

RESEARCH PAPER

Precision Nutrient Management and Plant Stand Influence the Growth and Productivity of Maize under North Eastern Ghat Region of Odisha, India

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ABSTRACT

Cereal crops are the major contributors for the global food security and serves as a staple food crop for majority of the world population. Among the cereals, maize (*Zea mays L.*) is one of the most versatile and important cereal crops cultivated under various agro climatic conditions. There are various factors limiting the maize productivity in India. Among they agronomic practices like nutrient management and proper plant stand is one of the major factors effecting crop growth and productivity. Under these circumstances, the Nutrient Expert for maize serves as an efficient decision-support system for field-specific nutrient management in maize. Plant density is a critical cultural practice that significantly influences the growth and performance of maize. In light of this, a field study was carried out at the Post Graduate Research Farm of Centurion University of Technology and Management, Odisha, India. (18.8° N latitude, 84.8° E longitude) during the *Rabi* season of 2022-23. The experiment was conducted by adopting a split-plot design and it comprised three main plot treatments with different levels of plant population (S_1 : 66,666 plants ha^{-1} ; S_2 : 83,333 plants ha^{-1} ; S_3 : 11,111 plants ha^{-1}) and four subplot treatments with various nutrient management treatments (N_1 : 100 % RDF; N_2 : Nutrient Expert-based recommendation (NE) for a target yield of 6 t ha^{-1} ; N_3 : NE for a target yield of 8 t ha^{-1} ; N_4 : NE for a target yield of 10 t ha^{-1}). The analysed data of the study revealed that, the highest plant height, dry matter accumulation and leaf area per plant were recorded in 1,11,111 plants ha^{-1} ; However, the maximum stem girth was recorded with 66,666 plants ha^{-1} . Among the yield attributing characters, significantly higher number of cobs plant⁻¹, number of grains cob⁻¹, weight of the cob, length of the cob, girth of the cob, grains rows cob⁻¹ and grains row⁻¹ were registered with 66,666 plants ha^{-1} . The highest grain yield (6362 kg ha^{-1}), stover yield (9789 kg ha^{-1}) and biological yield (15563 kg ha^{-1}) were noted with 1,11,111 plants ha^{-1} and it remained significantly superior to the remaining plant stands. Moreover, in case of nutrient management, the NE-based nutrient management for a target yield of 10 t ha^{-1} recorded the highest values in terms of growth attributes, yield attributes, and yield of maize. The experiment concluded that nutrient management through NE-based nutrient recommendations for a target yield of 10 t ha^{-1} with a spacing of 60 cm × 15 cm can be considered the most suitable plant stand for obtaining better growth, yield attributes and yield of maize under North Eastern Ghat Region of Odisha, India.

HIGHLIGHTS

- Site-specific nutrient management is one of the scientific approaches for optimization of nutrients;
- The application of primary nutrients through Nutrient Expert-based recommendations for

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a target maize grain yield of 10 t ha⁻¹ with a spacing of 60 cm × 15 cm can be considered the most suitable practice for maize under north eastern ghat region of India.

Keywords: Maize, Nutrient expert, Plant population, Yield, SSNM

Global agriculture is facing a huge problem with change in climate, population enhancement and dwindling natural resources and stagnation of agricultural productivity (Yuan *et al.* 2024; Ray and Majumder, 2024; Ray and Sairam, 2024; Mukesh *et al.* 2024; Palai *et al.* 2024;). These changes lead to both biotic and abiotic stress on the crops such as drought, heat stress, pest and disease incidence, etc. (Kumar *et al.* 2022; Maitra *et al.* 2024a; Ray *et al.* 2024). Addressing these challenges, there is a huge requirement for adopting advanced agricultural practices for optimum resource use and efficient crop management (Malhi *et al.* 2021; Datta *et al.* 2022; Manepalli *et al.* 2022; Gitari *et al.* 2020; Maitra *et al.* 2000, 2001; Hossain *et al.* 2021;). In this context, cereals and cereals-based cropping systems can play a major role as they provide a large portion of the dietary energy to the human populace (Maitra, 2020a, b; Maitra and Ray, 2019). Cereals are edible grains that are the basis of human nourishment and are considered staple food worldwide (Sairam *et al.* 2024a; Nduwimana *et al.* 2020). Among the major grains, maize (*Zea mays* L.) is one the important crops cultivated under diverse agroclimatic conditions (Manasa *et al.* 2020; Patil, 2019). Maize is renowned for its remarkable genetic production potential as well as its utility for human and animal consumption (Maitra *et al.* 2019; Manasa *et al.* 2018, 2021;). Globally, maize is grown on 201.98 million hectares, producing an astounding 1162.3 million tonnes and a productivity of 5.75 t ha⁻¹ (FAOSTAT, 2021).

According to the country's statistics, maize production in India accounts for 33.62 million tonnes and has a productivity of 3.349 t ha⁻¹ on an area of 10.04 million hectares. Moreover, with a noteworthy productivity of 2.886 t ha⁻¹ and a total production of 0.733 million tonnes, maize is cultivated in 0.254 million hectares in the state of Odisha (Behera *et al.* 2024). By 2050, when the world's population is expected to reach 10 billion, maize output must quadruple to fulfil the world's expanding food demands (UN DESA, 2017; Ramirez-Cabral *et al.* 2017). The production of maize has increased by 2.5 times as a result of the introduction of hybrids

(Department of Agriculture, Cooperation and Farmer's Welfare, 2021), however, the full potential of the hybrids is yet to be exploited. The cereal cultivation in continuous succession, can degrade soil fertility and result in overabundance of nutrient uptake (Pervaiz *et al.* 2020). The use of site-specific nutrient management (SSNM) presents a viable solution to this problem. Maintaining soil health and advancing sustainable farming practices can be achieved by SSNM through fertilizer optimization and timely application of the proper quantity of nutrients (Krishna *et al.* 2024). Maize and other cereal crops' growth and productivity were highly influenced by the application of primary nutrients like nitrogen (N) potassium (K) and phosphorus (P), Particularly during vegetative growth, maize responds favourably to nitrogen fertilizers and has a high nitrogen need (Asib *et al.* 2019; Mohana Rao *et al.* 2020; Varma *et al.* 2020; Cheptoeck *et al.* 2021, 2022; Zhai *et al.* 2024).

Further, the growth and development of maize depend critically on phosphorus and potassium in addition to nitrogen. In the early phases of maize development, phosphorus promotes root growth, facilitating more effective access to nutrients and water. Conversely, potassium controls water balance fortifies plants against pests and diseases, and improves stress tolerance and production (Mirriam *et al.* 2022; Ahmed *et al.* 2023). Nevertheless, there may be unforeseen repercussions from using these mineral nutrients (Ghosh *et al.* 2021; Mwadalu *et al.* 2022). Farmers frequently use excessive amounts of inorganic fertilizers in commercial maize farming, which degrades the soil, causes nutrient runoff, lowers soil biodiversity, and compacts the soil. These problems can hinder water infiltration, inhibit root growth, and eventually affect crop yield (Maitra *et al.* 2018, 2024b). Adopting sustainable nutrient management techniques which maintain a balance between crop nutritional requirements and environmental considerations is therefore crucial (Venkatesh *et al.* 2017). In this scenario, site-specific nutrient management tools have been created to solve the difficulties associated with managing nutrients in maize cultivation (Raza



et al. 2023). The Nutrient Expert, created by the International Plant Nutrition Institute (IPNI), is a noteworthy illustration of a nutrient management decision assistance tool. By applying the appropriate amount of fertilizer, this program optimizes crop yields for maize producers by offering tailored recommendations (Wasay *et al.* 2024). Apart from optimum application of nutrients, the growth, development and yield of maize are significantly influenced by plant density. The overall nutrient need increases with plant density. Individual plants may have less access to vital nutrients like potassium, phosphorus, and nitrogen where as more plants will compete for the same nutrients hence affecting the growth and development of the crop. Plant density has a major impact on crop health, nutrient requirements, and absorption capacity in association with the Site-Specific Nutrient Management (SSNM) of maize (Singh, 2024). Plant stand can affect plant architecture, alter growth and developmental patterns and influence carbohydrate production and partitioning. As maize is more sensitive to variations in plant density, modern hybrids possess the ability to withstand intra-species competition to high population densities, which in turn enables producers to establish higher plant populations, leading to higher biomass and yield production per unit area (Watson *et al.* 2018). Thus, an increase in plant population with efficient nutrient management through a site-specific approach can enhance the productivity of maize per unit area. Considering above facts, the present study was designed to determine the optimum plant population for hybrid maize and

efficient recommendation of primary nutrients for a site-specific approach by using Nutrient expert-maize for a target yield under North Eastern Ghat Region of India.

MATERIALS AND METHODS

A field experiment was carried out during *Rabi* season of 2022-23 at Post Graduate research farm of Centurion University of Technology and Management (CUTM), Odisha, located at 23° 38' N latitude and 87 ° 43' longitude. The weather information was recorded from the automated weather station located at CUTM. The meteorological data showed that the maximum temperature during the crop period varied from 28.4 °C to 40.0 °C; whereas, the minimum temperature ranged between 13.0 °C and 28.6 °C. The maximum and minimum relative humidity recorded during the crop period was 80.6% to 91.0% and 37.4% to 68.4% respectively. Further, the crop received 38.2 mm of rainfall between December 2022 to April 2023 and the mean daily bright sunshine hours varied between 4.6 h day⁻¹ to 9 h day⁻¹. The data recorded for physio- chemical properties of the soil revealed that the soil is having a pH of 6.3, organic carbon of 0.42%, available nitrogen (231 kg ha⁻¹), available phosphorous (12.2 kg ha⁻¹) and available potassium (131.6 kg ha⁻¹). The experiment was laid out in split plot design with 12 treatment combinations, which were replicated thrice. The treatment details of the study includes three levels of plant populations S₁: 60 cm × 15 cm (1,11,111 plant population⁻¹), S₂: 60cm × 20 cm (83,333 plant population⁻¹) and S₃: 60 cm × 25 cm (66,666 plant population⁻¹) and in the

Table 1: Meteorological data during the crop period (Dec 2022- Apr 2023)

Date and Month	Temperature (°C)		Relative Humidity (%)		Rainfall (mm)	Sunshine (hrs day ⁻¹)	ET (mm)	Wind speed (km hr ⁻¹)
	Max	Min	Max	Min				
2 nd fortnight December	30.8	16.8	90.7	64.4	0.0	8.7	2.8	4.4
1 st fortnight January	29.5	15.6	89.5	59.3	0.0	4.8	2.6	5.1
2 nd fortnight January	31.2	16.1	86.8	50.6	0.0	5.4	2.6	4.4
1 st fortnight February	33.7	16.6	86.8	43.7	0.0	5.1	3.3	6.0
2 nd fortnight February	35.0	19.1	85.5	44.5	0.0	5.3	3.1	4.7
1 st fortnight March	35.0	19.0	81.7	40.5	0.0	5.5	2.8	4.9
2 nd fortnight March	32.6	22.5	85.6	63.5	17.0	5.1	2.5	5.3
1 st fortnight April	38.2	25.2	84.5	42.9	21.2	7.6	3.9	4.4

Data Source: Automated weather station CUTM, Odisha, India.

sub plot comprises of four nutrient management treatments, namely, N₁: 100% RDF, N₂: Nutrient expert-based recommendation for a target yield of 6 t ha⁻¹, N₃: Nutrient expert-based recommendation for a target yield of 8 t ha⁻¹, N₄: Nutrient expert-based recommendation for a target yield of 10 t ha⁻¹.

After the final layout preparation according to the experiment, fertilizers were applied according to the treatment and the sources were urea for N, single super phosphate for P and muriate of potash for K. Full doses of P and K fertilizers were applied as basal doses and 50% of urea was applied during basal and the remaining 50% was applied in two equal splits at knee high and tasselling stages as per treatment specifications. Gap filling and thinning were done at 9 days after sowing (DAS) to maintain a uniform plant population as per the treatments. The first top dressing of nitrogen was done at knee high stage (27 DAS) followed by first spraying of (tank mix) post emergence herbicide Tembotrione @ 0.35 l ha⁻¹ a.i + Atrazine @ 2 kg ha⁻¹ a.i after 30 DAS to maintain a weed free condition. Further, the earthing up operation was carried out at 34 DAS to provide extra support for the plant against lodging and the second top dressing of nitrogen was done at 55 DAS when the crop was at tasselling stage. Total six irrigations were given at 2, 12, 26, 37, 56 and 86 DAS to the crop as per the crop requirement. Chlorantraniliprole 0.4% GR was broadcast in the field to control the population of stem borer (*Chilo polychrysus*) at 20 DAS, followed by chlorpyrifos 20% EC (@ 2.0 ml L⁻¹) was sprayed in the field to control fall army worm population at 61 DAS and Novaluron 5.25% + Emamectin benzoate 0.9% SC was sprayed (@ 0.5 ml L⁻¹) in the field at 80 DAS to control the maize plants from fall army worm infestation.

Biometric observations were taken at different stages of the crop. Six plants were randomly selected and labelled from each treatment plot at different growth stages of 30, 60, 90 DAS and harvest to estimate the data about different growth parameters and yield attributing characters. The productivity of maize was noted at harvest and recorded as per the treatments. The cobs from the net plot area (3.0 m × 3.6 m = 10.8 m²) were harvested treatment-wise separately, sun-dried and shelled. The grain yield was recorded per plot when grains reached constant weight after sun-drying with a moisture level of

12% and yields were converted into kg ha⁻¹. After removal of cobs, the stover was allowed to dry in the field for seven days before weighing them and was converted into kg ha⁻¹. Additionally, the harvest index was calculated by dividing economic yield to the biological yield (Puteh *et al.* 2014) and expressed in percentage.

$$\text{Harvest Index (\%)} = \frac{\text{Economical Yield}}{\text{Biological Yield}} \times 100$$

The data on biometric observations recorded during the course of investigation were tabulated and analysed statistically to draw a valid conclusion. The data was analysed as per the standard procedure and analysis of variance was calculated as described by Gomez and Gomez (1984). The significance of treatments was tested by F test. The standard error of mean was computed in all cases. The difference in the treatment means were tested using the critical difference (CD) at 5% level of probability. Further, for all the statistical analysis, the Microsoft excel software (Microsoft Office Home and Student version 2019-en-us, Microsoft Inc., Redmond, Washington, USA) was considered.

RESULTS AND DISCUSSION

Growth attributes

Various plant populations showed a significant difference among themselves during all the growth stages of maize (Table 1). At 30 DAS, the plant population of 1,11,111 plants ha⁻¹ resulted in the highest plant height (69 cm), which was significantly higher than other plant stands, namely, 83,333 (57 cm) and 66,666 ha⁻¹ (56 cm). Further, the plant population of 83,333 and 66,666 ha⁻¹ remained statistically at par with each other in expression of plant height at the same growth stage. A similar trend was noted at 60 DAS and 90 DAS. Where the highest plant population (1,11,111 plants ha⁻¹) consistently produced significantly taller plants compared to its lower plant populations. Moreover, the plant population of 83,333 and 66,666 plants ha⁻¹ registered statistically at par values for plant height of *Rabi* maize in above-mentioned growth stages. The highest plant height of maize recorded in the treatment with the higher plant stand (1, 11, 111 plants ha⁻¹) can be due to more competition between the plants resulted in taller plants. Similar



results were also recorded by previous researchers like Djaman *et al.* (2022). Considering the levels of nutrient, significant differences were observed among treatments at all growth stages (Table 1). At 30 DAS, the NE@10t ha⁻¹ (153:58:79) produced the tallest plants (72 cm) and it showed its significant superiority over NE@8t ha⁻¹ (140:47:71), NE@6t ha⁻¹ (120:40:46) and RDF (120:60:60) with values of 67 cm, 50 cm and 54 cm respectively. The treatment NE@8t ha⁻¹ (140:47:71) registered significantly taller plants than NE@6t ha⁻¹ (120:40:46) and RDF (120:60:60). The treatment with NE@10t ha⁻¹ recorded the tallest plants in other growth stages also; however, its relationship with other treatment levels varied at different growth stages. At 60 DAS, NE@10t ha⁻¹ being statistically at par with NE@8t ha⁻¹ recorded significantly taller plants than NE@6t ha⁻¹ (174 cm) and RDF (179 cm). At the same growth stage, NE@8t ha⁻¹ (140:47:71) showed significantly higher plant height than NE@6t ha⁻¹ (120:40:46); however, it was statistically at par with 100% RDF (120:60:60). Moreover, at the same growth stage, treatments with RDF (179 cm) and NE@6t ha⁻¹ (174 cm) also remained on par with each other. At 90 DAS, the similar trend of increase in plant height was recorded as observed earlier at 60 DAS where, NE@10t ha⁻¹ (253 cm) remained statistically at par with NE@8t ha⁻¹ (248 cm) and recorded significantly taller plants than NE@6t ha⁻¹ (227 cm) and RDF (238 cm). The treatments consisting of NE@8t ha⁻¹ and RDF (245 cm) remained on par, however, they were significantly superior to NE@6t ha⁻¹ (231 cm) in expression of plant height at harvest. The highest values of plant height in the treatment with NE@10t ha⁻¹ could be due to application of optimum amount of nutrients namely nitrogen, phosphorous and potassium by considering the site specificity might be the reason for enhanced plant height in the above-mentioned treatment. Similar results are also reported by Hargilas *et al.* (2017) and Singh *et al.* (2022). The interaction effect between plant population and nutrient levels did not show any significant difference in plant height across growth stages. Such results suggested that the combined effect of plant population and nutrient level on plant height might remain independent in expression of the growth character (Dahal *et al.* 2018; Ahmad *et al.* 2023).

Dry matter accumulation was increased continuously with the progression of growth stages and remained

significantly different among the study (Table 1). The experimental results revealed that with an increase in the plant population, dry matter accumulation per unit area was increased. The highest dry matter production was recorded with the treatment with 1,11,111 plants ha⁻¹, with a value of 334 g m⁻², followed by 83,333 plants ha⁻¹ (296 g m⁻²), and 66,666 plants ha⁻¹ (264 g m⁻²). The treatment with 1, 11,111 plants ha⁻¹ produced significantly higher dry matter accumulation than other plant population considered in the experiment. Further, 83,333 plants ha⁻¹ recorded significantly higher dry matter than 66,666 plants ha⁻¹. A similar trend was noted in other growth stages. At 60 DAS, the treatment with 1,11,111 plants ha⁻¹ exhibited the highest dry matter production of 907 g m⁻² and it remained significantly superior to other plant populations, namely, 83,333 plants ha⁻¹ (825 g m⁻²) and 66,666 plants ha⁻¹ (762 g m⁻²). The treatment 83,333 plants ha⁻¹ also yielded significantly higher dry matter than 66,666 plants ha⁻¹ at the same growth stage. The remaining growth stage, i.e., 90 DAS also showed a similar trend in expression of results. At 90 DAS, the population of 1,11,111 plants ha⁻¹ resulted in production of 1544 g m⁻² of dry matter and it was significantly superior to other plant populations, namely, 83,333 plants ha⁻¹ (1357 g m⁻²) and 66,666 plants ha⁻¹ (1300 g m⁻²). Further, the treatment with 83,333 plants ha⁻¹ produced significantly higher dry matter than 66,666 plants ha⁻¹ (Djaman *et al.* 2022).

Dry matter production of maize was impacted by various nutrient levels (Table 1). The treatment NE@10t ha⁻¹ produced the highest dry matter (329 g m⁻²) at 30 DAS which was on par with NE@8t ha⁻¹ (312 g m⁻²) and they recorded significantly higher dry matter than RDF and (290 g m⁻² and 262 g m⁻² respectively). Moreover, the treatment RDF registered its superiority over NE@8t ha⁻¹ in dry matter accumulation at the same growth stage. At 60 DAS, NE@10t ha⁻¹ produced the highest dry matter (899 g m⁻²) which was significantly superior to other nutrient levels, namely, NE@8t ha⁻¹ (859 g m⁻²), NE@6t ha⁻¹ (758 g m⁻²) and RDF (810 g m⁻²). The treatment with NE@8t ha⁻¹ yielded significantly higher dry matter than NE@6t ha⁻¹ and RDF. The treatment NE@6t ha⁻¹ recorded the least dry matter and it was significantly inferior to other nutrient levels at the same growth stage. At 90 DAS, a slightly different type of performance was noted. However,

the treatment NE@10t ha⁻¹ showed its significant superiority (1610 g m⁻²) over other treatments. The treatment NE@8t ha⁻¹ produced significantly higher dry matter (1415 g m⁻²) than NE@6t ha⁻¹ (1280 g m⁻²) and RDF (1295 g m⁻²) and the later treatments were on par with each other. The hybrids of maize have a greater potential for photosynthates production as well as translocation to different vegetative and reproductive parts of the plants during various phenophases (Pooniya *et al.* 2015). This phenomenon resulted in development of more biomass during the vegetative growth stages of maize which resulted in more dry matter accumulation during all the growth stages under optimum dose of primary nutrient application (Kumar *et al.* 2019; Naik *et al.* 2022; Sairam *et al.* 2023a).

At 30 DAS, there was non-significant difference in dry matter production between different nutrient levels and plant populations (Table 2). However, the interaction between spacing and nutrient level was significant at the later stages, i.e., 60 DAS and 90 DAS respectively. The study clearly revealed that both treatments, namely, plant population and nutrient level impacted on dry matter accumulation individually and as well as in combination at harvest stage of maize. The higher plant stand (1, 11,111) with the highest levels of nutrients (NE-based nutrient management for a yield target of 10 t ha⁻¹) facilitated dry matter production in maize (Adeniyi, 2014; Imran *et al.* 2015).

The leaf area measured at 30, 60, and 90 DAS clearly showed that there was an increase in leaf area from 30 DAS to 60 DAS and after that it declined as the crop entered into the reproductive stage (Fig. 1). There was a significant variation among different plant stands (1, 11,111 plants ha⁻¹, 83,333 plants ha⁻¹ and 66,666 plants ha⁻¹). At 30 DAS, the population of 1,11,111 plants ha⁻¹ recorded the highest leaf area (2448 cm² plant⁻¹) which was significantly superior to 83,333 plants ha⁻¹ (2376 cm² plant⁻¹) and 66,666 plants ha⁻¹ (2205 cm² plant⁻¹). Further, the population of 83,333 plants ha⁻¹ recorded significantly more leaf area than the population of 66,666 plants ha⁻¹. The similar trend was observed at other growth stages also. The results are in conformity with the findings of Fattah *et al.* 2019; Djaman *et al.* 2022.

Leaf area plays a crucial role in photosynthesis, assimilates production and overall productivity where varied levels of nutrient influenced this growth parameters (Fig. 2). At 30 DAS, maize plants provided with NE @10 t ha⁻¹ exhibited the highest leaf area (2532 cm² plant⁻¹); however, it remained on par with the leaf area noted under NE @8 t ha⁻¹ (2434 cm² plant⁻¹). The above-mentioned two treatments showed their significant superiority over nutrient levels of NE @ 6 t ha⁻¹ (2161 cm² plant⁻¹) and RDF (2245 cm² plant⁻¹). Moreover, RDF recorded significantly higher leaf area than the nutrient dose as suggested by NE @ 6 t ha⁻¹ at the same growth stage. At 60 DAS, the nutrient level of NE @10 t ha⁻¹

Table 2: Effect of plant population and nutrient management on plant height (cm) and dry matter accumulation of *Rabi* maize at different growth stages

Treatments	Plant Height			Dry matter Accumulation		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Plant population (Plants ha⁻¹)						
S ₁ : 1.11,111	69	194	258	334	907	1544
S ₂ : 83,333	57	179	235	296	825	1357
S ₃ : 66,666	56	178	232	264	762	1300
S. Em. ±	1.12	1.85	2.12	3.35	5.07	6.43
CD at 5%	4.39	7.25	8.32	13.17	19.90	25.26
Levels of nutrients (kg ha⁻¹)						
N ₁ : RDF (120:60:60)	54	179	238	290	810	1295
N ₂ : NE@6t ha ⁻¹ (120:40:46)	50	174	227	262	758	1280
N ₃ : NE@8t ha ⁻¹ (140:47:71)	67	188	248	312	859	1415
N ₄ : NE@10t ha ⁻¹ (153:58:79)	72	193	253	329	899	1610
S.Em. ±	1.01	3.18	4.57	6.08	8.80	9.22
CD at 5%	2.99	9.43	13.56	18.05	26.15	27.38
Spacing × nutrient Interaction						
S. Em. ±	1.75	5.50	7.91	10.52	15.24	11.76
CD at 5%	NS	NS	NS	NS	45.29	34.94

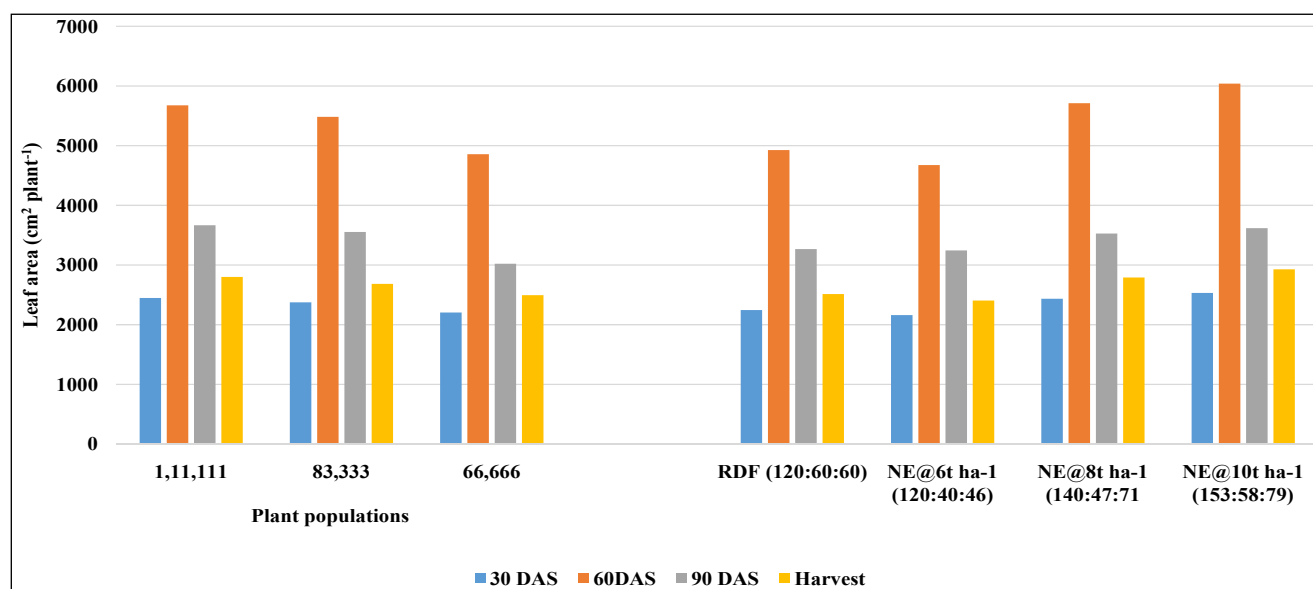


Fig. 1: Effect of plant population and levels of fertilizer on leaf area of *Rabi* maize at different growth stages

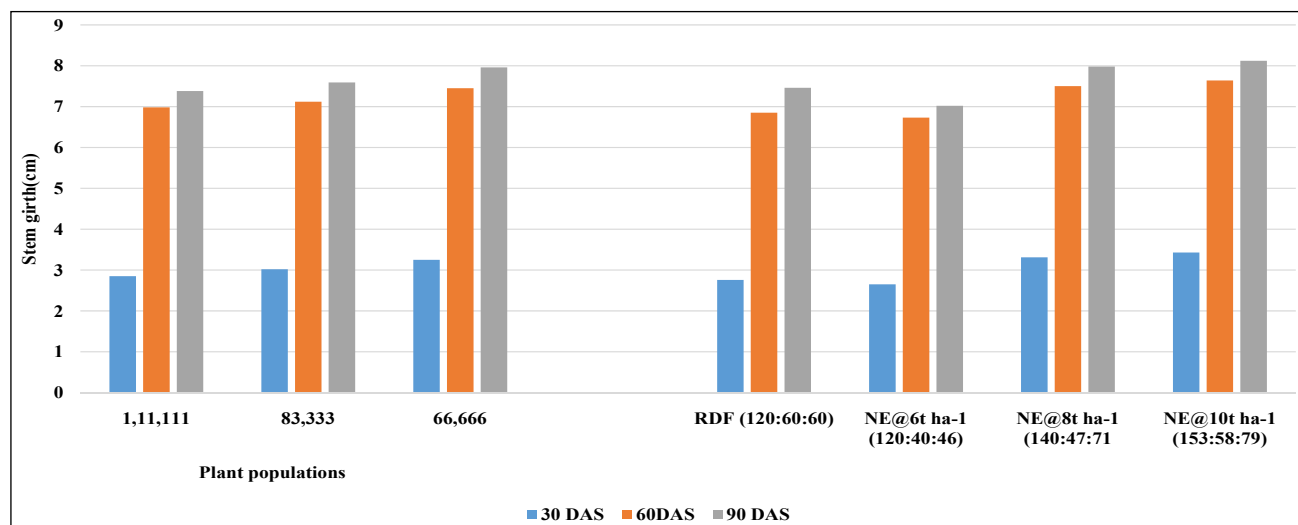


Fig. 2: Effect of plant population and nutrient management on stem girth of *Rabi* maize at different growth stages

noted the highest leaf area (6038 cm² plant⁻¹) and the treatment was significantly superior to other treatments of the study. Further, NE @ 8 t ha⁻¹ (5713 cm² plant⁻¹) produced significantly higher leaf area than NE @ 6 t ha⁻¹ (4676 cm² plant⁻¹) and RDF (4926 cm² plant⁻¹). It was also recorded that the nutrient level of NE @ 6 t ha⁻¹ remained significantly inferior to RDF. At 90 DAS, treatments consisting of NE @ 10 t ha⁻¹ and NE @ 8 t ha⁻¹ registered on par values in expression of leaf area plant⁻¹ (3617 cm² and 3528 cm² respectively) and they were significantly higher than RDF (3267 cm²) and NE @ 6 t ha⁻¹ (3245 cm²). The timely and optimum level of nitrogen topdressing allowed more green leaf pigmentation and more

leaf area enabled the plant to intercept the higher amount of solar energy which probably resulted in more assimilation of photosynthate registering more crop canopy (Yang *et al.* 2021; Fang *et al.* 2023). The interaction between plant population (1,11,111, 83,333 and 66,666 plants ha⁻¹) and nutrient level (RDF, NE @ 6 t ha⁻¹, NE @ 8 t ha⁻¹ and NE @ 10 t ha⁻¹) significantly influenced leaf area at 60 DAS (Ahmad *et al.* 2023).

The stem girth of maize varied under different plant populations at different growth stages, namely, 30 DAS, 60 DAS and 90 DAS (Fig. 2). There was an increasing trend in the stem girth of maize with progression of crop growth stages. At 30 DAS,

maize population of 66,666 ha⁻¹ resulted in the largest stem girth of 3.25 cm which was significantly superior to the plant stand of 83,333 ha⁻¹ (3.02 cm) and 1,11,111 plants ha⁻¹ (2.85 cm). Moreover, the population of 83,333 plants ha⁻¹ produced a higher stem girth than 1, 11,111 plants ha⁻¹. A similar type of trend was noted at other growth stages where the maize plant population of 66,666 ha⁻¹ showed its superiority over other plant stands. At 60 DAS, the maize plant population of 66,666 ha⁻¹ resulted in the highest stem girth of 7.45 cm which was significantly superior to the population of 83,333 plants ha⁻¹ (7.12 cm) and 1,11,111 plants ha⁻¹ (6.98 cm). Maize plant population of 83,333 ha⁻¹ recorded significantly higher stem girth than the population of 1, 11,111 plants ha⁻¹. At 90 DAS, the maize population of 66,666 ha⁻¹ resulted in the highest stem girth of 7.96 cm which was significantly superior to 83,333 plants ha⁻¹ at (7.59 cm) and 1,11,111 plants ha⁻¹ (7.59 cm). Moreover, maize population of 83,333 ha⁻¹ recorded significantly higher stem girth than the population of 1, 11,111 plants ha⁻¹. As plants faced comparatively less competition among themselves under a lower plant population which provided a luxuriant and healthy growth of plants which was reflected in the stem girth of maize. The findings are in the tune with the previous research of Naik *et al.* (2022).

The stem girth (cm) data across different growth stages for various nutrient levels (RDF, NE @6 t ha⁻¹, NE @8 t ha⁻¹ and NE @10 t ha⁻¹) indicated significant differences among them (Fig. 2). At 30 DAS, the stem girth of the treatment NE @10 t ha⁻¹ showed the highest stem girth (3.43 cm) which was statistically at par with the treatment NE @8 t ha⁻¹ (3.31 cm). The aforesaid treatments were significantly superior to RDF and NE @6 t ha⁻¹ in expression of stem girth of 2.76 cm and 2.65 cm respectively and they were statistically similar to each other. There was a similarity in the trend for stem girth of maize at 60 DAS where the treatment NE @10 t ha⁻¹ recorded the highest stem girth (7.64 cm) which was on par with the treatment NE @8 t ha⁻¹ (7.50 cm). These two treatments noted significantly higher stem girth than RDF (6.85 cm) and NE @6 t ha⁻¹ (6.73 cm) and the later treatments were statistically at par with each other. However, there was slight variation in the trend for 90 DAS compared to earlier growth stages. At this growth stage, nutrient levels of

NE @10 t ha⁻¹ and NE @8 t ha⁻¹ noted statistically similar values for stem girth (8.12 cm and 7.98 cm) and they remained significantly superior to other nutrient levels such as RDF (7.46 cm) and (7.02 cm). Furthermore, RDF expressed significantly higher values than NE @6 t ha⁻¹ (6.73 cm). Such results might be obtained because of sufficient supply of nutrients with superior treatments (Pooniya *et al.* 2015; Sairam *et al.* 2023b,c). The interaction effect between plant population and nutrient level on stem girth was found to be non-significant at all growth stages. (Yan *et al.* 2016; Worku *et al.* 2020).

Yield Attributes

Different plant populations in maize had a substantial impact on the yield attributes of the crop, including the number of cobs per plant, the number of grains per cob, the weight of the cob, cob length and girth, the number of grains per row, and the number of cobs per plant (Fig. 3 and 4). The treatment with a lower plant population density (66,666 plants ha⁻¹) outperformed the higher plant populations of 83,333 plants ha⁻¹ and 1,11,111 plants ha⁻¹, according to the yield-attributing character data analysis. Among the traits that contributed to the yield, the treatment with 66,666 plants ha⁻¹ had noticeably more cobs per plant (1.79), grains per cob (326), weight of the cob (259 g), length of the cob (22.75 cm), girth of the cob (12.80 cm), grains rows per cob (22.03), and grains per row (12.80). Furthermore, in terms of the number of cobs per plant, this treatment stayed statistically at par to 83,333 plants ha⁻¹. Except for test weight and the number of cobs per plant, the plant population treatment with 66,666 plants ha⁻¹ continued to be significantly superior than the other two treatments in terms of expression of all other yield-attributing characteristics throughout the trial. In terms of nutrient management, the treatment NE@10t ha⁻¹ (153:58:79 kg ha⁻¹ of N:P₂O₅:K₂O) produced the highest number of cobs plant⁻¹ (1.83), number of grains cob⁻¹ (346), weight of cob (243 g), test weight (246 g), length of the cob (24.17 cm), girth of the cob (13.23 cm), grains per cob (24.17), and grain rows per cob (13.08) in relation to fertilizer doses (Fig. 4). Furthermore, in terms of cob weight (258.67 gm), test weight (241.67 gm), and number of cobs per plant (1.79), this treatment remained statistically at par to NE@8 t ha⁻¹ (140:47:71 kg ha⁻¹

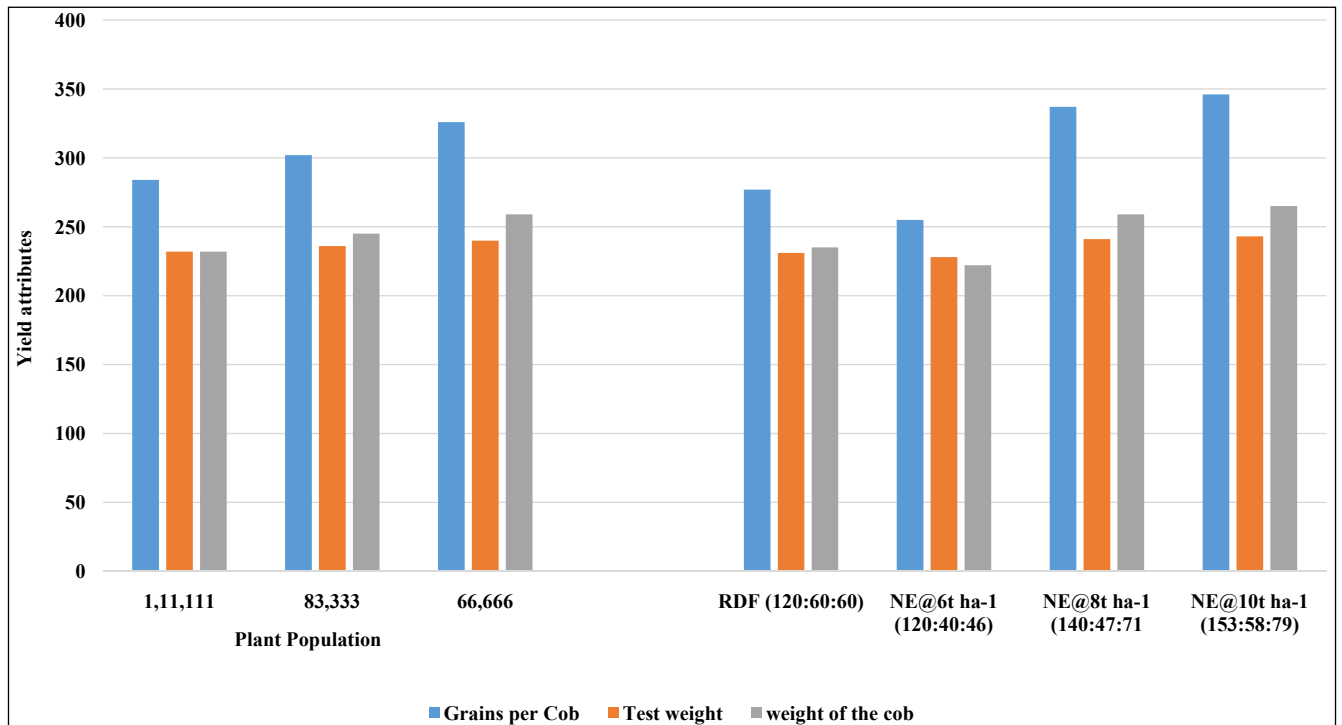


Fig. 3: Effect of plant population and nutrient management on yield attributes of *Rabi* maize

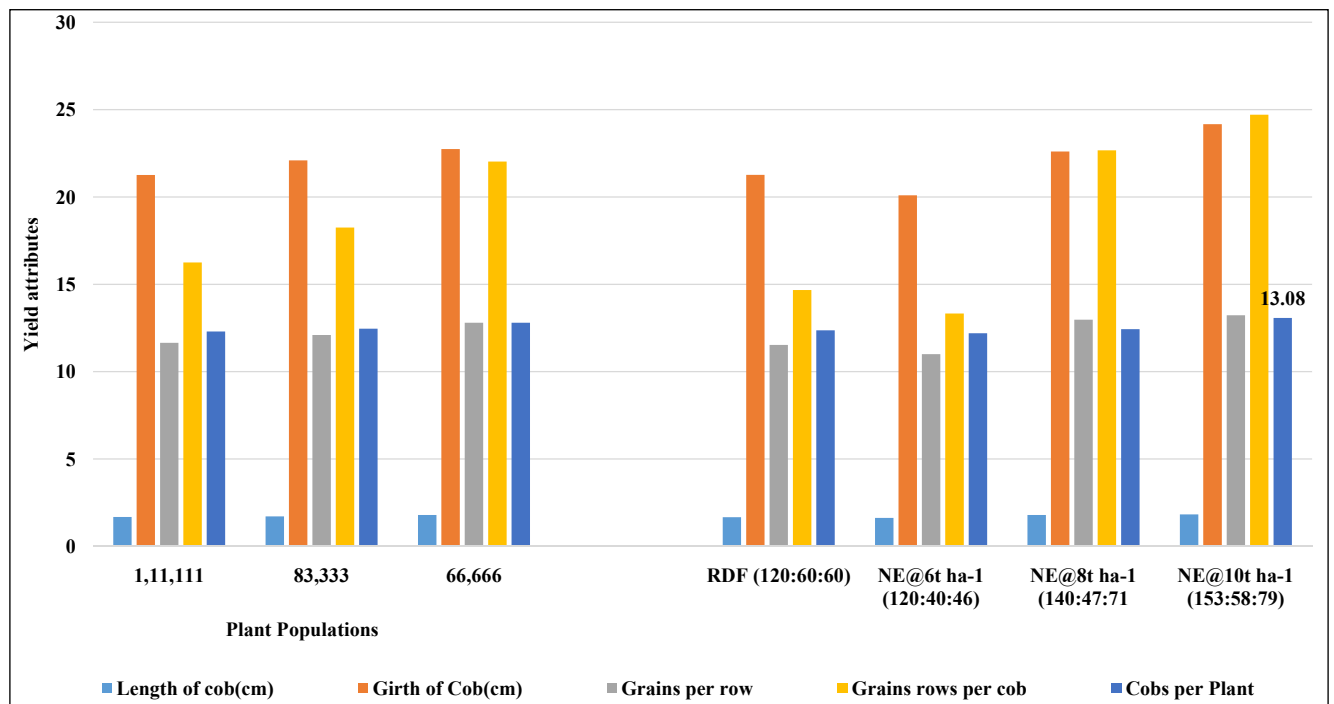


Fig. 4: Effect of plant population and nutrient management on yield attributes of *Rabi* maize

of $N:P_2O_5:K_2O$). NE@6 t ha⁻¹ (120:40:46 kg ha⁻¹ of $N:P_2O_5:K_2O$) and 100% RDF, treatments, continued to perform noticeably inferior than NE@10 t ha⁻¹ (153:58:79 kg ha⁻¹ of $N:P_2O_5:K_2O$). Ample nutrient application through NE@10t ha⁻¹ (153:58:79 kg

ha⁻¹ of $N:P_2O_5:K_2O$) increased maize's dry matter accumulation and leaf area, which may improve photosynthetic assimilation and consequently improve the translocation of carbohydrates to the grain and cob (Singh *et al.* 2022; Sivamurugan *et*

al. 2017). There was no discernible variation in the expression of any of the traits that contribute to yield attributes when the plant population and nutrient level were combined. The aforementioned findings are consistent with earlier research by Kumar *et al.* (2021) and Sapkota *et al.* (2021).

Yield

The grain, stover and biological yield of maize were significantly influenced by plant population and nutrient management treatments (Fig. 5). The treatment with 1,11,111 plants ha⁻¹ registered the highest grain yield (6362 kg ha⁻¹), stover yield (9789 kg ha⁻¹), and biological yield (15563 kg ha⁻¹) among the plant population treatments. It was still noticeably better than the other treatments, which included 83,333 plants ha⁻¹ and 66,666 plants ha⁻¹ (Figure 5). In terms of grain, stover, and biological yield of maize, the treatment of 66,666 plants ha⁻¹ continued to be noticeably inferior than the other plant population treatments. Grain, stover, and biological yield of maize increased due to a higher plant stand per unit area, even though the per plant yield was lower in the treatment with 1, 11,111 plants ha⁻¹ (Mahesh *et al.* 2016; Djaman *et al.* 2022). In case of nutrient management treatments, the maximum grain yield (7065 kg ha⁻¹), stover yield (9334 kg ha⁻¹) and biological yield (16353 kg ha⁻¹)

were recorded with NE@10t ha⁻¹ (Fig. 5). For stover yield, it remained statistically at par to NE@8 t ha⁻¹. However, the treatment NE@10t ha⁻¹ continued to be much better than all other nutrition management treatments in terms of grain yield expression. In terms of grain yield, stover yield, and biological yield, the nutrient management treatments NE@6 t ha⁻¹ and 100% RDF remaining were inferior to NE@10 t ha⁻¹. In comparison to RDF, which produced the highest grain and stover yield of maize, site-specific application of primary nutrients through NE for a target yield of 10 t ha⁻¹ may offer a better supply of nutrients with optimal application of nitrogen. The NE@10t ha⁻¹ treatment's quantitative improvement in yield attributes may help achieve a higher yield than 100% RDF. (Djaman *et al.* 2022; Mahesh *et al.* 2016)

There was a notable variation in maize yield between the plant population and nutrient level treatment combinations (Table 3). The highest biological and grain yields were recorded with 1, 11,111 plants per hectare at NE@10t ha⁻¹. With 83,333 plants per hectare, this treatment remained statistically at par with NE@10t ha⁻¹ and NE@8 t ha⁻¹ with 1, 11,111 plants per hectare. But with 1, 11,111 plants ha⁻¹, the treatment combination of NE@10t ha⁻¹ produced the highest stover yield. NE@10t ha⁻¹ with 83,333 plants ha⁻¹ was comparable

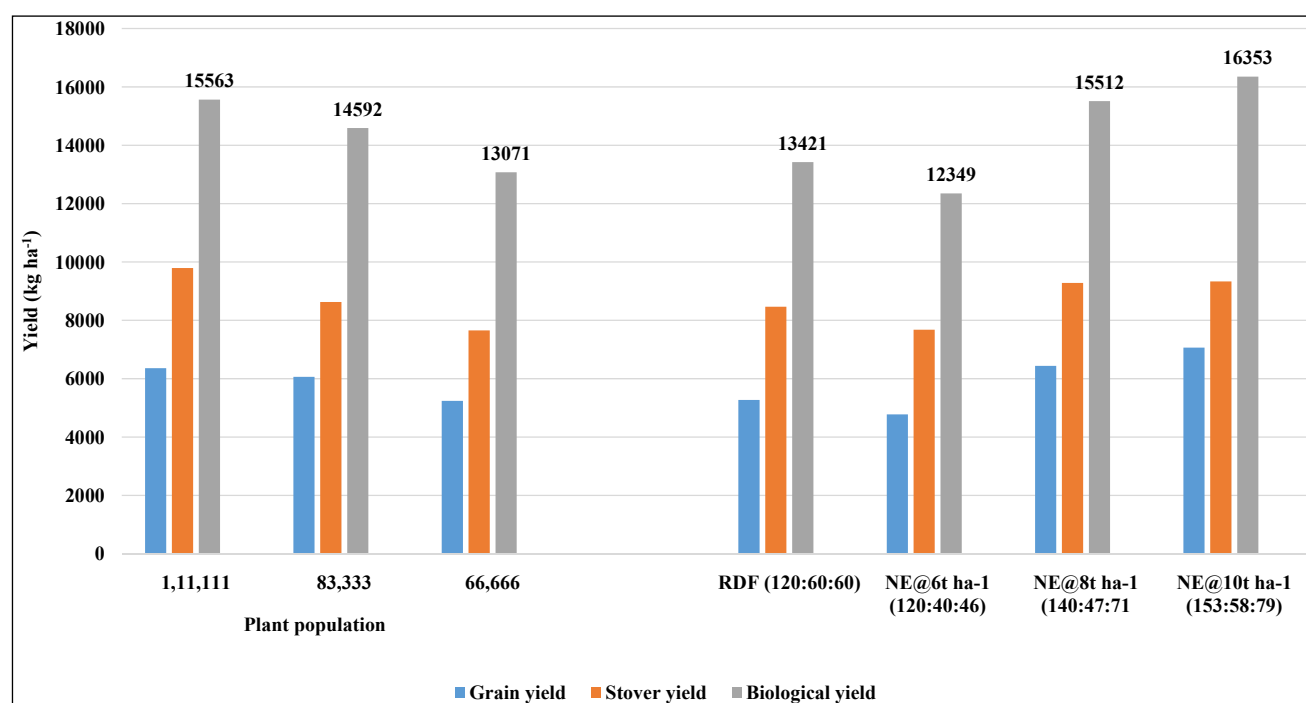


Fig. 5: Effect of plant population and nutrient management on yield of *Rabi* maize



to this treatment. Furthermore, the aforementioned treatment combinations continued to outperform all other combinations of plant population and nutrient dosages with a significant superiority. In terms of grain production, stover yield, and biological yield, NE@6 t ha⁻¹ with 66,666 plants ha⁻¹ had the lowest values among the interaction treatments. Yields may be impacted by a larger plant population with an abundant supply of nutrients.

Table 3: Interaction effect of plant population and nutrient levels on grain yield, stover yield, biological yield of *Rabi* maize

Treatment	Grain yield	Stover yield	Biological yield
S1N1	5641	10091	14856
S1N2	5013	8103	13117
S1N3	7379	10312	17064
S1N4	7418	10652	17216
S2N1	5487	7992	13479
S2N2	4823	7692	12115
S2N3	6648	9303	15951
S2N4	7291	9532	16823
S3N1	4681	7312	11928
S3N2	4503	7247	11815
S3N3	5289	8231	13520
S3N4	6487	7817	15019
S. Em. ±	211	243	316
CD at 5%	627	721	945

CONCLUSION

Nutrient expert-based site-specific nutrient management and different plant populations were showed a significant effect on various growth attributes, yield attributes and productivity of maize. Among the treatments considered in the study, application of N, P and K through NE-based recommendation for a target yield of 10 t ha⁻¹ registered significantly higher plant parameters and yield. On the other hand, highest plant-stand by reducing plant to plant distance with a plant population of 1,11,111 plants ha⁻¹ (60 cm × 15 cm) recorded its superiority among the treatment. Considering the above facts, the present study concludes that the application of nutrients through Nutrient expert-based nutrient management for a target yield of 10 t ha⁻¹ under the plant population of 1,11,111 plants ha⁻¹ (with a spacing of

60 cm × 15 cm) can be chosen as the most suitable agronomic management for improving growth and productivity in maize under North Eastern Ghat Region of Odisha, India.

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