EC	4.4	4.6	Saline
N (%)	0.061	0.058	Medium
P_2O_5 (ppm)	18.5	14.7	High
K_2O (ppm)	280	240	High
Organic Matter	1.26	1.19	Medium
Sand (%)	20	19	
Silt (%)	17	16	
Clay (%)	63	65	

Experimental design and treatments

Treatments for current experiment were different levels of nitrogen (N1=100, N2=200, N3=300 kg/ha) and phosphorus (P1=50, P2=100, P3=150 kg/ha). Source for N was urea (46%N) and the source for P was tripple super phosphate (46%P). Experiment was laid out using RCBD design with split plot arrangement and 3 replicates keeping phosphorus levels in subplots, while nitrogen levels in main plots. Crop was sown in spring season and experimental unit size was 3 m × 8 m.

Soil preparation and seed sowing

Field was flood irrigated prior to tillage. Tillage operations were carried out when soil was at its field capacity. Maize hybrid DK6724 sourced from local market of Faisalabad was used as trial crop. Sowing was done on 30th July 2019 by choppa method keeping 75 cm distance between rows and 25 cm between plants with using 20 kg/ha seed rate.

Cultural operations and harvesting

Crop was irrigated as per requirements. Thinning was also done after germination to maintain plant population. The crop was kept free from weeds by hoeing twice to prevent competition between weeds and crop plants. *Furadon* (18 kg ha^{-1}) was used to prevent the attack the stem borer during experiment. Crop was harvested manually on 30th October 2019. The cobs were removed from the plants and shelled with mechanical sheller after drying.

Statistical analysis

Data was recorded by following standardized protocol for each parameter Table 2. Following parameters formulae and methods were used for data collection.

Table 2 - Different parameters observed during the experiment along with their respective formula

Parameter	Formula	Reference
Leaf area index	$LAI = \frac{leaf area}{land area}$	(Watson, 1958)
Crop growth rate	$CGR = \frac{W_2 - W_1}{t2 - t1}$	(Hunt, 1978)
Leaf area duration	$LAD = \frac{(LAI1 + LAI2)}{2} \times (t2 - t1)$	(Hunt, 1978)
Net assimilation rate	$NAR = \frac{TDM}{LAD}$	(Hunt, 1978)
Nitrogen use efficiency	$\mathrm{NUE_{Agr}} = \frac{[\mathrm{GY(N)} - \mathrm{GY(N_0)}]}{\mathrm{N\ Aplied\ (kg)}}$	
Phosphorus use efficiency	$\mathrm{PUE_{(Agr)}} = \frac{\{\mathrm{GY(P)} - \mathrm{GY(P_o)}\}}{\mathrm{P_{Applied}\ (kg)}}$	
Growing degree days	$\frac{Tmax + Tmin}{2} - Tbase$	(McMaster & Wilhelm, 1997)

Recorded Collected data was analyzed using Fisher's analysis of variance technique. MSTAT-C was used for statistical analysis and means were compared at 5% probability level of HSD test.

Results

Crop phenological stages and growing degree days

Plant phenological parameters; Days to tasseling, days to silking and days to maturity were noted on the onset of each stage and data was recoded up to the dates when visually 50% plants have been reached to the said stage. Response of phenological development in maize was observed with applied treatments and the data is provided in Table 3.

The average values for nitrogen (N) demonstrated that the time taken for tasseling to occur increased with higher levels of nitrogen. The highest number of days to tasseling (47.000) was observed when 300 kilograms of nitrogen per hectare (kg N ha^{-1}) were applied, while the shortest time to tasseling was observed when nitrogen was applied at a rate of 100 kg ha^{-1}.

Furthermore, the subunits where phosphorus (P) was supplied at a rate of 150 kg ha^{-1} exhibited a longer duration to tasseling, with an average of 46.78 days. When considering the interaction between nitrogen and phosphorus, it was found that the maximum number of days to tasseling occurred when 300 kg ha^{-1} of nitrogen and 150 kg ha^{-1} of phosphorus were applied. This indicates that tasseling tended to occur later with increasing levels of both nitrogen and phosphorus.

Greater durations for the process of silking, with an average of 57.67 days, were observed in plots where fertilizer was applied at a rate of 300 kilograms per hectare (kg ha^{-1}) in comparison to those receiving only 100 kg of nitrogen per hectare (kg N ha^{-1}). The mean values for nitrogen indicate a consistent trend of increased days to silking with each incremental rise in nitrogen levels, with the highest duration of 57.667 days recorded when 300 kg of nitrogen per hectare was applied. Similarly, a longer duration to silking (57.778 days) was noted in plots that received phosphorus (P) at the rate of 150 kg ha^{-1}. When considering the interaction between nitrogen and phosphorus, it became apparent that the greatest duration for days to silking occurred when 300 kg of nitrogen and 150 kg of phosphorus were applied per hectare. This indicates that the prolongation of days to silking is more prominent when higher levels of both nitrogen and phosphorus are employed. The longest duration to reach maturity, with values of 85.89 and 86.22 days, was observed when nitrogen was applied at rates of 300 kg per hectare (kg ha^{-1}) and 150 kg ha^{-1}, respectively. Conversely, the shortest duration, with values of 84.22 and 84.33 days, was recorded when nitrogen and phosphorus were applied at rates of 100 kg ha^{-1} and 50 kg ha^{-1}, respectively. It's worth noting that the interactive effect of nitrogen and phosphorus was found to be statistically non-significant, indicating that the combination of these two nutrients did not have a significant impact on the time taken for maturity to occur.

Growth parameters

Application of both N and P resulted non-significant on days to 50% tasseling regardless of the levels used (Table 4). However, application of both nutrients in higher levels significantly increased the No. of days to reach 50% silking stage. Nitrogen level 300 kg/ha produced 50% silking in 57.66 days, while Phosphorus level 150 kg/ha produced 50% silking in 57.77 days in comparison to other levels applied. Interaction of both nutrients was found non-significant for all levels. Gradual increase in N dose delayed the crop maturity. Similar trend was followed by P as increasing P level also delayed the maturity time. However, interaction of both was non-significant in increasing or decreasing the maturity time. Highest level of N (300 kg/ha) increased the maturity time 1.97% in comparison to lowest level (100 kg/ha). The highest level of P (150 kg/ha) increased maturity time 2.24% in comparison to lowest level (50 kg/ha). Nitrogen played role in increasing No. of leaves in maize where N level 200 kg/ha produced 12.95% more leaves, while the effect of P levels and interaction of both remained non-significant in increasing leaves per plant. Leaf area index was also highest with N level 200 kg/ha producing 15.99% more leaf area. Phosphorus level 100 kg/ha also produced 15.59% more leaf area when compared to other levels used.

Leaf area duration showed non-significant response to both N and P applied individually or in interaction. Total dry matter (TDM) produced from 300 kg/ha N was the highest among N levels, while P level 150 kg/ha produced TDM at par with P level 100 kg/ha producing 9.36% higher TDM. Crop growth rate (CGR) was 40% higher with N level 300 kg/ha, whereas, P and interaction of both showed non-significant effect. Similar trend in NAR was resulted with application of N and P.

Among the N levels, the maximum nitrogen use efficiency (PUE) was observed with level 200 kg/ha. However, 300 kg/ha N produced results at par with 200 N kg/ha. PUE was highest with 100 kg/ha P level. Nitrogen use efficiency (NUE) was also highest with similar levels of both nutrients. Interaction for PUE and NUE was also significant with combined application of 300 kg/ha N and 50 kg/ha P. Similarly, NUE was also significantly increased with interaction of these nutrients and was maximum with combined application of 100 kg/ha N and 150 kg/ha P. Data for growth parameters is presented in Table 4 and Table 5 indicating the response of maize growth to individual factor and their interactions, respectively.

Yield parameters

Number of Grain Rows per Cob

The number of grain rows on each cob is a significant characteristic of maize cobs as it can impact the arrangement of grains and, to some extent, the visual appearance of the cob. However, in this study, changes in nutrient levels, particularly nitrogen and phosphorus, did not lead to statistically significant alterations in the number of grain rows on cobs (Table 6).

Among the yield parameters of maize, application of both N and P resulted non-significant in enhancing the No. of grain rows on each cob.

Number of Grains per Cob

The number of grains per cob is a critical yield parameter, as it directly influences overall grain production. In this study, it was observed that when nitrogen and phosphorus were applied individually, there was a significant increase in the number of grains per cob. This suggests that each nutrient, when used alone, had a positive impact on the number of grains produced on a single cob. A greater number of grains per cob can significantly enhance overall maize yield, making it a crucial parameter for optimizing crop productivity. When considering nitrogen (N) application, the highest grain count was observed in cobs that received an application rate of 200 kg N ha^{-1}. In contrast, among the various phosphorus (P) levels tested, the greatest number of grains per cob was achieved with an application rate of 100 kg P ha^{-1} (Table 6).

Cob weight

Cob weight is an important indicator of maize productivity. Heavier cobs generally indicate larger and more productive cobs, which contribute to higher overall yield. In this study, the weight of individual cobs was heaviest when nitrogen was applied at a rate of 200 kg per hectare (kg N/ha) and when phosphorus was applied at a rate of 100 kg per hectare (kg P/ha). This suggests that higher levels of these nutrients led to larger and potentially more productive cobs (Table 6). An intriguing finding in this study was the significant interaction between 200 kg of nitrogen per hectare and 100 kg of phosphorus per hectare in increasing cob weight. This interaction indicates a synergistic effect, suggesting that these specific combinations of nutrients resulted in a greater increase in cob weight than what would be expected from the sum of their individual effects (Table 7). This finding is valuable for crop management strategies, as it implies that certain combinations of nutrients may be particularly effective in optimizing maize productivity.

Table 3 - Crop phenological stages

Growth Stages	N Levels	Calendar Date P_1	P_2	P_3	Calendar Days (Days)			Growing Degree Days (˚C) Days		
Sowing		**30/07/2019**	**30/07/2019**	**30/07/2019**	0	0	0	0	0	0
	N1	15-09-2015	15-09-2019	15-09-2019	47	47	47	1099.30	1099.00	1107.00
Days to Tasseling Initiation	N2	15-09-2019	14-09-2019	15-09-2019	47	46	47	1099.30	1091.00	1107.00
	N3	15-09-2019	14-09-2019	15-09-2019	47	46	47	1107.30	1091.00	1107.00
	N1	24-09-2019	25-09-2019	25-09-2019	56	57	57	1313.60	1328.00	1328.00
Days to Silking Initiation	N2	24-09-2019	24-09-2019	25-09-2019	56	56	57	1305.5	1313	1328
	N3	25-09-2019	24-09-2019	24-09-2019	57	56	56	1328.3	1306	1314
	N1	20-10-2019	23-10-2019	23-10-2019	82	86	85	1761.80	1800.00	1805.00
Days to Physical Maturity	N2	22-10-2019	24-10-2019	22-10-2019	84	86	84	1790.40	1811.00	1780.00
	N3	23-10-2019	23-10-2019	23-10-2019	85	85	85	1795.30	1800.00	1806.00

Table 4 - Effects of different fertilizer doses on maize growth parameters. LAI= leaf area index, LAD= leaf area duration, TDM= total dry matter, CGR= crop growth rate, NAR= net assimilation rate, PUE= phosphorus use efficiency, NUE= nitrogen use efficiency

Fertilizer dose (kg/ha)	Days to 50% tasseling	Days to 50% silking	Days to maturity	Leaves per plant	Plant height	LAI	LAD	TDM	CGR	NAR	PUE	NUE
N_1=100	46.78	55.88 c	84.22 b	10.88 b	218.19 b	3.94 b	168.94	1926.0 b	13.75 b	11.43 c	2.01 b	1.08 b
N_2=200	46.44	56.88 b	85.33 ab	12.29 a	239.67 a	4.69 a	174.17	2550.4 a	16.37	13.11 b	3.90 a	1.95 a
N_3=300	47.00	57.66 a	85.88 a	11.31 ab	230.46 ab	4.36 ab	173.51	2264.6 a	23.06 a	14.74 a	3.03 a	1.27 b
LSD value (nitrogen levels)	1.02	0.51	1.61	1.40	12.64	0.50	4.15	323.63	4.96	5.41	0.90	0.40
P_1=50	46.78	56.11 b	84.33 b	11.289 a	210.99 b	4.04 b	164.41	2132.5 b	12.3	13.2	1.91 b	1.27 b.
P_2=100	46.67	56.55 b	84.88 b	11.667 a	246.58 a	4.67 a	171.66	2352.4 a	17.18	13.56	4.74 a	1.67 a
P_3=150	46.78	57.77 a	86.22 a	11.522 a	230.74 ab	4.28 ab	180.54	2256.1 ab	23.71	12.52	2.30 b	1.35 b
LSD value (phosphorus levels)	0.85	0.68	1.00	1.15	24.15	0.48	3.06	210.79	10.7	4.97	0.45	0.10

Table 5 - Effects of interactions among different fertilizer doses on maize growth parameters. LAI= leaf area index, LAD= leaf area duration, TDM= total dry matter, CGR= crop growth rate, NAR= net assimilation rate, PUE= phosphorus use efficiency, NUE= nitrogen use efficiency

Nitrogen (kg/ha)	Days to 50% tasseling	Days to 50% silking	Days to maturity	Leaves per plant	Plant height	LAI	LAD	TDM	CGR	Nar	PUE	NUE
$N_1 \times P_1$	46.67	54.67	82.33	10.9	204.83	3.5	162.12	1848	6.9	11.82	2.91 c	1.07 b
$N_1 \times P_2$	46.67	56.00	84.67	10.56	230.63	4.41	165.84	2027.2	23.39	11.83	1.61 d	1.02 b
$N_1 \times P_3$	47.00	57.00	85.67	11.16	219.1	3.91	178.86	1902.9	10.95	10.65	1.52 d	1.12 b
$N_2 \times P_1$	46.78	56.67	85.00	11.96	216.97	4.58	165.35	2129.5	11.59	13.1	4.88 b	1.75 b
$N_2 \times P_2$	46.67	56.33	84.67	12.9	260.83	4.81	174.09	2447	12.68	14.08	2.27 cd	1.66 b
$N_2 \times P_3$	46.33	57.67	86.33	12	241.2	4.7	183.05	2217.2	24.86	12.15	1.95 cd	2.44 a
$N_3 \times P_1$	46.33	57.00	85.67	11	211.17	4.05	165.76	2420.1	18.4	14.69	6.45 a	1.22 b
$N_3 \times P_2$	46.44	57.33	85.33	11.53	248.27	4.79	175.06	2582.9	15.48	14.79	3.01 c	1.13 b
$N_3 \times P_3$	47.00	58.67	86.67	11.4	231.93	4.23	179.72	2648.1	35.32	14.76	2.25 cd	1.46 b
LSD value	2.24	1.53	3.07	2.13	36.33	1.20	23.87	628.79	15.94	5.96	1.68	0.49

Table 6 - Effects of different fertilizer doses on maize yield parameters

Nitrogen (kg/ha)	Cob weight	No.of rows per cob	No.of grains per cob	1000 grains weight	Biological yield	Grain yield	Harvest index
N_1=100	154.78 a	13.454	389.00 b	312.14 b	19.14 c	4.78 c	22.40 b
N_2=200	208.99 a	14.233	496.00 a	369.04 a	25.550 a	6.20 a	29.01 a
N_3=300	184.44 b	13.782	422.33 b	335.53 ab	22.64 b	5.54 b	26.38 a
LSD value (nitrogen levels)	12.49	1.03	1.03	1.03	1.03	0.60	1.03
P_1=50	165.82 b	13.722	397.00 c	324.40 c	21.39 b	5.37 b	24.33 b
P_2=100	195.67 a	13.91	479.22 b	353.46 a	23.51 a	5.86 a	27.34 a
P_3=150	186.72 b	13.838	430.67 b	338.85 b	22.382 ab	5.30 b	26.13 ab
LSD value (phosphorus levels)	9.92	1.27	1.27	1.27	1.27	0.20	1.27

Table 7. Effects of interaction among different fertilizer doses on maize yield parameters

Nitrogen (kg/ha)	Cob weight	No.of rows per cob	No.of grains per cob	1000 grains weight	Biological yield	Grain yield	Harvest index
$N_1 \times P_1$	133.33 f	13.13	371.67	291.75	18.69	4.45	20.74
$N_1 \times P_2$	170.00 de	13.56	409.00	322.72	19.6	4.61	24.43
$N_1 \times P_3$	161.00 e	13.66	386.33	321.96	19.14	5.28	22.04
$N_2 \times P_1$	190.80 bc	14.3	452.67	355.83	21.29	5.44	26.92
$N_2 \times P_2$	224.33 a	14.33	554.67	387.35	24.47	5.27	30.29
$N_2 \times P_3$	211.83 a	14.06	480.67	363.95	22.17	5.93	29.82
$N_3 \times P_1$	173.33 cde	13.73	368.00	325.61	24.2	6.22	25.33
$N_3 \times P_2$	192.67 b	13.83	474.00	350.32	26.48	6.01	27.29
$N_3 \times P_3$	187.33 bcd	13.78	425.00	330.66	25.82	6.37	26.53
LSD value	18.66	2.07	2.07	2.07	2.07	2.07	2.07

1000 grains weight

The weight of 1000 grains is an important measure of grain quality. Heavier grains are often preferred for consumption and processing because they typically contain more starch and nutrients. In this study, the weight of 1000 grains was highest when the plants received 200 kg of nitrogen per hectare and 100 kg of phosphorus per hectare (Table 6). This suggests that these nutrient levels resulted in grains of greater weight and potentially higher quality. Farmers aiming for higher-quality maize may consider optimizing nitrogen and phosphorus levels accordingly.

Nitrogen use efficiency (NUE)

NUE was significantly influenced with the application of N and P. The most effective treatment in increasing NUE (2.44) was the N2P3 where 200 kg N/ha and 300 kg P/ha were used in combination. While, lowers NUE (1.02) was observed from treatment N1P2 receiving a combination of 50 kg N/ha and 100 kg P/ha (Table 5).

Phosphorus use efficiency (PUE)

PUE was significantly influenced with the application of N and P. The most effective treatment in increasing PUE (6.45) was the N3P1 where 300 kg N/ha and 50 kg P/ha were used in combination. While, lowers PUE (1.61) was observed from treatment N1P2 receiving a combination of 50 kg N/ha and 100 kg P/ha (Table 6).

Discussion

Nitrogen is a key component of chlorophyll, which is vital for photosynthesis (Mu & Chen, 2021). Sufficient nitrogen encourages healthy leaf growth and overall plant vigor (Ye, Tian, & Jin, 2022). Maize plants with ample nitrogen tend to grow vigorously. Nitrogen is also necessary for the synthesis of proteins and enzymes involved in plant metabolism, including reproductive development (Tessari, 2006). When there is enough nitrogen available, the plant can allocate resources to reproductive structures like tassels more promptly, potentially resulting in earlier tasseling. Phosphorus is crucial for energy transfer within plants, as it is part of adenosine triphosphate (ATP), the primary energy currency (D. Liu, 2021; Malhotra, Vandana, Sharma, & Pandey, 2018). Adequate phosphorus supports robust root development, which enhances nutrient uptake, including nitrogen (D. Liu, 2021). This indirectly impacts tasseling as it ensures the plant has enough resources and energy for reproductive growth.

Nitrogen plays a significant role in the vegetative and reproductive growth of maize (Ariraman, Prabhaharan, Selvakumar, Sowmya, & Mansingh, 2020). Adequate nitrogen availability can promote vigorous vegetative growth and healthy foliage, which can indirectly support timely silking (Leghari et al., 2016). The plant needs to accumulate sufficient resources and energy, including nitrogen, to initiate the silking process (Shrivastav et al., 2020). Therefore, maize plants with ample nitrogen are more likely to silk on time. Similar to nitrogen, phosphorus supports overall plant growth, including root development (Malhotra et al., 2018). Well-developed roots can enhance nutrient and water uptake, ensuring the plant has the resources it needs for reproductive processes like silking (Hodge, 2010). Adequate phosphorus can indirectly contribute to timely silking by facilitating resource acquisition (Ceulemans et al., 2017).

Nitrogen also affects the timing of maturity in maize (Gheith et al., 2022). Nitrogen availability can influence the rate at which the plant accumulates biomass and fills its grains (X. Liu, Hu, & Chu, 2022). Adequate nitrogen levels can lead to faster grain filling, which may result in earlier maturity (Guo et al., 2022). Conversely, nitrogen deficiency can delay maturity as the plant prioritizes resource allocation to complete grain development (Zhang et al., 2022). Phosphorus is essential for energy transfer within the plant. It plays a role in processes like photosynthesis and respiration, which are critical for biomass accumulation and grain filling (Day & Ludeke, 1993). Adequate phosphorus levels can support efficient energy production, potentially leading to earlier maturity as the plant completes grain ripening more effectively (Biswas Chowdhury & Zhang, 2021).

Nitrogen is essential for the synthesis of chlorophyll, the pigment responsible for photosynthesis (Bassi, Menossi, & Mattiello, 2018). Adequate nitrogen levels promote healthy leaf growth (Vos, Putten, & Birch, 2005). More leaves with efficient photosynthesis capacity mean that the plant can produce and allocate more carbohydrates, including starches, which are essential for grain development. Nitrogen plays a critical role in resource allocation within the maize plant. When nitrogen is readily available, the plant can allocate resources to different plant parts, including the cob where grains form. Adequate nitrogen levels may support the development of a greater number of grain rows on the cob as more resources are allocated to this reproductive structure (Correndo, Fernandez, Vara Prasad, & Ciampitti, 2021). Nitrogen is closely associated with overall plant health and vigor. Healthy plants are better equipped to develop and maintain a higher number of grain rows per cob. A robust and vigorous plant can optimize the utilization of available resources for grain development (Agrahari, Kobayashi, Tanaka, Panda, & Koyama, 2021). More leaves with efficient photosynthesis capacity translate to increased carbohydrate production, including starches, which are stored in grains. This surplus of carbohydrates provides the necessary resources for the formation of a greater number of grains on the cob (Ainsworth & Bush, 2010). When nitrogen is readily available, the plant can allocate more resources to its reproductive structures, such as the cob. This includes allocating nutrients and energy for grain development, thereby favoring the production of more grains per cob (The, Snyder, & Tegeder, 2021).

Nitrogen promotes vegetative growth, including the development of the cob structure, while phosphorus is essential for energy transfer processes required for cob formation (Hasan, Hasan, Teixeira da Silva, & Li, 2016; Singh et al., 2022). When sufficient nitrogen and phosphorus are available, the plant can allocate resources to cob development, leading to larger and heavier cobs. This allocation includes nutrients, energy, and carbohydrates, which contribute to cob weight.

Grain yield is the most important paraments among all as it is the final outcome for any crop. Grain yield depends upon many factors and other parameters (Saleem et al., 2020). Both nitrogen and phosphorus enhance nutrient uptake, including essential macronutrients like potassium, which is critical for grain development. This improved nutrient uptake contributes to higher number of grains leading to more yields. Nitrogen played its role in photosynthesis (Urban, Rogowski, Wasilewska-Dębowska, & Romanowska, 2021), protein synthesis, enzyme activity and root growth which ultimately enhanced the final grain yield in maize.

Both P and N are essential for growth mechanisms in plants. Application of these nutrients has been markedly increased since onset of green revolution (Haygarth et al., 2013). A continuous supply of nutrients is required for plant production. Higher N application increased the succulency and leafiness of plants which tend to delay in crop maturity. Phenology of maize was delayed with increasing nutrients application (Dolan et al. 2006; Li et al. 2003). Sharifi and Taghizadeh (2009) reported delayed maturity by the increase in N dose.

High fertilizer application increases nutrient losses to environment (Haygarth et al., 2013).

Nitrogen helped the plants in synthesis of new leaves (Gungula et al., 2005) which ultimately increased plant growth rate.

Increased leaves also resulted in more photosynthesis and accumulation of dry matter Asif et al. (2013).

Nitrogen is a key component for vigorous growth and improved the maize productivity. This facilitates the division of cells into plants resulting in increased dry matter accumulation and increased maize productivity (Ahmad, 2000).

A possible reason for lower number of grains per cob with lower nitrogen dose was nutrient use efficiency which decreased the biomass production factors. Haseeb-ur-Rehman et al. (2010) concluded that No. of grains per cob was increased with increase in nitrogen doses.

Nitrogen played role in formation of new cells and also increased the photosynthetic activity which helped plant to gain more weight (Farooqi et al., 2019). Grain production is associated with better nutritional management and nutrient availability. Application of N poses positive results on yield parameters (Akbar et al., 2002). Ubribelarra et al., (2009) reported improvement in biomass production, grain yield, leaf area index with N supply to maize. Maximum grain weight and yield of crop was attained with N availability, but it delayed the leaf senescence (Li-na et al., 2010).

Increased P level enhanced the process of fertilization and grain development. Availability of P and N promoted source-sink relation and improved the translocation of photosynthates into seeds which produced healthy and bold seeds. Maqsood et al., (2000) and Ali et al., (2002) also found higher weight of grains with N and P application. There are many aspects due to which maize crop yield is low and improvement in low yield by applying some adaptations (Chughtai et al., 2002). Climatic conditions, soil fertility are major unbalanced applications, improper management are major causes that effecting the growth and maize yield. Decrease in nitrogen will stop synthesis of chlorophyll finally low yield of crop productivity (Osborne et al., 2002). Nitrogen is essential for better yield, but excess dose may reduce crop yield adversely (Hammad et al., 2016). System of plant growth and development supported by macro nutrients such as nitrogen improves vegetative growth (Ali et al., 2003). Maize grain yield and quality is determined by the availability of P (Maqsood et al., 2000). Maize yield and shelling percentage was increased with P application (Amanullah et al., 2009). Maize growth and yield enhanced when levels of N and P were increased (Sabir et al., 2000).

Conclusion

Achieving an equilibrium in the application of nitrogen and phosphorus is of paramount importance in maximizing maize yield. There exists a pressing demand for the enhancement of nutrient utilization efficiency to augment agricultural productivity. The emergence of novel maize hybrids with distinct nutrient demands underscores the necessity to reexamine nutrient concentration standards for crop cultivation. Notably, the application of 200 kg of nitrogen per hectare (N/ha) in conjunction with 150 kg of phosphorus per hectare (P/ha) yielded substantial improvements in both plant growth and yield-related characteristics. Consequently, it is strongly advised to employ a judicious and harmonized nutrient dosage for both nitrogen and phosphorus to optimize nutrient utilization efficiency. In conclusion, the balanced and synchronized application of nitrogen and phosphorus fertilizers is indispensable for achieving peak maize production. This imperative is underscored by the need to boost nutrient utilization efficiency, especially in light of evolving maize hybrids with varying nutrient requirements. The demonstrated benefits of employing 200 kg N/ha and 150 kg P/ha highlight the potential for improved plant growth and yield. Therefore, the prudent recommendation is to adopt a balanced approach when administering these vital nutrients to maximize agricultural productivity and sustainability.

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