Maize Journal (April 2023) 12(1): 45-51

RESEARCH PAPER

Influence of planting density and nitrogen management on growth and productivity of maize in eastern India

Indrani Saha[1,2,3] · S. L. Jat[2] · Preeti Singh[1] · Smruti Ranjan Padhan[3] · Radheshyam[3] · Abhijit Mandal[3] · Ramniwas[2] · Manish Karkraliya[2]

Abstract: A field experiment was conducted during *kharif* 2022 for exploring the effect of planting density and N management on hybrid maize (*Zea mays* L.) in eastern India at the experimental farm of ICAR-Indian Agricultural Research Institute, Gauria Karma, Jharkhand. The treatments comprised of three planting densities *viz*., 67.5 cm × 20 cm (D_1), 67.5 cm x 22 cm (D_2) and 67.5 cm × 25 cm (D_3) in main-plots and five nitrogen management practices *viz*., control, farmers practices (FP), RDN-conventional, 75 per cent RDN-SSB (sub-surface band placement) and RDN-SSB in sub-plots and replicated thrice. The results of the study indicated that the growth parameters, *viz* plant height, leaf area index (LAI), dry matter accumulation and net assimilation rate was significantly higher at D_1. However, crop growth rate, relative growth rate and net assimilation rate was obtained highest in D_2 and D_3, respectively. Similarly, these growth parameters were enhanced by RDN-SSB. However, significantly higher grain yield was obtained with D_2 with RDN-SSB. Further, statistically at par growth parameters as well as grain yield was obtained under RDN-conventional and 75 per cent RDN-SSB which shows that saving of 25 per cent N could be achieved through sub-surface band placement. It was concluded that of growing of maize with 67.5 cm × 22 cm spacing and fertilization with recommended dose of N as sub-surface band placement is recommended for yield maximization and saving of 25 per cent N can be achieved with sub surface band placement without any yield penalty and benefit-cost ratio is also higher at 67.5 cm × 22 cm in Eastern region of India.

Keywords: Dry matter accumulation · Nitrogen saving · Planting density · Sub surface band placement · Maize

✉ S. L. Jat: sliari2016@gmail.com

[1]ICAR-Indian Agricultural Research Institute, Gauria Karma, Jharkhand, India

[2]ICAR-Indian Institute of Maize Research, Delhi Unit, Pusa Campus, New Delhi, India

[3]Post Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, India

Received: 02 January 2023/ Accepted: 27 March 2023

Introduction

Maize (*Zea mays* L.) being one of the most adaptable crops, has a wide range of adaptation under the various agro-climatic situations worldwide. Maize is referred to as the "queen of cereals" internationally due to the highest yield potential among all the cereals. It was grown in 202 m ha worldwide with production of 1162 mt with a productivity of 5.8 t/ha (FAOSTAT, 2022). In India during 2020-21, 9.9 m ha of maize were cultivated and producing 30 mt of maize with a productivity of over 3 t/ha despite the challenging *kharif* season environment over 82 per cent of the land. Due to its competitive advantage over C_3 plants as a C_4 plant, maize has an advantage over other crops in terms of the scenario of climate change and the sustainability of natural resources (Dass *et al*., 2012; Padhan *et al*., 2023). Poultry feed, which accounts for 47 per cent of all maize consumption and has increased over the past five years with a CAGR of 11 per cent (FICCI, 2022) is the most significant usage and demand driver of maize. The eastern India, specifically known for higher winter maize productivity whereas the productivity during the *kharif* season is below the national average despite grown under good agro-climatic conditions with adequate rainfall. The inappropriate adoption of crop management practices specifically planting density, nutrient and weed management leads to lower maize productivity in this region during *kharif* season.

Agro techniques *viz.*, Planting density and nutrient management are particularly important for boosting of the maize yield. The selection of inappropriate cultivars and inadequate plant population in the field are two of the major factors that contribute to low crop production (Yao *et al.*, 2016 and Battaglia *et al.*, 2019). The contribution of nitrogen, phosphate, and potassium fertilisers are between 40 and 45 per cent (Khan *et al.*, 2014), and their use must be optimised to increase the production of the maize crop by improved placement methods. The split application of nitrogen fertilizer was a best practise because it's minimised the losses and led to greater dry matter formation and plant development compare than solitary application (Harikrishna *et al.*, 2005). When nitrogen was applied at low rates, maize grain output decreased by 43–74 per cent and the number of grains per plant increased by 33–65 per cent (Andrea *et al.*, 2006). The point placement of the N in maize has increased the yield and nutrient use efficacy significantly (Nayak *et al.*, 2022).

The planting density x nitrogen management optimization is required in maize in order to reduce bareness under high density environment and to increase per plant yield under lower planting densities. Hence, a study was planned with a hypothesis that planting density or nitrogen placement alone cannot optimize maize productivity but their synergistic or antagonistic effect need to accounted for yield maximization with lower environmental footprints.

Materials and methods

An experiment was conducted during *kharif* 2022 at the Gauria Karma experimental farm of the ICAR-Indian Agricultural Research Institute, Jharkhand (24.2852°N, 85.360E and 228.6 m above the mean sea level) under irrigated conditions. The rainfall was unevenly distributed and most of it is received between July and September. The experiment was laid out in split plot with treatments consisted of three planting densities; 67.5 cm × 20 cm (D_1), 67.5 cm × 22 cm (D_2) and 67.5 cm × 25 cm (D_3) were in the main-plots and five nitrogen management practices *viz.*, control, farmers practices (FP), RDN-conventional, 75 per cent RDN-SSB and RDN-SSB in sub-plot and replicated thrice. In farmers practice, 124.3:24.8:0 while in RDN, 150:26.2:33.2 kg NPK/ha was applied in our study. The sources used for applying N, P and K were urea, single super phosphate, di-ammonium phosphate (adjusted for its N content) and muriate of potash, respectively. Fertilizer application was made as per the treatment. Full dose of phosphorus and potassium and 1/3rd or 30 per cent N dose were applied at the time of sowing by drilling fertilizer in crop rows at ~4-5 cm below the seeding depth. The remaining N was given in two equal splits in farmers practice and RDN-conventional at knee high and tassel initiation stages as top dressing. In the SSB treatment, the N split at knee high stage was band placed along the crop rows by opening furrows with hand plough and the third split was applied at tassel initiation stages as top dressing. The maize hybrid CP 858 was used in our study. At harvest, the plants were counted from net plot area and expressed in thousands/ha as final plant stand. The plant height obtained from five tagged plants were averaged from each experimental unit. Three plants were randomly sampled at different growth stages (30, 60 and 90 DAS) from each experimental unit from designated rows outside net plot area (not from border) and samples were sun-dried and then oven-dried at 65°C for 72 hr and dry weight was recorded using electronic balance. The above-ground dry matter was averaged to get dry matter accumulation as g/plant and then converted to per square meter. Leaf area index was computed with formula given by Watson (1947) as follows:

$$\text{Leaf area index} = \frac{\text{Leaf area per plant (sq.cm)}}{\text{Ground area per plant (sq.cm)}}$$

The crop growth rate (CGR) was worked out at 30 days interval on the basis of dry matter accumulation at 30, 60 and 90 DAS and at harvest by using following equation:

$$\text{CGR (g/plant/day)} = \frac{W_2 - W_1}{T_2 - T_1}$$

Where, W_1: dry weight at first stage (g), W_2: dry weight at second stage (g), T_1: Days at first stage, T_2: Days at second stage

The relative growth rate (RGR) was calculated from the measurements taken at time T_1 & T_2 at 30 days interval. The RGR value was calculated by using following equation:

$$RGR\ (mg/g/day) = \frac{LogeW_2 - LogeW_1}{T_2 - T_1}$$

Similarly, the net assimilation rate (g/cm^2 leaf area/ day) was calculated by using the following formula:

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{LogeL_2 - LogeL_1}{L_2 - L_1}$$

Where, L_1 and L_2 are leaf area at stage 1 and 2, respectively.

Data were statistically analysed using the analysis of variance technique applicable to the split-plot design. The significance of the treatment effect was determined using F-test; the means of the treatments compared using the least significant difference (LSD) at 5% probability level.

Results and discussion

Growth parameters

There was a consistent increase in plant height up to 60 DAS, after that the rate of increase in plant height was marginal. Plant height was significantly higher in D_1 by 4.5 per cent over D_2 at 60 DAS and D1 is on par with D2 at 30 and 90 DAS and higher by 7.4, 7.8 and 7.7 per cent over D_3 at 30, 60 and 90 DAS, respectively (Table 1). The lowest plant height was recorded with D_3 at all crop growth stages. When plants are more densely spaced, more auxin is secreted in the shaded areas due to shading (Alene *et al.,* 2000; Kumar *et al*., 2012). On the other hand, it prevents the degradation of auxin and grows higher due to the increased concentration. However, the N-management practices have significant effect on plant height and the treatment RDN-SSB had statistically higher plant stand in our field experiment. The significantly lowest plant stand was recorded at harvest with control treatment. The plant height at 90 DAS was increased by 3.5, 6.6, 4.6 and 8.0 per cent with farmers practice, RDN-conventional, 75 per cent RDN-SSB and RDN-SSB, respectively over control. The better availability of N under SSB increased chlorophyll content, which increased the rate of photosynthesis and extension of stem resulting in increased plant height.

Similarly, the planting densities and nitrogen management practices have significant effect on the leaf area index (LAI) of maize at various growth stages. The

Table 1. Effect of different planting density and nitrogen management practices on the plant height and leaf area index at various growth stages of *kharif* maize

Treatments	Plant height (cm)			Leaf area index		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Planting density (plants'000/ha)						
D_1: 74 (67.5 cm × 20.0 cm)	90.1	212.2	215.1	2.21	4.80	4.60
D_2: 67 (67.5 cm × 22.0 cm)	89.4	203.1	205.5	1.75	4.36	4.09
D_3: 59 (67.5 cm × 25.0 cm)	83.9	196.8	199.7	1.42	3.67	3.26
SEm ±	0.90	1.93	2.48	0.014	0.032	0.041
LSD (p=0.05)	3.52	7.57	9.73	0.054	0.127	0.162
Nitrogen management (T or N)						
N_1: Control	76.7	192.5	197.8	1.35	2.81	2.50
N_2: Farmers practice	83.3	202.3	204.7	1.66	4.14	3.83
N_3: RDN-Conventional	92.7	208.7	210.9	1.98	4.73	4.42
N_4: 75% RDN-SSB	90.6	204.4	206.8	1.90	4.66	4.37
N_5-RDN-SSB	96.6	212.1	213.6	2.08	5.06	4.80
SEm ±	1.96	4.38	3.56	0.039	0.096	0.093
LSD (p=0.05)	5.71	12.79	10.40	0.115	0.280	0.272
Interaction						
SEm±	3.386	7.59	6.17	0.068	0.166	0.162
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

* Control: only P and K, Farmers practice: 124.3:24.8:0; RDN: 150:26.2:33.2 kg NPK/ha; DAS: days after sowing, SSB; Sub-surface band placement.

leaf area index was higher (4.60) with D_1 at 30, 60 & 90 DAS. The increase in LAI with increase in plant density may be due to a greater number of plants per unit area. Similar observation was also made by Muniswamy *et al*. (2007); Suryavanshi *et al*. (2008) and Kumar *et al*. (2012). Amongst the N management practices, significantly higher LAI was recorded in RDN-SSB which was found to be at par with RDN-conventional whereas it was significantly higher over the Farmers practice (Table 1). In case of RDN-SSB treatment, it is 92 per cent higher over the control treatment at 90 DAS. This might be due to higher nitrogen content stimulates protein synthesis, which in turn improves vegetative growth and increases photosynthetic surface area, resulting in longer and wider leaves. The plant height as well as in RDN-conventional and 75 per cent RDN-SSB was found to be statistically similar which reflects that similar key growth parameters can be achieved in maize with a saving of 25 per cent N by band placement of N to achieve that of conventional one. This could be due to the higher losses of N through N-volatilization in surface application in case of RDN-conventional whereas better N placement in 75 per cent RDN-SSB improved soil N availability and provided adequate available N throughout the growing season, resulting in favourable increases in plant height, girth, leaf area and finally dry matter accumulation (Biradar *et al.*, 2013; Sinha, 2016; Nayak *et al*., 2022).

Due to changes in plant density, dry matter accumulation (DMA) of maize exhibited considerable variation at the 30, 60, and 90 DAS developmental stages. The DMA/m^2 was significantly higher in D_1 by 21.3, 17.8, 24.7 and 11.6 per cent over D_3 at 30, 60, 90 and at harvest whereas it was at par with D_1 (Table 2). The increased plant population might have led in enhanced DMA per unit area in our study (Figure 1). The more space plant with increased LAI/plant could be primarily responsible for the higher dry matter production due to higher availability of the resources (sunlight, water, nutrient, space, etc.) (Valadabadi *et al*., 2010; Siamak *et al*., 2014).

The N management practices significantly affected the DMA at all growth stages except at 30 DAS and significantly higher DMA either per plant or per m^2 was recorded in RDN-SSB at 60, 90 DAS, and at harvest as compared to other practices. At harvest, the RDN-SSB increased the DMA in maize by 30.9, 56, 49 and 77.3 per cent over the control, Farmers practice, RDN-conventional and 75 per cent RDN-SSB, respectively. The DMA by RDN-conventional and 75 per cent RDN-

Table 2. Effect of planting densities and nitrogen management practices on dry matter accumulation of *kharif* maize at various growth stages

Treatments	Dry matter accumulation (g/m^2)				Grain yield
	30 DAS	60 DAS	90 DAS	At harvest	(kg/ha)
Planting density (plants'000/ha)					
D_1: 74 (67.5 cm × 20.0 cm)	217.2	497.2	1327.0	1798.1	7508
D_2: 67 (67.5 cm × 22.0 cm)	215.1	492.0	1244.2	1802.2	8331
D_3: 59 (67.5 cm × 25.0 cm)	179.1	422.0	1064.4	1611.6	6290
SEm ±	3.37	5.70	14.11	18.21	68.0
LSD (p=0.05)	13.24	22.38	55.40	71.50	267
Nitrogen management					
N_1: Control	191.3	436.5	1071.6	1217.9	3667
N_2: Farmers practice	201.3	459.0	1152.3	1594.3	7030
N_3: RDN-Conventional	208.1	482.9	1262.9	1900.0	8163
N_4: 75% RDN-SSB	203.2	477.7	1242.7	1814.5	8091
N_5: RDN-SSB	215.2	495.8	1329.8	2159.9	9931
SEm ±	5.42	10.70	27.64	38.48	174.1
LSD (p=0.05)	NS	31.23	80.66	112.32	508.0
Interaction					
SEm±	9.39	18.53	47.87	66.65	301.5
LSD (p=0.05)	NS	NS	NS	NS	879.9

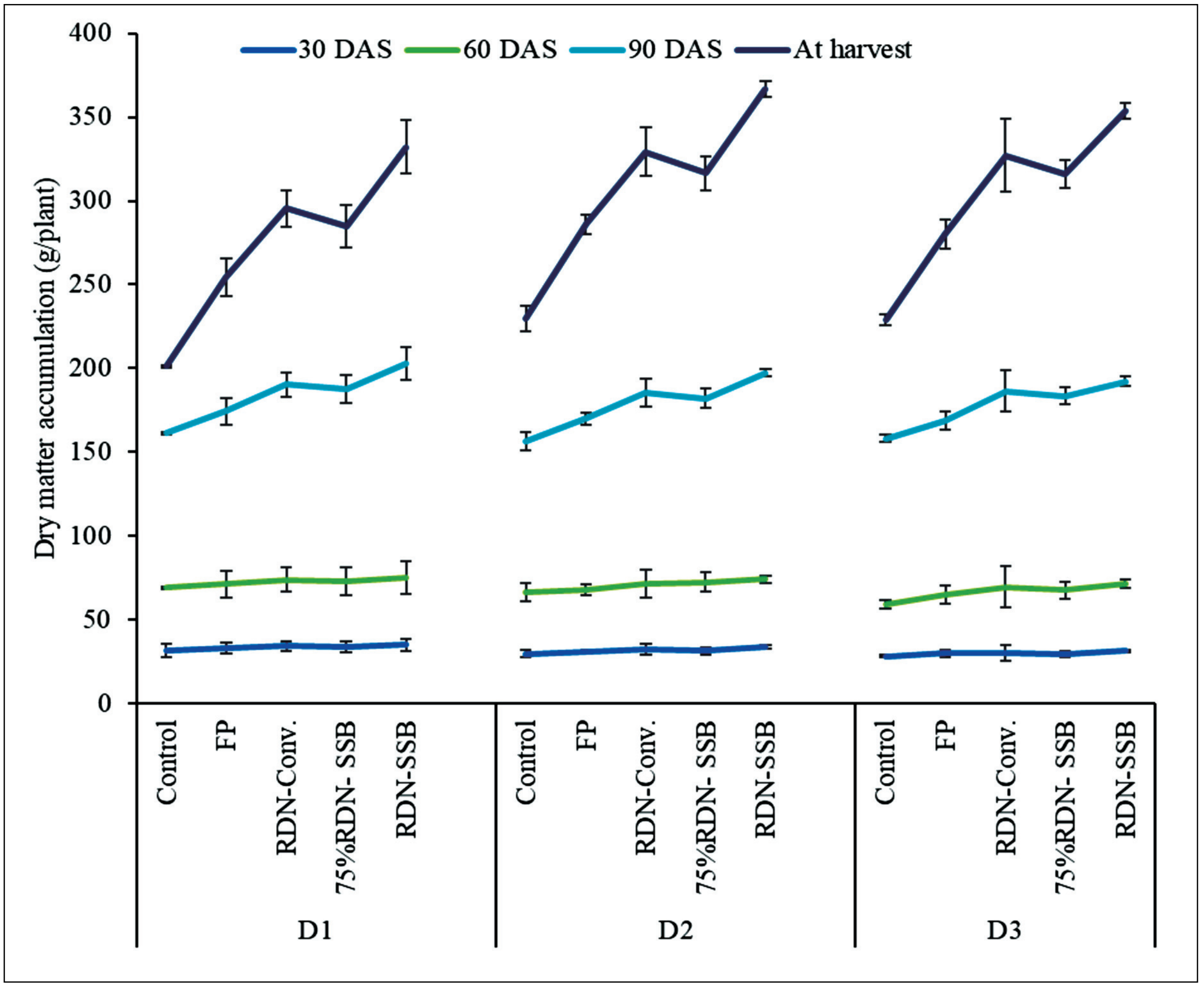

Figure 1. Interaction effect of plant densities and nitrogen management practices on the dry matter accumulation of *kharif* maize at various growth stages. The vertical bars represent the standard error (N=3). [D_1: 7.4 (67.5 cm × 20.0 cm); D_2: 6.7 (67.5 cm × 22.0 cm); D_3: 5.9 (67.5 cm × 25.0 cm); FP: Farmers practice: 124.3:24.8:0; RDN conv. (conventional): 150:26.2:33.2 kg NPK/ha; DAS: days after sowing; SSB: Sub-surface band placement)]

SSB in all the stages were statistically at par which indicates possibilities of the 25 per cent N saving through sub-surface placement. However, interaction effects between plant density and N management practices were found non-significant for all the growth parameters studied at various growth stages in our study.

Grain yield

The grain yield of the maize was significantly affected by density and N management methods and their interaction in our study. Compared to the wide spacing (67.5 cm × 25 cm) and closer spacing (67.5 cm × 20 cm), the yield performance at 67.5 cm × 22 cm spacing was primarily higher due to better optimization of space above and below ground leading to improved availability of resources such as sunshine, air movement, and nutrient availability. The grain yield at D_2 and D_1 increased by 32.4 per cent and 19.4, respectively over control. Similarly, the RDN-SSB the grain yield of maize by 170.8, 41.3, 21.7 and 22.7 per cent over control, Farmers practice, RDN-conventional and 75 per cent RDN-SSB, respectively (Table 2). The grain yield obtained by RDN-conventional and 75 per cent RDN-SSB was found to be statistically at par which indicates the possibility of 25 per cent N saving through sub-surface placement of the first conventional top dressing without any yield penalty. The maximum grain yield was realized under D2+RDN-SSB interaction which was at par with D1+RDN-SSB. The increased growth parameters of maize under RDN-SSB as well as better growth parameters with increased plant stand resulted in higher yield of maize under these treatment in our study. The increased yield due to better N placement in maize was also recorded by Nayat *et al*. (2022).

Physiological indices

Planting density of D_1 recorded significantly highest crop growth rate (CGR) followed by D_2 and D_3 at all crop growth stages except 60-90 DAS (Table 3). The rate of CGR increased till 60-90 DAS and afterwards it decreased and in RGR D1 recorded higher followed by D_2 and D_3 in our study. Planting density D_2had the highest RGR and NAR at 60-90 DAS. Generally, increased planting density had negative effects on CGR, NAR and RGR in our experimentation. The decrease in CGR, RGR and NAR with increasing planting density may be due the decrease in light interception and LAI at low than at high plant density.

However, CGR was significantly influenced by N management practices at all the stages except during early stage of sowing-30 DAS. The RDN-SSB recorded significantly highest CGR which was at par with RDN-conventional and 75 per cent RDN-SSB at 90 DAS-harvest. The RGR was significantly influenced by N management practices at 60-90 DAS. Similarly, NAR was significantly affected by N management only at 60-

Table 3. Interaction effect of planting density and nitrogen management on the maize grain yield (kg/ha)

Nitrogen management	D_1: 7.4 (67.5 cm × 20.0 cm)	D_2: 6.7 (67.5 cm × 22.0 cm)	D_3: 5.9 (67.5 cm × 25.0 cm)	Mean
Control	3222	4264	3514	3667
Farmers practice	7085	7229	6776	7030
RDN-Conventional	8210	9369	6910	8163
75% RDN-SSB	8094	9288	6891	8091
RDN-SSB	10928	11506	7359	9931
Mean	7508	8331	6290	7377
SEm ±	301.5			
LSD (p=0.05)	879.9			

Table 4. Effect of different planting densities and nitrogen placement practices on the physiological indices at various growth stages of the *kharif* maize

Treatments	CGR (g/m²/day)				RGR (mg/g/day)			NAR (g/cm² leaf area/day)	
	0-30 DAS	30-60 DAS	60-90 DAS	90 DAS-harvest	30-60 DAS	60-90 DAS	90 DAS-harvest	30-60 DAS	60-90 DAS
Planting density									
D_1: 7.4 (67.5 cm × 20.0 cm)	8.29	8.38	24.29	22.13	23.25	29.86	13.96	0.12	0.29
D_2: 6.7 (67.5 cm × 22.0 cm)	7.14	7.41	23.29	25.39	23.71	31.67	16.76	0.10	0.26
D_3: 5.9 (67.5 cm × 25.0 cm)	5.90	6.58	20.91	23.15	24.88	32.79	17.20	0.09	0.25
SEm±	0.16	0.14	0.86	0.37	0.65	0.67	0.48	0.00	0.01
LSD (p=0.05)	0.61	0.55	NS	1.47	NS	NS	1.88	NS	NS
Nitrogen management									
Control	6.73	6.02	18.30	11.68	21.31	29.86	10.80	0.10	0.25
Farmers practice	7.02	7.03	21.08	20.80	23.18	30.67	15.62	0.09	0.25
RDN-Conventional	7.18	7.99	24.37	27.13	25.08	32.01	17.51	0.11	0.27
75% RDN-SSB	7.05	7.84	23.62	25.15	25.13	31.79	16.80	0.11	0.25
RDN-SSB	7.58	8.39	26.79	33.03	25.04	32.87	19.13	0.12	0.31
SEm±	0.20	0.37	0.91	1.46	1.18	0.98	0.93	0.01	0.01
LSD (p=0.05)	NS	1.09	2.66	4.27	NS	NS	2.73	NS	0.04
Interaction									
SEm±	0.35	0.65	1.58	2.53	2.04	1.70	1.62	0.01	0.03
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

90 DAS. Among the N management practices, NAR in RDN-SSB was on par with RDN-conventional and 75 per cent RDN-SSB at 60 DAS-90 DAS.

Conclusion

It was concluded that planting of maize at 67.5 cm × 20 cm increased dry matter/m^2 and plant height whereas higher grain yield was obtained at 67.5 cm × 22 cm. Among the nitrogen management practices, growth parameters were recorded significantly higher with application of RDN-SSB. Also, RDN-conventional and 75 per cent RDN-SSB were statistically at par for all parameters including yield which indicates saving of 25 per cent N through sub-surface placement and reducing the cost of production and environmental footprints. Therefore, with an optimized spacing of 67.5 cm × 22 cm coupled with sub-surface N-placement can be adopted in eastern region of India and similar agro-ecologies for higher growth and productivity of *kharif* maize.

References

Alene, A. D., Poonyth, D. & Hassan, R. M. (2000). Determinants of adoption and intensity of use of improved maize varieties in the central highlands of Ethiopia: a Tobit analysis. *Agrekon,* **39**(4): 633-643.

Andrea, D., Otegui, M. E., Cirilo, A. G. & Eyherabide, G. (2006). Genotypic variability in morphological and physiological traits among maize inbred lines-nitrogen responses. *Crop Science*, **46**(3): 1266-1276.

Battaglia, M., Lee, C., Thomason, W. & Van Mullekom, J. (2019). Effects of corn row width and defoliation timing and intensity on canopy light interception. *Crop Science,* **59**(4): 1718-1731.

Biradar, A., Jayadeva, H. M., Shankarlingappa, B. C. & Vishwanath, A. P. (2013). Effect of target yield approach on growth, yield and nutrient uptake at flowering of maize. *Mysore Journal of Agricultural Sciences,* **47**(4): 707-712.

Dass, S., Kumar, A., Jat, S. L., Parihar, C. M., Singh, A. K., Chikkappa, G. K. & Jat, M. L. (2012). Maize holds potential for diversification and livelihood security. *Indian Journal of Agronomy,* **57**(3rd IAC Special Issue): 32-37.

FAOSTAT. (2022). Food and Agriculture Organization (FAO) statistics (FAOSTAT). https://www.fao.org/faostat/en/#data/QCL. Accessed on 8th June, 2022.

FICCI. (2022). Maize vision 2022- a knowledge report. The Federation of Indian Chambers of Commerce & Industry. https://ficci.in/spdocument/22966/India-Maize-Summit.pdf. Accessed on 8th June, 2022.

Harikrishna, B. L., Dasog, G. S. & Patil, P. L. (2005). Uptake of NPK, nitrogen use efficiency and available NPK in soils at different growth stages of maize crop. *Karnataka Journal of Agricultural Sciences*, **18**(2): 375.

Khan, I., Kakar, K. M., Khan, A., Shah, Z. & Hussain, Z. (2014). Growth and yield response of maize (*Zea mays* L.) to foliar NPK-fertilizers under moisture stress condition. *Soil & Environment,* **33**(2).

Kumar, M., Hazarika, S., Choudhury, B. U., Ramesh, T., Verma, B. C. & Bordoloi, L. J. (2012). Liming and integrated nutrient management for enhancing maize productivity on acidic soils of northeast India. *Indian Journal of Hill Farm*, **25**(1): 36-38.

Muniswamy, S., Rame, G. & Prasad, R. (2007). Effect of spacing and nitrogen levels on seed yield and quality of maize single cross hybrid PEHM2. *Mysore Journal Agricultural Sciences,* **41**(2): 186-191.

Nayak, H. S., Parihar, C. M., Mandal, B. N., Patra, K., Jat, S. L., Singh, R., Singh, V. K., Jat, M. L., Garnaik, S., Nayak, J. & Abdallah, A. M. (2022). Point placement of late vegetative stage nitrogen splits increase the productivity, N-use efficiency and profitability of tropical maize under decade long conservation agriculture. *European Journal of Agronomy*, **133**: (February 2022), 126417.https://doi.org/10.1016/j.eja.2021.126417.

Padhan, S. R., Jat, S. L., Mishra, P., Darjee, S., Saini, S., Padhan, S. R., Radheshyam & Ranjan, S. (2023). *Corn for Biofuel: Status, Prospects and Implications*. In: Kaushik, P. (eds) New Prospects of Maize. Intech Open, London, UK.

Siamak, E., Fatemeh, S., Farshad, Z. & Arezo, G. (2014). The effect of plant date and density on the growth index of maize variety (ksc704) in tropical region of Kermanshah Province. *International Journal of Agronomy and Agricultural Research,* **5**(6): 93-102.

Sinha, A. K. (2016). Effect of site-specific nutrient management on production and productivity of maize (*Zea mays* L.) under mid hill condition of Chhattisgarh. *International Journal of Plant Science,* **11**(2): 167-170.

Suryavanshi, V. P., Chavan, B. N., Jadhav, K. T. & Pagar, P. A. (2008). Effect of spacing, nitrogen and phosphorus levels on growth, yield and economics of *kharif* maize. *International Journal of Tropical Agriculture,* **26**(3): 287-291.

Valadabadi, S. A. & Farahani, H. A. (2010). Effects of planting density and pattern on physiological growth indices in maize (*Zea mays* L.) under nitrogenous fertilizer application. *Journal of Agricultural Extension and Rural Development*, **2**(3): 40-47.

Watson, D. J. (1947). Comparative physiological studies in the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years. *Annals of Botany,* **11**: 41–76.

Yao, M., Xue, J., Zhao, Y., Gou, L., Shi, Z. & Zhang, W. (2016). How high plant density of maize affects basal internode development and strength formation. *Crop Science*, **56**(6): 3295-3306.