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Effect of Different Spacing and Nutrient Management on Growth and Yield of Maize: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Optimal plant density influenced by crop geometric/planting techniques factors are crucial in achieving high yield to maize. In addition, nutrient management further enhances productivity. Increasing plant density can lead to higher grain yield per unit area, but it also reduces the yield per individual plant as the competition between plant to plant will increase. From different research it indicates that plant density lower than the optimum number result in higher productivity rate per plant but lower yield per area unit. After reviewing various research articles, it was concluded that the maximum growth and yield attributes of maize obtained with spacing 60: 20-30 cm. Highest nitrogen application up to 160 kg N per ha^{-1} by split application at sowing, 25 DAS and tasselling is most reliable to increase the maize productivity. The combined application of 70 kg ha^{-1} phosphorus and 60 kg ha^{-1} potassium is the most suitable to obtain the maximum growth and yield

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attributes such as plant height, number of leaves per plant, cob length, cobs per plant, dry matter accumulation and crop growth rate. Effective nutrient management, aligned with proper planting density, played a pivotal role in maximizing maize productivity, meeting the demands of a growing population, and contributing to sustainable agriculture.

Keywords: Nutrient management; production; spacing; sustainable agriculture.

1. INTRODUCTION

Maize (*Zea mays*) is a major cereal crop belonging to family Poaceae. Around 9000 years ago it was first cultivated in Mexico and was expanded throughout the Americas. The primary countries globally recognized for their maize production include the United States, China, regions of South and Central Africa, Argentina, Brazil, and Mexico. Within India, the states of Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, Punjab, Karnataka, Himachal Pradesh, and Andhra Pradesh are significant for their cultivation of maize [54,55]. The area of cultivation of this crop is increasing year after year. In the year 2020-21 maize was cultivated in 9.86 M ha and recorded production of 31.51 Mt of maize grains and a yield of 3195 kg/ha (Directorate of Economics and Statistics, 2021).

Maize used as dual-purpose crop *i.e.* food and feed purpose. Maize plant is C4 compact with defined nodes and internodes and having a fibrous root system with well-established prop roots or stilled root system which provides extra support to the plants and absorbing nutrients [49,53]. The leaves are opposite spirally arranged and comprises of a sheath, collar (ligules, auricles) and a blade with a white coloured mid-rib which runs through the length of the leaf, providing support to the leaf. Maize has monoecious flowers and the male flowers bloom in the tassel and female flowers bloom on the ear. Six varieties of maize are cultivated widely i.e., dent corn, flint corn, flour corn, pod corn, popcorn, and sweet corn. Maize is one of the cereals with the largest grain yield productivity but is also one to be affected by plant density fluctuations. Modern hybrids can typically sustain larger population densities because they can more easily manage adverse environmental circumstances induced by increased intra-specific competition, resulting in fewer barren plants and less stem lodging. Maize is widely grown in subtropical, tropical and temperate regions. It is known as the "Queen of Cereals" in the world [64,65]. It is consumed as raw, roasted, cooked or table purposes. Maize is used in many ways like other grain crops in food dishes including “Chapati”. The stalk and leaves given as a raw (green fodder) to animals or made into silage or hay (dry fodder) for long-term usage. The stalk and leaves are also used in the production of biodiesel, pigments, polymers and fibre. Maize grain has about 10% protein, 4% oil, 70% carbohydrates, 2.3% crude fibre, 10.4% albuminoids and 1.4% ash. Maize grain has significant quantities of vitamin A, nicotinic acid, riboflavin, vitamin E and low in calcium but high in phosphorus.

Maize yield is closely related to plant population. Productivity with relation to population density is a widely researched topic in the field of agronomy. The primary objective behind increasing the plant density is to improve the output, be it in the form of grain or biomass, thereby making the crop system more effective and competitive per unit area Chauhan and Opeña [1]. However, higher plant population increase yield because grain yield is directly proportional to the number of plants standing in field at the time of harvesting of the crop.[59] Generally, if the planting density of maize crop increased, the yield per plant tends to decrease, while the yield per acre will be increased [58,60,61]. The most effective strategy to enhance future grain yield potential lies in enhancing the tolerance of plants to high densities, along with improving the yield potential of each plant in low-stress environments. This approach highlights the importance of striking a balance between plant density and individual plant productivity in order to optimize maize yield outcomes in agricultural environments. Maize growth and yield is also impacted by different crop geometries, intercropping and nutrient application, Thavaprakash et. al., (2005). Distance between rows and the distance between plants in a row influence the plant population in a unit area. Sowing of maize crop at optimum distance eases field operations like fertilizer application and weeding, reduces plant competition for resources like sunlight, water, nutrients and reduces the risk of infestations and diseases [66,67,70]. Weed management is also an important factor for cultivation of maize to reduce the yield losses and enhance the crop

growth and development [2] Improved spacing technology has the potential to enhance crop yield by mitigating the misuse of land and seeds, ultimately leading to the achievement of self-sufficiency in food and feed, as reported in the research by Alam et. al. [3]. The utilization of spacing techniques not only facilitates the proper adjustment of plant populations in the field but also optimizes the utilization of land and nutrients available for plant growth [52,68,69]. Based on the literature review discussed above, an investigation was carried out to pinpoint the optimal spacing methods for maize farming, specifically examining the growth patterns, yield traits, and nutritional content of maize crops. The findings from this research are expected to contribute valuable insights towards improving maize cultivation practices and enhancing agricultural productivity in the future [68,69].

Nutrient management is a key factor in cultivation of crops to achieve higher yields and also maintain the soil health. To meet out the requirement of human as well as animals (fodder) required a lot of agronomic practices to enhance the production of maize. Maize has distinct requirements of nutrients at various stages of growth [39]. Nitrogen and phosphorous are required in early growth stages for root and shoot development [44]. Potassium is provided to ensure plant health and resilience against certain abiotic and biotic stresses. Nutrients are provided to the plants in various forms and sources such as organic manures and chemicals like compost, vermicompost, FYM, poultry manure, *etc* which also enhances the soil structure as well as the soil microbial activity and chemical compounds like rock phosphate, wood ash or conventional forms of fertilizers like urea, MOP, DAP, SSP, TSP, *etc* respectively [48]. Understanding the requirement of the crop and the available nutrient in the soil is necessary before application to prevent excess and provide a balanced and precise level of fertilizers. Significance of providing optimum distance and nutrient on various parameters i.e., growth, yield and quality of maize will be discussed as follows:

2. EFFECT OF SPACING ON GROWTH AND YIELD OF MAIZE

Maintaining distance of row to row and plant to plant is an important factor in the cultivation of crops as it significantly influences the growth and development of crops by ensuring efficient utilization of resources [47]. Proper spacing provides better vegetative growth as well as rooting, it also reduces the risks of disease incidence by reducing excessive humidity and weeds which may serve as a host. Maize being a C_4 plant has proper growth and photosynthesis rate when adequate and recommended rate of spacing is practiced, it also reduces competition of essential nutrients and water resources. Maintaining a proper space also ensures ease of weed control such as mechanical and manual weeding. Among plants if there is improper spacing, it limits the rate of photosynthesis, depletion of soil nutrients, water stress, incidence of pests and diseases and difficulties in weed control. Ideal spacing of maize can be different according to the topography and the climate of the area [46]. Recommended spacing of maize in Punjab region is 60 × 20 cm. It is also important to consider the recommended spacing according to the objectives of cultivation, be it for fodder production or for human consumption.

Plant population and spacing affects the biomass production and grain yield, Harhoff and Swanepoel, [4] employed two different row spacing levels @ 52 cm and 76 cm where productivity was higher in the treatment with larger width. This may be due to the competition of resources amongst the plants during vegetative stages, wider row spacings can also reduce crop failure caused by climate related factors. Similarly, Manan et. al., [5] reported that the spacing from narrow to wider distance increase the grain yield of the maize crop. The effects of combination of sowing methods and intra-row spacing was observed in plant growth attributes and the effects of sowing methods were highly significant at grain yield of the maize crop. The grain yield of 3.53 t ha^{-1} was the highest yield obtained from ridge sowing method integrated with 20 cm intra-row spacing was suitable for the satisfactory growth of maize crop as conducted by Hamid et. al., [6] as compared to drilling method integrated with 20 cm intra row spacing, terrace method combined with 30 cm intra-row spacing. According to Meena et. al., [7] fodder maize grown at a wider row spacing of 40 cm have better growth in terms of foliage, growth and yield of maize. Alam (2020) reported that the highest plant height, stem diameter and the length of leaf was highest with 60 cm x 30 cm in contrast to the 50cm x 20cm, 55cm x 25cm, 65cm x 35cm and 70cm x 40cm of maize variety Bari hybrid Butta-09. In the same year, Rina et. al., [8] found that providing a spacing of 60 x 20 cm gives better values in terms of growth and yield attributes like harvest index, test weight, etc. Similarly, Mahato et. al., [9] observed that

maintaining spacing of 60 x 20 cm and maintaining the plant population contributes to grain per unit area *i.e*., maximum grain yield (7.5 t/ha). It was also observed that wider spacing causes drastic reduction in crop yield. As compared to Rina et. al. [8] using a spacing half the size they have experimented, Paul [10] concluded that using spacing distance of 35cm x 10cm gives the maximum production of green fodder. Sharifi and Namvar [11] found that the significantly taller plants, total dry matter was found in intra row spacing of 45cm. In the same year Devi and Ghosh [12] recorded that the best performance with spacing of 60 × 15cm on plant growth attributes, grain yield and stover yield.

Singh et. al*.,* [13] demonstrated that intercropping maize with lentils in a ratio of 1:2 produced highest cob length cob weight per plant. The choice of crop companions, ratio and the spacing significantly influence the overall yield. Similarly, El-Ghobashy et al [14] observed higher land use efficiency when maize and cowpea were planted in a ratio of 2:4 respectively. Babu and Senthivel [15] conducted an experiment in Kharif season of 2014 and 15 to assess the significance of plant spacing and weed management of maize where it is indicated that maintaining a spacing of 60 x 25 cm and pre-emergence spraying of atrazine and hand weeding at 30 DAS had a favourable impact on increasing grain yield. In accordance with these findings, it may be considered emphasizing on plant spacing and weed management as strategies of achieving optimum yield and profit. Maintaining optimum spacing and cropping geometry can be considered as a sustainable method as it reduces the use of inputs which may be harmful to the crop ecosystem, human health and the environment if wrongly applied [41]. Practicing a proper spacing and crop geometry improve the maize production system, thus giving a major emphasis in sustainable agriculture [50].

Table 1. Effect of different cropping geometry on growth and yield attributes of maize.

Cropping geometry	Results obtained	References
Ridge sowing method combined with 20 cm intra-row spacing.	The grain yield 3.53 t ha^{-1} were obtained.	Hamid et. al., [6]
Row spacing width of 40 cm	Obtained better foliage, height, occurrence of internodes and stem girth.	Meena et. al., [7]
Row spacing of (60 x 30) cm	Performed best at this spacing interval in terms of growth and yield.	Alam [20]
Spacing of (60 x 15) cm,	Obtained highest yield (4.11 Mt/ha), leaf area index.	Gaire et. al., [17]
Spacing of (60 x 20) cm	Obtained higher harvest index, test weight, significantly highest grain yield (7.5 t/ha).	Rina et. al., [8] , Mahato et. al., [9]
Spacing of (60 x 25) cm	Obtained significant highest yield attributes and grain yield of 3.5 t/ha.	Koirala et. al., [21]
Spacing of (75 × 25) cm	Obtained highest stover yield of 31.29 t ha^{-1} and grain yield of 11.67 t ha^{-1}.	Kebede [16]
Spacing of (60 x 25) cm	Obtained the maximum grain yield (7431 kg/ha).	Nagarajan et. al., [19]
Intra row spacing of 45cm.	Significant result of plant height, total dry matter was recorded.	Sharifi and Namvar [11]
Spacing of (60 × 15) cm	Obtained better plant growth parameters like plant height, plant dry weight, grain yield and stover yield.	Devi and Ghosh [12]
Spacing of (60 x 25) cm	Increased the yield of grain.	Babu and Senthivel [15]
Intercropping maize with lentils in a ratio of 1:2	Produced highest cob length cob weight per plant. The choice of crop companions, ratio and the spacing significantly influence the overall yield.	Singh et. al. [13]

Rina et. al., [8] reported that the combination treatment of spacing 60 x 20 cm with 80 kg/ha P on PSB treated seeds obtained the best results with higher results namely in grain yield (5.22 ton/ha), harvest index (43.13%) and test weight (28.33 g). According to these findings it may be considered that offering strategies of spacing and nutrient management techniques like using of biofertilizers may improve the maize production system giving a major emphasis in sustainable agriculture.

Kebede [16] reported that the highest stover yield of 31.29 t ha^{-1} and grain yield of 11.67 t ha^{-1} was obtained in the combination of 75 cm × 25 cm in 20cm. Therefore, he concluded that optimum inter-row and intra-row spacing combination of 75 cm x 25 cm gives the highest grain yield for both varieties (BH-661 and BH-QPY-545) under sufficient amount and proper distribution of rainfall. According to his findings, knowing the appropriate agronomic practices is also a key factor to maximize maize production. Gaire et. al., [17] reported that maintaining a crop geometry effects on the grain yield of the crop. The highest grain yield (4.11 Mt/ha) can be achieved by maintaining a spacing of 60 x 15 cm. The LAI is also found to be higher in the 60 x 15 cm spacing.

In the same year (2020) Koirala et. al., revealed highest yield was recorded at 60 x 25 cm spacing practiced. After all the findings we can say that maintaining a row to row spacing of 60 cm is advisable in the cultivation of maize [21]. During the kharif season of 2018, Ezung and Jamir [18] conducted an experiment by practicing two different spacing patterns *i.e*., x 25 cm has significantly influenced the growth and yield of the crop. Nagarajan et. al., [19] revealed that the highest grain yield was achieved in 60 x 25 cm spacing.

3. EFFECT OF NUTRIENT MANAGEMENT ON GROWTH OF MAIZE

Maize is a heavy feeder and required a lot of nutrients for its physio-morphological growth. Plant requires various nutrients to be provided. According to Ariraman et. al., [22,39] application of nitrogen at a range of 150 to 200 kg/ha was the suitable dose for maize cultivation and resulting a better growth, yield and quality mainly protein content and fibre content. Hirpara et. al., (2017) revealed that 120 kg/ha of N and 60 kg/ha P resulted in highest plant height and in maize cultivation in South Saurastra region. Sabu et. al., [23] recorded that combined spraying of 75 kg/ha P + 40 kg/ha K as a basal treatment have produced most significant better results on various plant growth parameters like plant height (95.4 cm), number of leaves (10.83) and dry weight (77.33 g) over the other nutrient treatment in baby corn. Interaction effect of both the nutrients also significantly enhance the growth and yield attributing characters over the individual one fertilizer. Sakandiya and Sanodiya [24] resulted that treatment combination of 70 kg/ha P + 60 kg/ha K gave the maximum values of growth parameters, such as plant height, number of leaves, dry matter and crop growth rate over the nutrient treatment in maize cultivation. Khan et. al., [25] reported that growth attributes such as plant height, number of leaves per plant, dry weight and crop growth rate were recorded higher with 60 kg/ha P through DAP in sweet corn variety Sweety as compared with other levels of phosphorus during the kharif season.

Ezung and Jamir (2020) reported that the application of 100% recommended dose had a significant positive impact on the plant growth attributes of the maize like plant height at monthly intervals and leaf area index. Kumar and Mehera [26] concluded that the combined treatment of Azotobacter + KSB + Potassium @ 50 kg/ha gives highest values of growth and yield attributes namely, height of plant (222.6 cm) and crop growth rate (27.4 g/m^2/day). Similarly, by exploiting the combined effects of biofertilizers and organic fertilizer with conventional fertilizers [56]. Singh et. al., [27] recorded that the maximum growth was observed in application of 100% RDF than the treatment combination of azotobacter, vermicompost and NPK fertilizers. It was also statistically on par with treatment of 50% RDF + vermicompost +FYM + Azotobacter and treatment of 75% RDF + vermicompost. In a similar manner Dilshad et al [28;63] found that integrated use of NPK fertilizers and organic inputs namely FYM and biofertilizers can yield higher grain harvest as compared to their sole treatments, it was also concluded that integrated application of nutrients has more nutrient use efficiency and reduced ecological hazards as compared to using only mineral fertilizers in lesser fertile soil and rainfed conditions [45]. Similarly, Priya et. al., [29] concluded that the integrated use of recommended dose of NPK with poultry manure increase the grain yield of hybrid maize compared to the control treatment *i.e* without any nutrient application. Mahato et. al., [9] revealed that the significant highest values of growth parameters mainly plant height, leaf

area index and dry matter accumulation was found in application of vermicompost + 75% RDF + $ZnSO_4$. Singh et. al., [30] states that application of 150 kg/ha N and 30 kg/ha Zn resulted in higher values in growth and yield of maize. Kannan et al. [31] concluded that integrated use of inorganic fertilizers along with vermicompost at resulted in the best performance for maize growth parameters like leaf area, plant height, and yield parameters like number of grains per cob, 100-seed weight, and grain yield. The integrated nutrient management practice including vermicompost and the recommended dose of NPK also showed the highest organic carbon content, bulk density, and porosity in the soil compared to other treatments [38]. Thus, for enhancing maize productivity and improving soil fertility, integrated nutrient management can result in better yield and soil health.

4. EFFECT OF NUTRIENT MANAGEMENT ON YIELD OF MAIZE

Baby corns are small and immature corn cobs that are harvested before the kernels become mature and hardened. During the zaid season of 2021, Sabu et. al., performed an experiment to estimate the influence of phosphorous and potassium on the yield attributes of baby corn. It was concluded that application of 75 kg/ha P + 40 kg/ha K have performed better as compared to other treatments with yield and yield contributing characters like cob length (12.97 cm), cob weight (9.7 g), total yield (5214 kg/ha) and stover yield (20.18 t/ha). According to the findings of Gaire et. al., (2020), maize tends to show a significant increase in yield with applying of nitrogen levels @ 90 kg/ha and 120 ka/ha. Several yield attributes like length of cob, cob diameter, kernels per row and thousand grain weight was highest in application of nitrogen fertilizer at 90 kg/ha. Hirpara et. al. [57] concluded that application of 120 kg/ha of N resulted in highest plant growth, yield attributing characters and straw yield of maize.

Ponmozhi et. al., [32] resulted that the application of recommended dose of fertilizers, vermicompost, FYM, and zinc sulphate gives significantly higher impacts on dry matter accumulation, seed yield, straw yield and harvest index with the treatment combination of 100% RDF + 25% vermicompost + 25% FYM + 25 kg $ZnSO_4$. Similarly, Singh et. al., [27] found that the combined application of 75% RDF + 5 t/ha vermicompost + 5 t/ha FYM + Azotobacter contributes in maximum values of yield and yield attributes namely cobs per plant (2.11), cob length (19.2 cm), no. of grain/cob (399.7), no. of grain/row (28.5), shelling % (76.67%) seed index (30.45 g), grain yield (63.7 q/ha) and harvest index (29.58%). In an analogous manner to Ponmozhi et. al., (2019) by using combination of chemical fertilizers with vermicompost and micronutrients, Mahato et al., [9] estimated the impact of combined application of nutrient management on the plant growth of hybrid maize cultivation where highest values of yield parameters mainly grain yield of 9.04 t/ha and straw yield of 13.50 t/ha was found in treatment combination of vermicompost + 75% RDF + $ZnSO_4$.

Nsanzabaganwa et al., [33] stated that winter grown maize is a heavy feeder and lacks proper nutrient management practices. They studied the impacts of applying N and P fertilizers as sole treatments and as interactions in maize cultivation where highest yield and yield contributing characters mainly grain yield, stover yield, harvest index, total biomass index and 1000 grain weight recorded were at application of 240 kg/ha N and 26.4 kg/ha P. According to Khan et al., [25] yield attributes such as cob weight, grains per row, rows per cob, grains per cob and 100 grain weight were recorded maximum with application of 60 kg/ha Phosphorus applied as DAP in Sweety variety of sweet corn. Patil and Basavaraja [34] concluded that highest grain and stover yields can be achieved by application of 125% K through potassium schoenite. Sankadiya and Sanodiya [24] conducted a study on a sandy loam soil which have low N content and medium content of P and K. Various yield attributes like cob per plant, cob length, no. of row per cob, no. of grains per row, grains per cob, grain yield, stover yield, seed weight and harvest index was found in application of 70 kg/ha (Phosphorus) + 60 Kg/ha (Potassium) [40].

Hammad et. al., [35] experimented on the response of different levels of nitrogen on maize hybrids Syngenta 7720 and Muqabla S25W87. It was observed that highest N use efficiency was achieved in low N application, *i.e.*, 75 kg/ha and contrastingly highest grain yield, dry weight and grain protein content was observed in application of 300 kg/ha N. [43] Singh et. al., [27] evaluate the impact of planting date and foliar application ok KNO_3 on grainyield and yield contributing characters of spring maize. It was found that foliar application of 1% KNO_3 at development stage, specifically at tassel initiation enhanced the grain yield. Dadhich et. Al. [36,51] revealed that application of 60 kg/ha K and 45 kg/ha Mg has the highest grain and stover yield of 2690

Table 2. Effect of nutrient management on cultivation of maize as cereal and fodder

Nutrient Management Practice	Significance	References
Application of 300 N kg/ha	Obtained highest grain yield, dry weight and grain protein content.	Hammad et. al., [35]
The combined treatment of Azotobacter + KSB + Potassium @ 50 kg/ha	Obtained the significant values of growth and yield attributes namely, plant height and crop growth rate, cob yield, grain yield, stover yield, harvest index and test weight.	Kumar and Mehera [26]
Application of Vermicompost + 75% RDF + $ZnSO_4$	Remarkable results in plant height, LAI and dry matter content.	Mahato et al., [9]
Combined application of 75 kg/ha P + 40 kg/ha K as a basal treatment	Obtained significant better results on plant growth parameters.	Sabu et. al., [23]
Application of 70 kg/ha P + 60 kg/ha K	Obtained highest values of growth, such as plant height, number of leaves per plant, dry matter accumulation and crop growth rate.	Sakandiya and Sanodiya [24]
Application of 150 kg/ha N and 30 kg/ha Zn	Obtained higher values in growth and yield of maize.	Singh et. al., [30]
100% RDF + 25% vermicompost + 25% FYM + 25kg $ZnSO_4$	Significant results on dry matter accumulation, grain yield, stover yield and harvest index	Ponmozhi et al., [32]
Application of 60 kg/ha P through DAP	Obtained better growth attributes like height, foliage, dry weight and CGR	Khan et al., [25]
Application of 120 kg/ha N	Obtained significant values regarding cob characteristics, dry matter, grain yield and stover yield.	Hirpara et al., (2017) [57]
75% RDF + 5 t/ha vermicompost + 5 t/ha FYM + Azotobacter	Increases yield attributes namely cob/plant, cob length, no. of grain/cob, no. of grain/row, shelling %, seed index, grain yield and harvest index.	Singh et. al., [27]

kg/ha and 6592 kg/ha for K treatment and 2831 kg/ha and 7000 kg/ha for magnesium treatment.

Kumar and Mehera [26,42] concluded that combined treatment of Azotobacter + KSB + Potassium @ 50 kg/ha produced highest values of growth and yield attributes namely, plant height (222.6 cm), dry weight (229.5 g), crop growth rate (27.4 g/m^2/day), cob yield (1.6/plant), grain yield (7.97 t/ha), straw yield (11.5 t/ha), harvest index (40.91%) and 1000 seed weight (243.3 g). Similarly, Raghavendra et. al*.,* [37] concluded in his study that application of 50% recommended dose of K + KSB gives highest yield contributing characters in maize, *i.e*., length of cob, cob girth, cob weight and biological yield.

Nutrients may be applied through incorporation of organic compounds like compost, vermicompost, humic acid *etc*. By using vermicompost as a source of nitrogen, Ezung and Jamir [18] conducted an experiment on four different levels of vermicompost where it is found that application of 100% recommended dose gives a significant positive impact on the yield and yield attributes of the crop, like grains per cob, 1000 seed weight, grain yield and straw yield of maize.

5. CONCLUSION

In conclusion, the vital importance of management of plant distance and nutrient application in maize cultivation cannot be overstated. Through a review of numerous studies and experiments, it is evident that the choice of spacing configurations and optimal application of nutrients and have a crucial impact on the overall success in crop production. Maintaining proper spacing ensures that maize plants efficiently utilize essential resources such as sunlight, water, and nutrients which in turn, leads to better vegetative growth, root development, and a reduced risk of diseases and weed infestations. Overall, the findings emphasize the need to practice proper crop geometry and precise nutrient management practices to optimize maize cultivation, enhance crop performance, and ensure better quality harvests. These insights are valuable for farmers and agricultural practitioners seeking to enhance maize production and contribute to food security. Implementing the proper plant spacing and

nutrient application will increase the yield potential, resource efficiency and future sustainability [62].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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