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RESEARCH PAPER

Quantifying the impact of nitrogen levels on spring maize varieties (*Zea mays* L.) in Kanchanpur, Nepal

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Abstract

Maize has tremendous potential for increasing productivity, profitability, and sustainability in agriculture. A crucial obstacle to maximizing yield of the suitable maize variety with appropriate nitrogen (N) doses. In order to assess the impact of varying N levels on the growth and yield of spring maize varieties, a two-factorial study was conducted in the farmer's field at Kanchanpur, Nepal. Conducted from February to July 2022, the experiment design was randomized complete block with two factors; where hybrid varieties Bioseed 9220 and Arun-2 were the first factors and four different levels of nitrogen (0, 60, 120, and 180 kg N ha^{-1}) were the second factors. Results showed that 180 kg N ha^{-1} and Bioseed 9220 treatment produced significantly higher plant height, kernel row^{-1}, kernel row cob^{-1}, cob plant^{-1}, and thousand-grain weight as compared to other doses and Arun-2, respectively. Similarly, Bioseed 9220 and 180 kg N ha^{-1} treatment had significantly longer days for tasseling and silking. The grain yield of Bioseed 9220 (5.48 t ha^{-1}) was significantly greater than Arun-2 (4.15 t ha^{-1}) and the N level of 180 kg ha^{-1} had a higher yield (5.11 t ha^{-1}) compared to 120 kg ha^{-1} (4.8 t ha^{-1}), 60 kg ha^{-1} (4.78 t ha^{-1}) and least in 0 kg ha-^{1} (4.56 t ha^{-1}). The result indicates that Bioseed 9220 performs better than Open Pollinated Variety (OPV) Arun-2 in growth and yield attributes. N enrichment also boosts yield and yield-attributing characteristics. Bioseed 9220 with 180 kg N ha^{-1} should be prioritized among farmers to increase the productivity and yield of maize.

Keywords

Arun-2, bioseed 9220, maize, kernel, silking, yield

Introduction

Agriculture in Nepal is a vital economic sector, employing the majority of the population (Cchetri and Ghimire 2023). Rice, maize, wheat, and potatoes are the major crops grown in Nepal, contributing significantly to the country's agricultural landscape and food security (Ghimire and Kandel 2023). Maize, one of the key cereal crops in the global agricultural economy, sometimes referred to as corn, is used as both human food and animal feed (Erenstein et al. 2022). The Queen of Cereals, maize, is a widely cultivated, highly nutritious, and fast-growing crop with a short lifespan and immense potential for high yields. Maize is the third highest-producing cereal crop worldwide, following rice and wheat (Ghimire and Gyawali 2023). However, it surpasses all other cereals in terms of productivity and is commonly referred to as a "crop of miracles" due to its exceptional grain potential, which is twice that of other cereal crops (Terrin et al. 2015). The US, China, Brazil, and Argentina continue to produce majority of the world's maize, accounting for more than two-thirds of the total (Tigchelaar et al. 2018). In the Terai region of Nepal, it serves as the primary source of animal feed for various feed companies, with a total country-wide production of 3,106,397 tons (Agriculture Information and Training Center 2023).

It has been determined that the main factor restricting maize yield levels is fertilizer management (Ghimire et al. 2023a). The agricultural crop production in Nepal is currently experiencing low levels (Chhetri and Ghimire 2023a; Ghimire and Chhetri 2023a; Chhetri and Ghimire 2023b). The biggest problem nowadays is ensuring a balanced amount of nutrients in a specific soil for healthy plant growth because soil yield potential varies (Ahmed et al. 2021). Balanced manuring is necessary to improve soil health and maintain prolonged crop output. A nutrient supplement in an appropriate amount is always crucial for the growth, development, and yield of a crop (Amirnia et al. 2019). Fertilizer management has been found to be the primary factor limiting maize yield levels (Basarir et al. 2022). Chemical application of fertilizers could not be avoided because maize is more receptive to them, and they can provide large amounts of nutrients in readily accessible forms (Amanullah et al. 2021). Inorganic fertilizers have been a common and straightforward solution for a temporary increase in yield and efficiency (Ahmed et al. 2021). The quantity of nitrogen (N) to apply to a maize plant depends on the variety of maize, the soil type, the crop's nutrient state, the location, and the yield. Nitrogen, phosphorus, and potassium (NPK) fertilizer application is among the several factors determining the yield potential of maize. N is a critical limiting factor for maize grain output since it is necessary for plant metabolism, takes part in many crucial metabolic processes, and aids in protein synthesis (Anas et al. 2020). The development and progress of plants can be hampered by a lack of N since it is essential for several vital activities like growth, leaf region enlargement, and biomass yield generation (Anas et al. 2020). Increases in height, stem dimension, leaf surface, leaf area index, net assimilation ratio, dry matter accumulation, and yield per hectare have been linked to higher N levels (Cheema et al. 2010; Azarpour et al. 2014). Phosphorus (P) is necessary for the growth of roots, flowering, fruiting, storing, and transferring energy, and producing DNA and other important chemicals in plants. Potassium (K) is an essential nutrient for plants because it supports a few physiological functions that control water intake, increase disease resistance, improve photosynthesis, and generally increase plant vigor (Heydarzadeh et al. 2023).

Crop genotypes are highly responsible for yield (Ghimire et al. 2023). Agroecological regions, seasons, purposes, and maturity should be taken into consideration when choosing cultivars to get the best yield (Ghimire and Chhetri 2023b). Local varieties of maize are less responsive to N than hybrid and modified varieties (Ghimire and Chhetri 2023b). Choosing the right fertilizer type and dosage to suit the crop's needs for growth and development over its whole life cycle is crucial for maize hybrids.

The demand for maize is expected to increase by 4% to 6% annually over the next two decades, driven by the growing livestock and poultries industry (Shrestha et al. 2018), as well as population growth and rising incomes (BK et al. 2018). However, due to low production and limited availability of N, farmers are finding it difficult to maintain soil fertility, and as a result, crop productivity has declined recently due to a loss in soil fertility status (Dawadi et al. 2023; Ghimire et al. 2023b; Poudel Chhetri et al. 2023). Due to a dearth of knowledge and information flow, most farmers use high amounts of N haphazardly, as there is limited information available on appropriate doses and hybrid varieties, and different hybrids respond differently to varying N doses. It is crucial to combine a suitable maize variety with appropriate N doses to maximize yield (Kogbe and Adediran 2003). Against this backdrop, the current study's objective is to evaluate the ideal ratio of N dosages and maize varieties for maximizing yield, which is crucial for increasing productivity, profitability, and sustainability in agriculture. The study provides practical recommendations for farmers to increase the output and productivity of maize, which can contribute to food security and economic development in the region.

Materials and methods

Experimental site

The fieldwork carried out in Ultakham, Kanchanpur, Nepal, from February to July 2022 involved conducting tests at the coordinates of 28°55'41.52"N, 80°12'37.65"E, which had an elevation of 203 meters above mean sea level.

The temperature ranged from 16 to 28 degrees Celsius (°C) from January to May and June respectively, with a minimum temperature of 8 °C in February and a maximum of 34 °C in May. The rainfall followed a typical temperate climate pattern, with minimal rainfall from February to May and heavy rainfall between June and July, averaging between 300 and 500 mm, as shown in Fig. 1.

The experimental soil had a high sand content of 82.25%, with lower levels of silt and clay at 15.33% and 2.4%, respectively. It was acidic (pH 6.22) and low in organic matter (1.90%), with less than 0.10% N and 60 and 132.33 kg ha^{-1} of available P and K, respectively, as presented in Table 1.

Table 1. Physio-chemical properties of the soil in the research field.

Properties	Content	Class
Physical Properties		
Sand	82.25%	-
Silt	15.33%	-
Clay	2.4%	-
Chemical properties		
Soil pH	6.22	Acidic
Soil Organic Matter (%)	1.90	Low
Total N (%)	<0.10	Low
Available P (kg ha^{-1})	60	High
Available K (kg ha^{-1})	132.33	Medium
Texture Class	Sandy	-

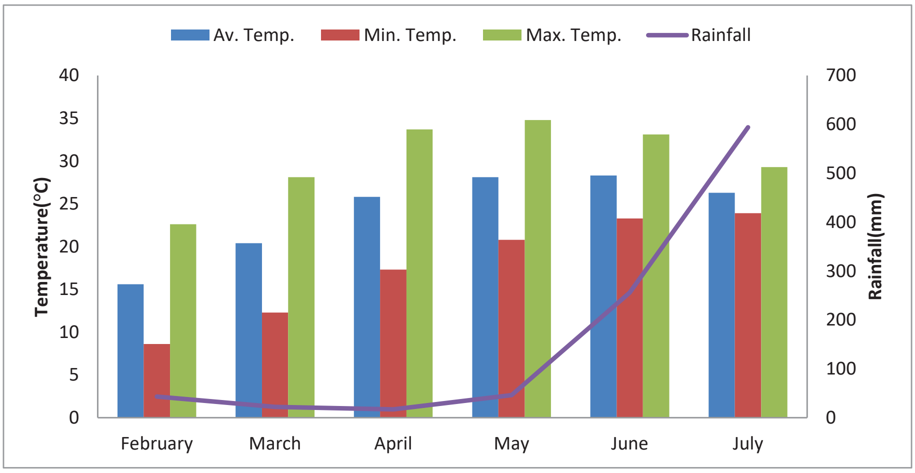

Figure 1. Weather of Ultakham during the experimentation period (February–July, 2022).

Research design and details of treatment

Eight treatments with three replications were used in the two-factorial (Maize varieties and N dosages) randomized complete block design (RCBD). The hybrid maize varieties Bioseed 9220 and Arun-2 were the first factors, and and four different levels of N (0, 60, 120, and 180 kg N ha^{-1}) were the second factors. The maize seeds were collected from the Agriculture Knowledge Center, Kanchanpur, Nepal. All the organic and inorganic fertilizers were collected from Kailapal Agrovet, Kanchanpur. The maize was sown in 7 rows in each plot, with a depth of approximately 3 inches. The row-to-row and plant-to-plant distances were 60 cm and 30 cm, respectively. The spacing between two replications was kept at 90 cm, and between treatments, it was 40 cm.

In the field, farmyard manure (FYM) was used as the primary source of organic fertilizer and applied uniformly at a rate of 5 t ha^{-1} across all experimental plots. Urea (46% N), single superphosphate (SSP) (16% P_2O_5), and muriate of potash (MOP) (60% K_2O) were used to supply N, P, and K, respectively. NPK fertilizers were used in four dosages: N1 (0:60:40), N2 (60:60:40), N3 (120:60:40), and N4 (180:60:40) kg ha^{-1}. Half of the N dose and the entire doses of P and K were administered as a basal dose during sowing as band placement in the maize row, 5 cm deep and 5 cm apart, and the remaining N dose was applied as a top dressing at the knee-high phase and tasseling phase. During the maize growing season, there were two manual weedings performed: the first was at 25 days after sowing (DAS), and the second, along with earthing up, was done at 55 DAS. The irrigation was carried out as needed.

Data and variables

To avoid the "border effect," 42 plants in a plot had their border rows excluded from sampling. Instead, a representative sample of five plants was chosen, and all necessary data were collected from these five samples to represent the entire plot.

Plant height, Days to tasseling (DT), and Days to silking (DS)

At 75 DAS, plant height was measured on five samples from the soil level to the base of the tassel. To determine the timing of tasseling and silking, the total number of days from the date of sowing at which at least 50% of plants in a plot were in the respective stages was recorded. Specifically, DT was the number of days at which 50% of plants were in the tasseling stage, and DS was the number of days at which 50% of plants were in the silking stage.

Tassel length and ear length

The length of the tassel was measured from the lowest branch to the central spike's tip, while cob length was measured at full harvest.

Kernel rows ear^{-1}, Kernels row^{-1}, cobs $plant^{-1}$, and thousand grain weight (TGW)

After harvesting, the number of kernel rows ear^{-1} was determined by counting every one of the five ears in a row and recording the total number of whole kernel rows on five sample cobs. Kernels row^{-1} were determined by multiplying the count of kernels row^{-1} by each ear's row number. A representative sample of five kernel rows from each cob in each plot was used to calculate the number of kernels row^{-1}. The count of cobs $plant^{-1}$ was recorded by sampling plants in each plot, excluding the border rows, and averaging the results. TGW was determined by weighing a random sample of 1000 well-developed, whole grains that were dried to 13% moisture content, using a precision balance.

Grain yield, biological yield, and harvest index (HI)

For greater precision, grain yield was determined using the whole plot method. All five rows were harvested, excluding border rows, and the maize grain yield was recorded after drying the grains to 13% moisture content. The biological yield was recorded by using the net field area, consisting of three rows, excluding border rows, sampling rows, and guard rows. The samples were cut, dried, and weighed. The HI was calculated by dividing the grain yield by the harvest yield, as shown in Equation 1.

$$HI = \left(\frac{\text{Grain yield}}{\text{Biological yield}}\right) \times 100 \quad (1)$$

Data analysis

All the collected data were scrutinized and refined before analysis. The obtained data were complied with MS Excel 2010 (version 14.0.4734.1000) and analyzed using R-Studio (version R-3.6.3). An analysis of variances and Least Significant Difference (LSD) tests was undertaken to determine the treatment effects. A mean comparison was done with Duncan's Multiple Range Test (DMRT) at a 5% probability level when significant differences existed between treatment means.

Results and discussions

Plant height

The average plant height was found to be 186.54 cm. The Bioseed 9220 plant height (202.83 cm) was significantly greater than Arun-2 (170.25 cm). Similarly, the N levels significantly influenced the plant height of maize. Plant height was significantly higher in 180 kg N ha^{-1} (197.83 cm) as compared to 0 kg N ha^{-1} (171.83 cm) but was statistically equivalent in 120 kg N ha^{-1} (189.33 cm) and 60 kg N ha^{-1} (187.17 cm) as illustrated in Table 2.

Statistical analysis of the data revealed that the N levels had a considerable impact on the height of the maize plants (Imran et al. 2015). The height of the plants went up as N rates went up because of improved vegetative growth, which promoted shared shading and inter-nodal elongation, which was similar to the findings of (Sharifi and Namvar 2016). The observed height disparity between the two varieties can be attributed to innate genetic traits. Different maize types can have different growth potentials, including vegetative growth features like internodal elongation and canopy development. In this situation, Bioseed 9220 appears to have better growth properties than Arun-2, resulting in higher plants. N is a necessary nutrient for plant growth, especially for vegetative development (Tegeder and Masclaux-Daubresse 2018). Higher N levels allow the plants to devote more energy to growth and provide amino acids, proteins, and chlorophyll, all of which are essential for plant growth and development, resulting in higher plant height. Improved vegetative growth may result in thicker canopies, higher inter-nodal elongation, and shared shading across plants, all of which contribute to taller plant heights. Amanullah et al. (2009) also found that an increase in the N rate increased plant and ear heights. With the highest N quantity of 180 kg N ha^{-1}, plants grew taller, and their ear heights increased, whereas the plots that received the lowest dose of 60 kg N ha^{-1} reported shorter plants and lower ear heights. The larger dose of N administration causes an increase in cell division, cell elongation, nucleus creation, green foliage, and therefore chlorophyll content, which raises the photosynthesis rate and causes the stem to extend, increasing plant height (Thakur et al. 1998). As the N level rises, plants' heights rise as well (Khan et al. 2011).

Table 2. Plant height influenced by nitrogen levels and varieties of spring maize.

Treatment	Plant height (cm)
Variety	
Bioseed 9220	202.83[a]
Arun-2	170.25[b]
LSD(0.05)	3.03
SEm(±)	1.27
F-test	***
CV%	4.72
Nitrogen level (kg ha^{-1})	
0	171.83[b]
60	187.17[a]
120	189.33[a]
180	197.83[a]
LSD(0.05)	10.92
SEm(±)	0.90
F-test	**
CV%	4.72
Grand mean	186.54

Columns with the same letters in DMRT are not significantly different at p = 0.05, SEm(±) = Standard Errors of Means, CV = Coefficient of Variation, LSD = Least Significant Difference, ** = significant at $p < 0.01$, *** = significant at $p < 0.001$.

Effect on phenology

The days to tasseling and days to silking for the two spring maize types, Bioseed 9220 and Arun-2, differ significantly, as Table 3 demonstrates. The average DT was 68.92 days. Bioseed 9220 exhibited a significantly higher DT (79.08 days) compared to Arun-2 (58.75 days) and a significantly greater DS (85.50 days) compared to Arun-2 (65.33 days), which was similar to the findings of Khanal et al. (2019).

The table also indicates that the N level significantly influenced the DT and DS of maize. The application of different N levels affected the timing of tasseling and silking. DT were significantly higher in 0 kg N ha-1 (70.67 days) as compared to 180 kg N ha^{-1} (67.67 days), but were statistically equivalent to 60 kg N ha^{-1} (70.67 days). This outcome was consistent with that reported by Bakht et al. (2006), Dawadi and Sah (2012) and Sharifi and Namvar (2016), who claimed that a rise in N levels resulted in a reduction in the number of days for tasseling, and silking. The average DS was 75.45 days. The DS of Bioseed 9220 (85.5 days) was significantly greater than that of Arun-2 (65.33 days). The DS were significantly higher in 0 kg N ha^{-1} (77.67 days) as compared to 180 kg N ha^{-1} (72.17 days) but were statistically equivalent with 60 kg N ha^{-1} (77.5 days) as shown in Table 3.

Differences in DT and DS between Bioseed 9220 and Arun-2 can be related to genetic differences and the physiological properties of the maize types. Different varieties have diverse genetic features that influence the timing of reproductive development (Ghimire et al. 2023c). In this scenario, Bioseed 9220 has a longer DT and DS than Arun-2. This implies that Bioseed 9220 possesses genetic features that promote a longer duration from the vegetative to reproductive stages. It could be genetically programmed to take longer to achieve the tasselling and silking stages, which could be owing to slower vegetative development, unique photoperiod requirements, or other variables impacting the flowering process, in line with the findings of Khanal et al. (2019). Moreover, Arun-2 is a short-duration variety (90 days), and Bioseed 9220 is a hybrid cultivar with a medium lifespan (125 days) (Khanal et al. 2019).

N availability affects the progression of reproductive development in maize (Liu et al. 2019). When N is limited or insufficiently available, it can restrict the overall growth and development of the plant. As a result, the plants may take longer to reach the reproductive stages, including tasseling and silking. This is reflected in the longer DT and DS observed in the treatment without N application. Khan et al. (2014) also found that the flowering days (DT and DS) were delayed with high N applications. Conversely, the application of N at higher rates, such as 180 kg N ha^{-1}, provides an abundant supply of N to the plants. This ample N availability enhances the plant's growth and metabolic processes, including the development of reproductive structures (Hammad et al. 2020). Consequently, the plants in the high-N treatment reach the tasseling and silking stages earlier, resulting in shorter DT and DS. N availability can also influence hormonal regulation within the plant, which plays a vital role in coordinating reproductive development (Luo et al. 2020). N can affect the synthesis, transport, and signaling of hormones involved in flowering and reproductive processes (Luo et al. 2020). The application of N at higher rates may affect the balance and interaction of plant hormones involved in flowering, such as gibberellins, cytokinins, and auxins (Dos Santos et al. 2022). These hormones play crucial roles in controlling the transition from vegetative to reproductive growth, as well as the timing of tasseling and silking. Increased N availability can stimulate the synthesis and activity of certain hormones that promote floral induction and flowering. This can lead to earlier tasseling and silking. Conversely, N deficiency may disrupt hormone balance, delaying the initiation and progression of reproductive development.

The logical reasoning behind the N-level effect on DT and DS in maize suggests that N availability is essential for promoting plant growth and metabolic processes, including the development of reproductive structures. Adequate N supply facilitates hormone regulation, resulting in earlier tasseling and silking. Conversely, N deficiency can delay reproductive development. These findings emphasize the importance of variety selection and N management for optimizing the phenological development of maize.

Table 3. Phenology influenced by nitrogen levels and varieties of spring maize.

Treatment	Days to tasseling	Days to silking
Variety		
Bioseed 9220	79.08a	85.50a
Arun-2	58.75b	65.33b
LSD(0.05)	2.35	2.42
SEm(±)	0.38	0.40
F-test	***	***
CV%	2.89	3.67
Nitrogen level (kg ha^{-1})		
0	70.67a	77.67a
60	70.67a	77.50a
120	67.67b	74.33ab
180	67.67b	72.17b
LSD(0.05)	3.03	3.03
SEm(±)	0.27	0.28
F-test	*	*
CV%	3.89	3.67
Grand mean	68.91	75.45

Columns with the same letters in DMRT are not significantly different ($p = 0.05$), SEm(±) = Standard Errors of Means, CV = Coefficient of Variation, LSD = Least Significant Difference, * = significant at $p < 0.05$, *** = significant at $p < 0.001$.

Effect on tassel length and ear length

Statistical analysis revealed that the change in the tassel length was non-significant due to both different varieties and different N doses. However, Bioseed 9220 had a longer tassel length (22.29 cm) than Arun-2 (22.24 cm), and 180 kg N ha^{-1} resulted in the longest tassel length (22.45 cm), while the shortest tassel length was observed in 0 kg N ha^{-1} (22.12 cm). Table 4 indicates that ear length was highly significantly affected by different varieties, with Bioseed 9220 having an average ear length of 19.85 cm and Arun-2 having an average ear length of 18.32 cm. However, different N doses had no significant effect on ear length. 180 kg N ha^{-1} had the longest ear length (19.20 cm), and the shortest was seen in 0 kg N ha^{-1}. The LSD value for ear length is 0.13, which indicates that the observed difference in ear length between the varieties is statistically significant.

The non-significant difference in tassel length between the two varieties suggests that the genetic factors associated with variety selection did not significantly influence tassel length in this study. Other factors, such as environmental conditions or interactions with other variables, may have played a more dominant role in determining tassel length. Similarly, the non-significance of the N doses on tassel length suggests that the application of different N levels did not have a noticeable effect on the development and length of the tassels in this experiment. It is possible that tassel length is less influenced by N availability compared to other growth and developmental traits.

Table 4. Tassel length and ear length influenced by nitrogen levels and varieties of spring maize.

Treatment	Tassel length (cm)	Ear length (cm)
Variety		
Bioseed 9220	22.29	19.85a
Arun-2	22.24	18.32b
LSD(0.05)	0.18	0.13
SEm(±)	0.03	0.22
F-test	NS	***
CV%	0.96	0.79
Nitrogen level (kg ha^{-1})		
0	22.12	18.96
60	22.13	19.05
120	22.35	19.13
180	22.45	19.20
LSD(0.05)	0.26	0.18
SEm(±)	0.02	0.01
F-test	NS	NS
CV%	0.96	0.78
Grand mean	22.26	18.09

Columns with the same letters in DMRT are not significantly different ($p = 0.05$), SEm(±) = Standard Errors of Means, CV = Coefficient of Variation, LSD = Least Significant Difference, *** = significant at $p < 0.001$, NS = non-significant.

The significant difference in ear length between the two varieties suggests that genetic factors associated with variety selection play a substantial role in determining the length of the ear in maize. The specific genetic traits and characteristics of Bioseed 9220 may contribute to its long ear length compared to Arun-2. On the other hand, the non-significance of different N doses on ear length suggests that the varying levels of N application did not have a significant impact on the length of the ear in this study. Other factors, such as genetic factors or environmental conditions [20], may have had a more dominant influence on ear length.

Yield contributing parameters influenced by variety and nitrogen

Statistically, the hybrid variety Bioseed 9220 showed greater kernels row^{-1} (30.50), followed by inbred Arun-2 at a 5% level of significance. The effect of N doses was the same, i.e., significant at a 5% level of significance. The greatest kernel row^{-1} was found in the plot with 180 kg ha^{-1} (29.30), and the lowest was in the control plot (28.70). The LSD value for kernel row cob^{-1} is 0.25, indicating that the observed difference between the varieties is statistically significant. The data on the row per cob indicated a significant ($p < 0.01$) change in row cob^{-1} because of the varieties and quantities of N. Variety Bioseed 9220 had higher rows cob^{-1} (14.17) than the Arun-2 variety (13.10). A N dose of 180 kg ha^{-1} had numerous rows per cob (13.73), that were statistically similar to the dose of 120 kg ha^{-1} (13.63). The control plot had the lowest data on rows cob^{-1} (13.53) which was statistically similar to the N level of 60 kg ha^{-1} (13.53). Effects of varieties were highly significant at 0.1%, as described by (Ghimire et al. 2023c in wheat. Variety Bioseed 9220 had a higher cob plant^{-1} (1.38) than Variety Arun-2 (1.23). N doses were also significant due to the difference in N doses at a 1% level of significance. The plot with 180 kg ha^{-1} N dose had the highest cob plant^{-1} (1.36), which was statistically similar to the N level of 120 kg ha^{-1} (1.36). The lowest data on cob plant^{-1} were found in the control plot (1.24), which was statistically matched to the plot having a 60 kg ha^{-1} N dose (1.28). Grain weight, which represents grain growth and plumpness, is a common indicator of grain yield. Due to both varieties and amounts of N, statistical analysis showed a substantial ($p < 0.001$) variation in the weight of 1000 kernels. Hybrid variety Bioseed 9220 had a higher 1000 weight (232.08 g) than inbred Arun-2 (204.16 g). Considering N levels, plots with 180 kg ha^{-1} were found to have the highest 1000 kernel weight (221.50 g), and the lowest was observed in the plot with no N application as presented in Table 5.

Bioseed 9220 may possess genetic traits that contribute to increased kernel row^{-1} development, row cob^{-1}, cob plant^{-1}, and TGW compared to Arun-2. N is an essential nutrient for plants and plays a crucial role in various physiological processes, including photosynthesis, protein synthesis, and grain filling (Cao et al. 2022; Ma et al. 2022). Adequate N availability promotes plant growth, resulting in higher yields and improved grain quality. N availability affects the uptake and assimilation of other essential nutrients (Wen et al. 2019). When N is limited, plants may prioritize N uptake over other nutrients, leading to nutrient imbalances. Plants can have sufficient N levels by providing a higher N dosage, allowing them to optimize the uptake and utilization of other nutrients, which contributes to improved plant growth and development. The poor growth of sinks and decreased transfer of photosynthates under lower N usage may be re-

Table 5. Yield contributing parameters influenced by varieties and nitrogen levels.

Treatment	Kernel row-1	Row cob-1	Cob plant-1	TGW (g)
Variety				
Bioseed 9220	30.50a	14.12a	1.38a	232.08a
Arun-2	27.53b	13.10b	1.23b	204.16b
LSD(0.05)	0.25	0.08	0.04	1.54
SEm(±)	0.04	0.01	0.00	0.80
F-test	***	**	***	***
CV%	0.98	0.70	3.42	0.80
Nitrogen level (kg ha^{-1})				
0	28.70b	13.53a	1.24b	214.16c
60	29ab	13.53a	1.28b	218b
120	29.07b	13.63a	1.36a	218.83b
180	29.30a	13.73a	1.36a	221.50a
LSD(0.05)	0.35	0.12	0.05	2.18
SEm(±)	0.02	0.00	0.00	0.18
F-test	*	*	**	***
CV%	0.98	0.70	3.42	0.80
Grand mean	29.01	13.60	1.30	218.12

Columns with the same letters in DMRT are not significantly different ($p = 0.05$), SEm(±) = Standard Errors of Means, CV = Coefficient of Variation, LSD = Least Significant Difference, * = significant at $p < 0.05$, ** = significant at $p < 0.01$, *** = significant at $p < 0.001$.

sponsible for reducing yield-attributing parameters (Dawadi et al. 2023). Higher N levels can promote increased cell division and elongation, leading to the increased ability of the plants to collect more biomass and increase their ability to transform more photosynthesis into sinks, which results in more kernels ear^{-1}, row cob^{-1}, cob plant^{-1}, and larger grain size, which increases with increased N rates [46,30], thereby contributing to higher measurements.

Effect on yield

The fundamental objective of crop cultivation is maize grain yield [47]. Changes in grain yield were statistically significant at a 0.1% level of significance due to both N levels and varieties. Bioseed 9220 was found to have higher grain yield (5.48 t ha^{-1}) than Arun-2 (4.15 t ha^{-1}). The plots with 180 kg ha^{-1} had the highest grain yield (5.11 t ha^{-1}), followed by the plots with 120 kg ha^{-1} (4.81 t ha^{-1}), 60 kg ha^{-1} (4.78 t ha^{-1}), and the lowest on the plot with no N application as shown in Table 6. The findings of a statistical study revealed that N dosages had no significant effect on biological yield. However, different varieties produced significant effects ($p < 0.5$) on biological yield [20]. Hybrid Bioseed 9220 had a higher biological yield (12.34 t ha^{-1}) than self-pollinated Arun-2 (11.60 t ha^{-1}). The efficiency of assimilation into the various components of the economic yield of maize plants (i.e., cob) is indicated by the harvest index. A higher harvest score indicates a greater assimilation transfer to cob. The harvest index varied significantly depending on N.

The plot with 180 kg N ha^{-1} was found to be with highest (44.05%) which was statistically similar to the 120 kg N ha^{-1} dose (42.03%). The lowest harvest index was found in the plots with no urea application (36.7%), and the results were statistically similar to the plot with 60 kg N ha^{-1} (38.64%).

The yield was significantly higher in Bioseed 9220 than in Arun-2 (Khanal et al. 2019). The amount of kernels ear^{-1}, the count of kernel rows ear^{-1}, and the ears length were all noted to be larger in Bioseed 9220 than in Arun-2 [35]. These yield components are directly related to grain production. Hybrid maize produces more grain per area than open-pollinated varieties (OPV) (Ghimire et al. 2016). The experiment's findings indicated that the modified maize Bioseed 9220 performed better than OPV (Arun-2) in terms of yield and yield attributes. This could be attributed to the cultivar's high leaf area at about 90 DAP, when grain filling begins, which may have positively impacted the carbon assimilatory process (Wang et al. 2017). More N levels may boost grain output because there is less competition for nutrients, which results in more plant canopy and more photosynthetic activity, which helps the grain grow bolder (Adhikari et al. 2021). Similar conclusions were drawn by (Lorenz et al. (2010) and Sharifi and Namvar (2016). The delay in the maturity time, reduction in the count of barren crops, and rising kernel count ear^{-1} could all be contributing factors to the rise in grain production at elevated N rates (Sharifi and Namvar 2016). Several researchers have noted an increase in maize production with increasing N rates (Khan et al. 1994), mostly because of its positive impact on maize yield components. N fertilization resulted in increased grain yield (43–68%) and biomass (25–42%) in maize (Ogola et al. 2002). N promotes the synthesis of proteins and starches, which are crucial components of grains. Adequate N levels can enhance the grain-filling process, resulting in larger and heavier grains, and vigorous vegetative growth, a larger plant size, and increased biomass production, ultimately increasing the grain yield. The number of kernel rows ear^{-1}, the count of kernels ear^{-1}, and the TWG all rose due to the rising N levels, which also boosted grain yield (Dawadi and Sah 2012). Research on the average values of Imran et al. (2015) results also revealed that fertilization with N at 210 kg ha^{-1} resulted in maximum grain production of 2673 kg ha^{-1}, which was statistically equivalent to 180 and 150 kg N ha^{-1}. Our findings supported those of Lawrence et al. (2008), Sharifi and Namvar (2016) and Adhikari et al. (2021), who discovered that the harvest index increased as fertilizer dose increased. The increase in harvest index with increasing N dosage suggests that N application favors resource allocation towards grain development, thereby contributing to a higher grain yield.

Table 6. Grain yield, biological yield, and harvest index influenced by varieties and nitrogen levels.

Treatment	Grain yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Variety			
Bioseed 9220	5.48a	12.34a	44.82a
Arun-2	4.15b	11.60b	35.89b
LSD(0.05)	0.14	0.68	1.84
SEm(±)	0.02	0.10	0.30
F-test	***	*	***
CV%	3.19	5.89	5.19
Nitrogen level (kg ha^{-1})			
0	4.56c	12.37a	36.70b
60	4.78b	12.44a	38.64b
120	4.81b	11.63b	42.03a
180	5.11a	11.43b	44.05a
LSD(0.05)	0.19	0.28	2.59
SEm(±)	0.01	0.07	0.21
F-test	***	NS	***
CV%	3.19	5.89	5.19
Grand mean	4.81	11.96	40.35

Columns with the same letters in DMRT are not significantly different ($p = 0.05$), SEm(±) = Standard Errors of Means, CV = Coefficient of Variation, LSD = Least Significant Difference, * = significant at $p < 0.05$, *** = significant at $p < 0.001$, NS = non-significant.

Conclusion

The study demonstrates that the improved spring maize variety Bioseed 9220 outperforms the open-pollinated variety Arun-2 in terms of growth and yield attributes. Moreover, the findings indicate that increasing N levels leads to higher yields and yield-contributing parameters. This can be attributed to the positive effects of nitrogen on plant growth, grain filling, and efficient resource allocation toward grain production. Specifically, the plot with 180 kg ha^{-1} exhibited the best results, followed by 120, 60, and 0 kg ha^{-1}. Therefore, to increase the production and productivity of spring maize, it is recommended to prioritize the cultivation of hybrid varieties, particularly Bioseed 9220, and to apply high N levels, particularly 180 kg ha^{-1} with an appropriate potassium and phosphorus dose. These suggestions have practical implications for farmers seeking to maximize their maize yields and achieve better economic outcomes.

Author contribution

Saurav Bhatt and Sudip Ghimire: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper; Reviewed initial draft of the manuscript; contributed analysis.

Conflict of interest

The authors declare no conflict of interest.

Data Availability

The data will be made available on request.

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