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*Review article*

# AGRONOMIC RESPONSES OF MAIZE TO PLANT POPULATION AND NITROGEN AVAILABILITY-A REVIEW

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**ABSTRACT:** Maize is one of the most important versatile cereal crops grown in tropical and temperate regions of the world. India ranks fifth in area and third in production and productivity among cereal crops. Potentiality of maize crop for its growth and development can be fully exploited by adopting suitable agronomic practices such as optimum spacing, fertilizers, soil conditions, growing season and water availability. The major plant nutrients N, P and K limit the normal plant growth. Increasing the productivity per unit area through agronomic management is one of the important strategies to enhance the productivity of maize. Keeping this in view an attempt was made to review the work done on the effect of plant population and N level on yield and economics of maize under irrigated as well as no-till conditions. In maize, the effect of plant density and N management was well documented.

**Key words:** Maize, Yield attributes, Plant density, Nitrogen, Uptake.

## INTRODUCTION

Maize (*Zea mays* L) is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions and successful cultivation in diverse seasons and ecologies for various purposes. Globally, maize is known as “Queen” of cereals because it has the highest genetic yield potential among the cereals. It is cultivated on nearly 150 m ha in about 160 countries having wider diversity of soil, climate, biodiversity and management practices that contributes 36 % (782 m t) of the global grain production. In India, maize is the third most important food crops after rice and wheat. Currently it is cultivated in India in an area of 8.49 m ha with a production of 21.28 m t and productivity of 2507 kg $ha^{-1}$. In Andhra Pradesh, it is grown in an area of 7.86 lakh ha with a production of 4.15 m t [4]. In addition to staple food for human being and quality feed for animals, maize serves as a basic raw material as an ingredient to thousands of industrial products that includes starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries *etc*. In modern maize production systems, enhanced plant-to-plant variability often results from increased competition among individual plants at progressively higher plant densities for limiting resources such as N, incident photosynthetically active radiation (IPAR), and soil moisture. Past studies have often emphasized that stand uniformity is essential for high productivity levels, and that the increased plant-to-plant variability (determined and expressed using a variety of maize growth and developmental parameters) reduces per-unit-area maize grain yields (GYA) through reduced stress tolerance [99]. Therefore, at higher plant populations, resource availability must be adequate to help maintain uniform growth, development, and grain yield of adjacent plants in a maize canopy.

Among different essential nutrients, N is highly limiting in Indian soils that exerts a profound effect on plant growth and development owing to its metabolic and physiological needs. The beneficial effects of nitrogen on crop production are well documented. However, nitrogen mining by crops for optimum productivity widely vary on account of different agro-climates, soils, cultivars, management practices and other factors. Maize responds more favourably to plant densities because of higher LAI (leaf area index) at silking, which results in more interception of photosynthetically active radiation and have higher radiation use efficiency during grain filling. The yield potential of maize can be realised only when if it is grown with adequate fertilization and optimum plant population (88). The impact of plant density on yield of rice fallow maize has been studied extensively, as it varies with genotype, agronomic management practices, and location. The importance of plant and crop geometry of planting factors in deciding growth and yield of maize is well established.

**PERFORMANCE OF MAIZE UNDER DIFFERENT PLANT POPULATIONS Growth:**

Singh and Tajbaksh [89] conducted a field trial during *kharif* season on loamy sand soils of Ludhiana (Punjab) and found that dry matter accumulation was significantly the highest under plant population of 100000 plants $ha^{-1}$ (60 cm x 16.6 cm) than that of with 50000 plants $ha^{-1}$ (60 cm x 33.3 cm) or 75000 plants $ha^{-1}$ (60 cm x 22.2 cm). Sachan and Gangawar [69] from an experiment conducted during *kharif* at Kanpur observed that growth attributes of maize *viz*., plant height, stem girth and number of functional leaves were significantly higher with wider row spacing (60 cm) than with narrow row spacing (45 cm). Singh *et al.* [84] reported that dry matter production at 90 and 120 days after sowing (DAS) increased significantly with increase in population levels from 55556 plants $ha^{-1}$ to 111111 plants $ha^{-1}$ on silty loam soils of Faizabad (U P) during winter season.

Chandankar *et al*. [17] from an experiment conducted on clay soils of Akola reported increase in plant height of maize hybrid (Pro Agro 4640) with higher plant density (111111 plants $ha^{-1}$) than with lower planting density (83333 plants $ha^{-1}$). Similar findings were also reported by Andrade *et al*. [3] from Argentina on Argiudols. Singh and Singh [88] from their field study during rainy season observed significantly higher dry matter production $plant^{-1}$ with lower planting density of 66000 plants $ha^{-1}$ (60 cm x 25 cm) as compared to that with higher densities of 83000 plants $ha^{-1}$ (60 cm x 20 cm), 133333 plants $ha^{-1}$ (50 cm x 15 cm) and 166666 plants $ha^{-1}$ (50 cm x 12 cm) on clay loam soils of Udaipur (Rajasthan). Muniswamy *et al.* [49] reported that plant height, leaf area and stem girth of maize increased linearly with the increase in spacing from 60 cm x 10 cm to 60 cm x 20 cm during *kharif* season at Bangalore. Boomsma *et al*.[15] from their field study reported that plant height declined with increase in plant density from 54000 plants $ha^{-1}$ to 79000 plants $ha^{-1}$ or 109000 plants $ha^{-1}$ on silty clay loam soils of Indiana. Suryavanshi *et al*. [96] revealed that spacing of 60 cm x 30 cm was significantly superior to spacing of 60 cm x 20 cm in increasing the leaf area, and total dry matter production per plant of maize on clay soils of Parbhani (Maharashtra). Plant height, dry matter accumulation and per cent barrenness were increased with increase in planting densities and the highest values of these parameters were recorded at higher planting density of 133333 plants $ha^{-1}$ on clay loam soil and 100000 plants $ha^{-1}$ on sandy clam loam soils at Bapatla, respectively [44, 103].

## Yield Attributes and Yield:

Krishnamurthy *et al*. [31] observed more barrenness, less grain weight per cob, test weight and shelling percentage with increase in plant population of maize from 55000 plants $ha^{-1}$ (60 cm x 30 cm) to 83000 plants $ha^{-1}$ (60 cm x 20 cm) on red sandy loam soils of Bangalore. Barthakur *et al*. [9] conducted an experiment at Jorhat and observed that narrow inter-row spacing (50 cm) resulted higher yield than wider inter- row spacing (75 cm). Verma and Singh [104] reported that grain and stover yield of spring maize were significantly improved with the increase in plant density from 65000 plants $ha^{-1}$ to 85000 plants $ha^{-1}$ on sandy loam soils of Bichpuri, Agra.

Singh and Tajbaksh [89] recorded significantly higher cob length and test weight of maize at lower plant population of 50000 plants $ha^{-1}$ (60 cm x 33.3 cm) over 75000 plants $ha^{-1}$ (60 cm x 22.2 cm) and 100000 plants $ha^{-1}$ (60 cm x 16.6 cm) on loamy sand soils at Ludhiana. Reddy *et al*. [66] observed the highest test weight of maize with lower plant density of 59200 plants $ha^{-1}$ than higher density of 66600 plants $ha^{-1}$, 76200 plants $ha^{-1}$ and 88800 plants $ha^{-1}$ on sandy loam soils of Hyderabad. Sandhu and Mavi [71] also reported similar results from Ludhiana on loamy sand soil.

Babu and Mitra [5] reported that lower plant density of maize *i.e*. 33333 plants $ha^{-1}$ (50 cm x 60 cm) recorded higher number of grains $cob^{-1}$ and test weight than higher plant densities of 66666 plants $ha^{-1}$ (50 cm x 30 cm) and 99999 plants $ha^{-1}$ (50 cm x 20 cm), but significantly higher grain yield was found at higher plant density (99999 plants $ha^{-1}$) than at lower planting densities of 66666 plants $ha^{-1}$ and 33333 plants $ha^{-1}$ on sandy clay loam soils of Allahabad during *rabi* season. Similar findings of higher yields were also recorded by Sawhney *et al.* [74] at higher planting density with narrow row spacing (40 cm or 50 cm) at Ludhiana on loamy sand soil. Singh *et al*. [84] from Faizabad (U P) reported significantly higher number of grains $row^{-1}$, grains $cob^{-1}$, grain weight $cob^{-1}$, test weight and shelling percentage of maize at lower plant density of 55555 plants $ha^{-1}$ over higher plant density of 66666 plants $ha^{-1}$, 83333 plants $ha^{-1}$ and 111111 plants $ha^{-1}$ on silty loam soils. From an experiment conducted on clay loam soils of Banswara ( Rajasthan), Ameta and Dhakar [1] revealed that with each successive increase in plant population from 65000 plants $ha^{-1}$ to 95000 plants $ha^{-1}$ there was significant increase in the grain yield of maize during winter season. Emam [21] reported that grain yield of maize responded to higher planting densities up to 83000 plants $ha^{-1}$ and this was owing increase the rate of grain filling with no significant change in duration in grain filling period at Koushkak, Iran. Widdicombe and Thelen [106] found higher yields for corn grown in narrow rows versus wide conventional rows irrespective of hybrids and plant populations tested in Indiana and Michigan of USA. Similar results also reported by Andrade *et al*. [3] from Argentina on Argiudols.

Blumenthal *et al.* [14] reported from their field study at Nebraska, reported that kernel yields were maximised by 202 kg N $ha^{-1}$ with 27200 plants $ha^{-1}$ and population increased above 27200 plants $ha^{-1}$ resulted in inconsistent kernel yields. Planting of maize at 83333 plants $ha^{-1}$ resulted in significantly higher yield attributes *viz*., ear diameter, grain weight $plant^{-1}$, test weight and grains $ear^{-1}$ than at 111111 plants $ha^{-1}$ on clay loam soils of Akola [17]. Sharratt and McWilliams [80] from their two years of study at Morris found that corn row spacing did not influence grain yield in first year, but did affect yield in second year as corn grown in 38 cm rows produced 10 per cent more grain than corn grown in 76 cm rows. Harvest index was also not influenced significantly between narrow and conventional wider row spacings. Maddonni *et al.* [38] reported that an increase in plant population from 3 plants $m^{-2}$ to 9 plants $m^{-2}$, increased kernel number per cob and grain yield but reduced kernel weight on silty clay loam soils at Argentina. The results of the experiment conducted at Tirupati, by Ramu and Reddy [62] revealed that grain yield of maize increased significantly with increase in plant population from 55555 plants $ha^{-1}$ to 66666 plants $ha^{-1}$ , beyond which the increase in yield was not statistically significant.

Reddy *et al.* [66] conducted an experiment on clay loam soils at Warangal (A P) during *rabi* season and observed that sowing of maize under no- till condition at wider spacing of 60 cm x 25 cm (66666 plants $ha^{-1}$) resulted in significantly higher yield attributes (such as number of kernels $cob^{-1}$ and 100 kernel weight) and grain yield over the other two spacings tested, 50 cm x 25 cm (80000 plants $ha^{-1}$) and 40 cm x 25 cm (100000 plants $ha^{-1}$). Van Roekel and Coulter [102] from their three years of field study at Minnesota on silty clay loam soil reported the quadratic-plateau response of grain yield to plant density with kernel yield maximized at 81700 plants $ha^{-1}$. Yield attributes (cob length, number of kernels $cob^{-1}$, kernel weight $cob^{-1}$, and shelling percentage) were significantly higher at lower planting density but kernel (80.5 q $ha^{-1}$) and stover yields (100.8 q $ha^{-1}$) were significantly higher at 100000 plants $ha^{-1}$ than that recorded with 67000 plants $ha^{-1}$ under no-till conditions [103].

Monga and Gautam [46] reported that yield of maize increased with increased intra-row spacing and the highest grain yield was obtained under the treatment having 30.0 cm intra-row spacing, which was significantly superior to that of 22.5 and 15.0 cm intra-row spacings at IARI, New Delhi. Similar findings were also reported by Mali and Singh [40] from Udaipur, Tyagi *et al.* [100] from Hissar and Muniswamy *et al.* [49] from Bangalore.

### Nutrient Uptake

Misra *et al*. [45] found that N uptake increased with increase in plant population from 55000 plants $ha^{-1}$ to 98000 plants $ha^{-1}$ on sandy loam soils during winter at Bahraich (U P). Singh *et al*. [84] indicated that the uptake of N P and K was significantly higher when the crop grown at 83333 plants $ha^{-1}$ compared to the rest of the treatments (55555 plants $ha^{-1}$, 66666 plants $ha^{-1}$ and 111111 plants $ha^{-1}$) on silty loam soils of Faizabad (U P) during winter season. Mercy *et al*. [44] conducted an experiment and found that nitrogen uptake was more with lower planting density of 66666 plants $ha^{-1}$ than that with higher plant densities (88888 plants $ha^{-1}$ and 133333 plants $ha^{-1}$) on clay loam soils at Bapatla. Similar findings were also reported earlier by Shapiro and Wortmann, [77] from Nebraska on silty clay loam soils. In contrast, nutrient uptake was significantly superior with higher level of planting density (100000 plants $ha^{-1}$) than lower plant population (67000 and 80000 plants $ha^{-1}$) [103] on sandy clay loam soils of Bapatla.

## EFFECT OF NITROGEN ON MAIZE

### Growth:

Yadav *et al*. [107] observed significant increase in plant height and dry matter production of maize up to 180 kg N $ha^{-1}$. Further, they reported that silking period was also significantly advanced by 10 days under the highest level of nitrogen over no nitrogen application on sandy loam soils of Chindwara. Sharma [79] from his field experiment conducted at IARI, New Delhi, on sandy loam soil, reported a significant increase in the plant height and number of leaves $plant^{-1}$, with each successive increase in the level of fertilizers used. Similarly, Krishnaveni and Ramaswamy [32] from Coimbatore and Prasad *et al*. [59] from Pusa also reported that increase in maize growth with increasing levels of N application from 0 to 120 kg $ha^{-1}$ and 0 to 150 kg $ha^{-1}$, respectively. A few other researchers also reported significant response of maize to N application up to 120 kg $ha^{-1}$ on light soils [6, 47, 55, 68, 76, 105].

In contrast, on sandy loam soils, Nandal and Agarwal [50] reported significant maize growth response up to 200 kg N $ha^{-1}$ from Hissar, Kumar *et al*. [35] up to 175 kg N $ha^{-1}$ from Ludhiana, Singh *et al*. [91] up to 150 kg N $ha^{-1}$ from Hissar, Raju *et al*. [61] up to 135 kg N $ha^{-1}$ from Karimnagar and Padmaja *et al*. [53] up to 150 kg N $ha^{-1}$ from Bapatla. Singh *et al*. [85] reported that the plant height of maize in pure stand increased with application of 180 kg N $ha^{-1}$ than with 120 kg N $ha^{-1}$ and 60 kg N $ha^{-1}$ on silty clay-loam soils of Tadong, Sikkim. Similarly, biomass production increased with increasing N level was also reported by Nimje and Seth [51] and Nunes *et al*. [52].

From Panthnagar, Shivay and Singh [81] and Shivay *et al*. [83] reported increase in plant height and dry matter accumulation in maize with the application of 120 kg N $ha^{-1}$ compared to that at lower rates of application on silty clay loam soils. Singh *et al*. [93] from their field study at Varanasi on clay loam soils revealed that the plant height and dry matter production per plant were significantly increased up to 150 kg N $ha^{-1}$. Patel *et al.* [56] observed that the growth parameters like plant height, number of leaves $plant^{-1}$, stem girth, leaf area index and dry matter accumulation $plant^{-1}$ were significantly influenced by N levels, and all these parameters tended to increase with increasing levels of N from 75 to175 kg $ha^{-1}$ on Alfisols of Anand (Gujarat).

Tabu *et al*. [97] from their experiment in small holder farmers fields revealed that N fertilizer @ 60 kg $ha^{-1}$ significantly increased the plant height and number of leaves $plant^{-1}$ over the rest of N levels (0, 20 and 40 kg $ha^{-1}$). Suryavanshi *et al.* [94] revealed that application of 150 kg N $ha^{-1}$ was found significantly effective over 100 kg N $ha^{-1}$ and 50 kg N $ha^{-1}$ in increasing mean plant height, leaf area, and total dry matter $plant^{-1}$ of maize on Vertisols of Parbhani. The experiment conducted by Bharathi [10] and reported from Guntur (A P), that significantly the maximum plant height and dry matter production were observed in maize with the application of 225 kg N $ha^{-1}$ on clay soils. Lakshmi [37] and Venakata Rao [103] also reported the similar kind of response up to 240 kg N $ha^{-1}$ from Bapatla under rice- fallow zero tillage conditions on sandy clay loam soils. Regardless of soils and regions, a few researchers [29, 33, 41, 70, 86] reported increased growth parameters and decrease in the days to reach 50 per cent tasseling and silking with increasing rate of N application.

## Yield Attributes and Yield

Verma and Singh [104] from Agra and Dhillon *et al*. [19] from Ludhiana reported increase in yield attributing characters and grain yield with increase rate of N application up to 120 kg $ha^{-1}$ on sandy loam soils. Similar trend of increase in grain yield of maize up to 200 kg N $ha^{-1}$ was also noticed earlier by Guar and Mathur [25] at IARI, New Delhi. Panchanathan *et al*. [54] from Coimbatore, Prusty *et al*. [60] and Nimje and Seth [51] from IARI, New Delhi, Bangarwa *et al*. [6] from Hissar, Sharma *et al*. [79] and Walia *et al*. [105] from Ludhiana, Gaur *et al*. [24] from Udaipur, Shivay and Singh [81] from Panthnagar, Meena *et al.* [42] from Junagadh and Satyam *et al*. [73] from Hyderabd reported similar results.

From a field study conducted during winter seasons on sandy loam soils of Hissar, Nandal and Agarwal [50] reported a linear response of maize to nitrogen application up to 200 kg N $ha^{-1}$. The highest grain yield obtained with the application of 200 kg N $ha^{-1}$ was significantly higher than that of the rest of N levels (0 to 150 kg $ha^{-1}$). Singh *et al*. [87] from Dholi ( Bihar) and Singh *et al*. [91] from Hissar noticed similar response of increase in maize yield attributes and grain yield up to 150 kg N $ha^{-1}$ application on similar type of soils.

Results of an experiment conducted by Raju *et al.* [61] during *kharif* season on sandy loam soils at Karimnagar revealed that the yield attributes, grain and stover yields of maize increased significantly up to 90 kg N $ha^{-1}$ and 135 kg N $ha^{-1}$ under rainfed situation with low and high rainfall coupled with its even distribution during first and second season, respectively. Further, Tyagi *et al.* [100] reported an increase in grain yield of maize from 61 to 137 per cent with increased level of N application from 75 to 250 kg $ha^{-1}$ over that of no nitrogen on sandy loam soil at Hisar. Padmaja *et al*. [53] reported that the grain and stover yields were increased significantly with increase in the level of N from 0 to 150 kg $ha^{-1}$ on clay soils of Bapatla during *rabi* season. Similar trend of findings were also reported by Singh *et al*., [86], Mahmood *et al.* [39] and Suryavanshi *et al.* [95].

Singh and Totawat [92] reported from Udaipur, that more number of kernels $cob^{-1}$, kernel and stover yield with 100 per cent recommended dose (90 kg N $ha^{-1}$) of N over 50 per cent and 75 per cent of recommended dose of N on clay loam soils. From a field study conducted during *rabi* at Varanasi, Singh *et al.* [93] observed that application of N at 50 per cent higher (180 kg N $ha^{-1}$) over recommended level (120 kg N $ha^{-1}$) significantly enhanced the length of cob, girth of cob, number of grains $cob^{-1}$, grain weight $cob^{-1}$, test weight, grain and stover yields of maize than lower doses which was at par with that of 75 per cent higher (210 kg N $ha^{-1}$) over recommended dose (120 kg N $ha^{-1}$) on clay loam soils.

Results of the field experiments conducted at Dharwad during *kharif* and *rabi* seasons revealed that application of 200 per cent RDN (300 kg N $ha^{-1}$) recorded significantly higher grain yield of hybrid maize (DMH-2) and was on a par with that of 150 per cent RDN (225 kg N $ha^{-1}$) due to 'law of diminishing returns' [27]. Patel *et al*. [56] from their field study at Anand stated that application of 175 kg N $ha^{-1}$ being at par with 150 kg N $ha^{-1}$ produced significantly higher grain yield (5077 kg $ha^{-1}$) than the rest of N levels. The lowest grain yield (3796 kg $ha^{-1}$) was registered by 75 kg N $ha^{-1}$ on Alfisols during *rabi*. Singh *et al*. [90] from Amrutsar and Tank *et al*. [98] from Anand reported that maize recorded more cob length, grains $cob^{-1}$, test weight, grain and stover yield with the application of 140 kg N $ha^{-1}$ and 180 kg N $ha^{-1}$, respectively on sandy loam soils. Similar kind of improvement of maize yield attributes and yield also reported by some other researchers elsewhere [20, 23, 36, 62, 63] even up to 240 kg N $ha^{-1}$. Bharathi *et al*. [11] reported that on clay soils of Guntur, Andhra Pradesh increase in yield attributes, kernel and stover yield of *rabi* maize under no-till condition was up to 240 kg N $ha^{-1}$ application. Similarly, Lakshmi [37] and Venkata Rao [103] also reported same findings up to 240 kg N $ha^{-1}$ from Bapatla under rice - fallow zero tillage conditions on sandy clay loam soils.

Bundy *et al*. [16] from their long term N experiments on silt loam soil at Madison, WI and the data combined over 50 years, the kernel yields increased linearly by about 150 kg $ha^{-1}$ $year^{-1}$ in the medium (140 kg N $ha^{-1}$) and high (240 kg N $ha^{-1}$) long term N treatments while yields in the control long term treatment have remained relatively constant over time. Similar lines of findings were also reported by Jantalia and Halvorson [29] from Colorado and Meena *et al*. [43] from Udaipur on clay loam soil. Reddy *et al*. [67] from Warangal observed that application of 180 kg N $ha^{-1}$ was found to be optimum for getting higher yields of maize under zero tillage conditions in rice fallows on sandy clay loam soil.

**Nutrient Uptake:**

Prasad *et al*. [59] from their experiment observed higher nutrient uptake with increase in levels of N application from 0 to 150 kg ha$^{-1}$ on calcareous sandy loam soil at Pusa. A field study conducted on maize and the data revealed that uptake of N at harvest was significantly increased with increasing N levels up to 120 kg N ha$^{-1}$ only resulting in the highest N uptake than 0, 60 and 180 kg N ha$^{-1}$ on black clay loam soils at Hyderabad [48] and clay soils of Junagadh [42], respectively.

Nitrogen uptake by grain and stover of 'Ganga 5' maize significantly increased with increasing level of N from 0 to 100 kg ha$^{-1}$ on clay loam soils of Pune [57]. Singh *et al*. [87] reported that nitrogen uptake by winter maize significantly increased with successive increment of N levels from 50 kg ha$^{-1}$ to 150 kg ha$^{-1}$ on sandy loam soils of Dholi, Bihar. Bhaskaran *et al*. [12] also reported a positive trend in NPK uptake with increase in N application at all growth stages of maize. Gaur *et al*. [24] from Udaipur and Shivay *et al.* (82) from Pantnagar also reported similar findings. Misra *et al*. [45] stated that protein content in grain and N uptake were higher under 200 kg N ha$^{-1}$ compared to that under with lower levels of N due to higher yield attributes recorded with 200 kg N ha$^{-1}$ on sandy loam soils of Bahraich, Uttar Pradesh. Selvaraju and Iruthayaraju [75] from their field experiment on clay loam soils of Coimbatore noticed an increase in N, P and K uptake with increased level of N application from 75 to 175 kg ha$^{-1}$, irrespective of the season.

Field experiments conducted on a clay loam soil at Bapatla, indicated the increment of added N had a distinct and significant effect on the uptake of N by grain and stover over the lower levels. The highest level of N (150 kg ha$^{-1}$) resulted in significantly the maximum uptake of N by the maize crop. Nitrogen application at this rate also increased P and K uptake by both the grain and stover [53]. Shivay and Singh [81] from their field study on silty clay loam of Pantnagar (Tarai) reported significant increase in N uptake with each successive increase in level of N application from 0 to 120 kg ha$^{-1}$. Similar results were also reported earlier by Vadivel *et al.*, [101] from Coimbatore on sandy clay loam soils; Singh and Totawat [92] from Rajastan on clay soils and Kumar and Singh [34] from Nagaland. Ananthi *et al.* [2] from their study at Coimbatore on sandy loam soils during *kharif* season reported that uptake of N and P increased with increase in N level from 150 to 200 kg ha$^{-1}$ and phosphorus from 75 to 100 kg $P_2O_5$ ha$^{-1}$. A few researchers [28, 30, 58] reported earlier an increase in nutrient uptake by maize with increasing level of N application.

Bharathi *et al*. [11] from Guntur; Lakshmi [37], Mercy *et al*. [44] and Venkata Rao [103] from Bapatla reported that increase of nitrogen at each incremental level had significant influence on nutrient uptake was recorded with higher level of N 240 kg ha$^{-1}$. Reddy *et al*. [67] from Warangal on sandy clay loam soil observed that application of 240 kg N ha$^{-1}$ resulted in significantly higher nitrogen uptake (kernel or stover or total) compared to lower doses of 120 and 180 kg ha$^{-1}$ under zero tillage conditions in rice fallows. Ciampitti *et al*. [18] reported a tight association between plant density and N rate on uptake of N P K was documented at Indiana.

**Response of maize to nitrogen levels under different planting densities:**

Krishnamurthy *et al.* [31] noticed that increase in N level from 100 to 200 kg ha$^{-1}$ and plant population level from 55000 plants ha$^{-1}$ to 83000 plants ha$^{-1}$ had no significant effect in increasing the grain yield of *kharif* maize and they opined that application of 100 kg N ha$^{-1}$ with 55000 plants ha$^{-1}$ was the optimum to achieve good yields on red sandy loam soils of Bangalore. Bangarwa *et al.* [6] reported the maximum grain yield of *rabi* maize with the application of 180 kg N ha$^{-1}$ in three splits (¼ + ½ + ¼) under plant density of 90000 plants ha$^{-1}$on sandy loam soils of Hisar. Misra *et al.* [45] reported from an experiment conducted at Bahraich (UP) during *rabi* revealed that irrespective of nitrogen levels (100 to 200 kg N ha$^{-1}$), grain yield of maize var. 'Deccan-103' was markedly increased with plant density up to 98000 plants ha$^{-1}$ and arrived at an optimum combination of 98000 plants ha$^{-1}$ and 200 kg N ha$^{-1}$. Kumar and Bangarwa [36] recorded the maximum grain yield of winter maize from the planting density of 110000 plants ha$^{-1}$ combined with 240 kg N ha$^{-1}$ on sandy loams of Hissar. From a field experiment conducted at Hissar, Tyagi *et al.* [100] recorded the highest grain yield of spring maize from a combination of 88888 plants ha$^{-1}$ fertilized with application of 225 kg N ha$^{-1}$ on sandy loam soils.

Ameta and Dhakar [1] reported that increasing the nitrogen dose beyond 120 kg ha$^{-1}$ was not significant with lower plant populations of maize (65000 plants ha$^{-1}$ and 75000 plants ha$^{-1}$) whereas, with higher plant populations (85000 plants ha$^{-1}$ and 95000 plants ha$^{-1}$) a significant response up to 150 kg N ha$^{-1}$ was noticed in respect of grain and stover yields on clay loam soils at Banwara, Rajastan during *rabi.* Barbieri *et al*. [7] from their field study at Argentina on Typic Argiudoll soil and recorded the maximum kernel number and grain yield of no-till maize under narrow rows (0.35 m) with combination of N (140 kg ha$^{-1}$). Farnham [22] from Iowa reported that there were significant plant density and row spacing effects on grain yields. Average grain yields were greater for 76 cm row spacings (10.5 Mg ha$^{-1}$) than for 38 cm row spacings (10.3 Mg ha$^{-1}$) across plant densities. Widdicombe and Thelen [106] conducted an experiment on clay loam soils at Saginaw and the results showed that corn grain yield increased 2 and 4 % when row width was narrowed from 76 cm to 56 cm and 38 cm, respectively and the highest grain yield obtained with plant density of 90000 plants ha$^{-1}$.

Sankaran *et al.* [72] from TNAU, Coimbatore obtained the maximum productivity of maize with application of 150 per cent of recommended dose of N (203 kg $ha^{-1}$) at recommended plant population of 83333 plants $ha^{-1}$on sandy loam soils under irrigated conditions. Barbieri *et al*. [8] conducted a field study at Argentina on loam soil and the higher kernel yield was recorded with application of 180 kg N $ha^{-1}$over the rest of N levels (0 and 90 kg $ha^{-1}$) with combination of row spacing 52 cm. Boomsma *et al*. [15] found that the maximum kernel yields of corn were recorded with a plant density of 79000 plants $ha^{-1}$ and 165 kg N $ha^{-1}$ on silty clay loam soils at Indiana. From the investigations conducted by Venaka Rao [103] at Bapatla on sandy clay loam soils and found that adoption of higher level of planting density (80000 plants $ha^{-1}$) with application of 240 kg N $ha^{-1}$ under zero tillage conditions was found to be optimum for getting higher yields. Bisht *et al.* [13] from Panthnagar reported that similar response up to 100000 plants $ha^{-1}$ on sandy loam soil.

## Economics

The highest net profit (Rs. 4916/-) was obtained with a plant population of 90000 plants $ha^{-1}$ with application of 180 kg N $ha^{-1}$ [6]. Ameta and Dhakur [1] reported higher monetory return and B:C ratio of maize with narrow row spacing (60 cm) when compared to wider row spacing (75 cm). Chandankar *et al*. [17] observed that cultivating maize at 60 cm x20 cm spacing resulted in higher net return and BCR (Rs. 19, 268 $ha^{-1}$ and 2.62). Sankaran *et al.* [72] opined that enhancement in fertilizer application to the tune of 25-50 per cent above the recommended level increased the gross, net and B:C ratio. Application of 150 per cent recommended dose of fertilizer with a plant population of 83333 plants $ha^{-1}$ is suggested for obtaining the maximum productivity and B:C ratio under irrigated condition. Raskar *et al.* [64] from Vadodara reported the highest BCR with the application of 160 kg N $ha^{-1}$ than lower levels of N (80 and 120 kg $ha^{-1}$) on sandy loam soil.

From the foregoing review, information pertaining to plant population and N requirement of maize varies widely. In maize, the effect of plant population and N levels is well documented. Summarizing the review undertaken, it is understood that the sustainable productivity of maize could be achieved though maintenance of optimum plant population and high N levels. In this context, the present review would show the way to improve the productivity of maize in order to get more net returns

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