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Growth Dynamics, Productivity and Economics of Quality Protein Maize (*Zea mays* L.) Under Varying Plant Density and Nutrient Management Practices

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A field experiment was carried out at G.B. Pant University of Agriculture & Technology, Pantnagar, U.S. Nagar, Uttarakhand to find out the effect of different plant population and nutrient management practices on Quality Protein Maize (QPM) on 20th February 2010 in factorial randomized block design replicated thrice with three plant densities *viz*., 66,666, 83,333 and 100000 plants ha^{-1} and five nutrient management practices viz., 100% recommended dose of fertilizer (RDF), 125 % RDF, 100 % recommended dose of nitrogen (RDN) through inorganic + 25 % RDN through organic, 75 % RDN through inorganic + 25 % RDN through organic and 50 % RDN through inorganic + 50 % RDN through organic. The results revealed that leaf area index (LAI) and dry matter accumulation were significantly higher under high and low plant density, respectively. Low plant density (66,666 plants ha^{-1}) also recorded significantly higher crop growth rate (2.85 g day^{-1}) and net assimilation rate (10.81 g m^{2} day^{-1}) during 30-60 DAS. However, leaf area ratio (139.72 cm^{2} g^{-1}) and relative growth rate (20.88 mg g^{-1} day^{-1}) were more under higher plant density (1,00,000 plants ha^{-1}) during 30-60 and 60-90 DAS, respectively. High plant density being at par with medium plant density produced maximum cob (99.76 q ha^{-1}) and grain (69.90 q ha^{-1}) yields. However, nutrient management practices consisting of either chemical fertilizers alone or with organic sources had non-significant effect on growth parameters and yields. High plant density gave the highest net return (₹ 42,960 ha^{-1}) but among nutrient management practices, higher net return was with 125% RDF (₹ 42,952 ha^{-1}).

Key words: Quality protein maize, plant density, nutrient management, growth parameters.

Maize is the third most important cereal crop of India grown for food, feed and several industrial purposes. It is a good source of carbohydrates, fat, protein and some important vitamins and minerals, however, deficient in essential amino acids viz., lysine and tryptophan that reduces its biological value. The amount of these deficient amino acids have been increased by incorporating opaque-2 gene in quality protein maize (QPM). Hence, the cultivation of QPM provides an opportunity to farmers to produce nutritionally superior maize grains. Among the various factors, the grain yield as well as other important growth and yield attributes of maize is remarkably affected by two most important factors viz., plant population and nutrient management. At low plant density, maize cannot compensate for low leaf area and small number of reproductive units neither by branching nor tillering as it doesn't share the trait of most tillering grasses while on the other hand, high population heightens inter-plant competition for light, water and nutrients. This may be detrimental to final yield because it ultimately induces bareness and decreases the number of ears and kernel number.

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Undoubtly, being heavy feeder of nutrients and high productivity potential, maize crop requires continuous and assured nutrient supply particularly nitrogen throughout its growing period right from germination to grain filling stage. Quality protein maize hybrids are either superior or at par in productivity with their duration of normal maize hybrids (Yadav, 2006). By considering its high nutritional values and productivity as to that of normal maize as well as little research study on plant density and nutrient requirement for QPM, the present experiment was conducted to find out optimum plant population and nutrient management for QPM.

Materials and Methods

The field experiment was conducted on 20th February 2010. The soil was classified as sandy loam hyperthermic *Aquic Hapludoll* under humid sub – tropical climate with an annual rainfall of 1433 mm, of which, more than 85% received during June to September. The experimental soil was neutral in soil reaction (p^{H} - 6.9), rich in organic carbon (1.18 %), low in available nitrogen (212.3 kg ha^{-1}) and medium in available phosphorus (18.14 kg ha^{-1})

and available potassium (258.2 kg ha^{-1}). The treatment combinations consisting of three plant densities viz., 66,666, 83,333 and 100000 plants ha^{-1} maintained through 60 cm × 25 cm, 60 cm × 20 cm and 50 cm × 20 cm, respectively, and five nutrient management practices viz.100% Recommended dose of fertilizer (RDF), 125 % RDF, 100 % Recommended dose of Nitrogen (RDN) through inorganic + 25 % RDN through organic, 75 % RDN through inorganic + 25 % RDN through organic and 50 % RDN through inorganic + 50 % RDN through organic were tested in factorial randomized block design replicated thrice. The recommended dose of fertilizers for N, P_2O_5 and K_2O was 120, 60 and 40 kg ha^{-1}, respectively. The source of organic was vermicompost containing 1.8 per cent N on dry weight basis.

Quality Protein Maize hybrid variety HQPM-1 was sown as per recommended practices. Nitrogen, phosphorus and potassium were applied as per treatment through urea, SSP and MOP, respectively. Full dose of P, K and Zinc as $ZnSO_4$ @ 25 kg ha^{-1} and one third amount of N were applied as basal at sowing time and remaining N was given in two equal splits through top dressing at knee high and tassel emergence stages.

After the well preparation of field with one deep ploughing followed by two harrows, furrows at the distance of 60 cm and 50 cm were opened by furrow opener. Seeds were sown at the distance of 25 cm and 20 cm as per treatments. One pre-emergence spraying of Pendimethalin @ 3.33 l/ha in 500 litres of water was done one day after sowing followed by one manual weeding at 27 days after sowing (DAS) for effective weed control. One pre-sowing irrigation on 1st February and 5 irrigations after 21, 35, 49, 56 and 77 DAS of crop were given. To control aphids and stem borers one spray of Metasystox and Endosulfan of 1:1 ratio was done @ 2ml/liter at 28 DAS while to control heliothis (*Helicoverpa armigera*) spraying of 'Profenophos' was done @ 3ml/liter at 41 DAS. Growth studies viz., speed of emergence, canopy spread, $\overline{\text{LAI}}$ $\overline{\text{CGR}}$, $\overline{\text{RGR}}$, $\overline{\text{NAR}}$ and $\overline{\text{LAR}}$ were recorded at 30 days interval however, plant height, cob, stover and grain yield were recorded at the harvest time. Economics was computed using the prevailing market prices for inputs. Gross return was calculated by multiplying grain yield with minimum support price and stover yield with market price.

Results and Discussion

Growth parameters

The plant population had significant effect on plant height, ear height, dry matter accumulation and LAI while nutrient management practices failed to bring any significant effect on any of the growth parameters under study (Table 1). Plant and ear height observed was the highest with higher plant density owing to inter-plant competition for light. Plant height was not influenced significantly by nutrient management practices and remained statistically similar. The probable reason might be that the crop received adequate amount of nutrients (100 or 125 % RDF) and did not face competition for nutrients. Because of non-significant differences in plant height, cob height also remained statistically at par with variation in nutrient management practices.

Table 1. Effect of plant density and nutrient management on growth parameters of QPM

Treatment			Leaf Area Index				Dry matter accumulation (g $plant^{-1}$)				Canopy spread at harvest (cm)
	Plant height at harvest (cm)	Ear height (cm)	30 DAS	60 DAS	90 DAS	harvest	30 DAS	60 DAS	90 DAS	harvest	
Plant Density (Plants ha^{-1})											
P_1 : 66,666	213.6	72.5	0.59	4.45	6.31	3.34	3.10	94.94	163.24	194.30	95.5
P_2 : 83,333	212.7	73.9	0.91	5.23	6.99	3.99	2.94	84.59	151.14	186.60	95.4
P_3 : 1,00,000	218.2	79.2	1.42	5.99	7.98	4.50	2.77	78.40	146.46	181.86	92.0
SEm ±	0.9	1.8	0.05	0.14	0.11	0.06	0.05	1.83	1.94	3.09	2.4
CD (5 %)	2.7	5.3	0.19	0.40	0.32	0.19	0.16	5.29	5.63	8.96	NS
Nutrient management											
N_1 : 100 % RDF	220.7	77.3	0.93	5.18	7.06	3.91	2.95	86.04	152.31	188.59	90.0
N_2 : 125 % RDF	216.3	76.8	1.08	5.33	7.29	4.10	2.97	88.48	159.69	191.37	98.3
N_3 : 100% N inorganic + 25 % N organic	215.0	75.8	0.96	5.26	7.14	4.03	2.96	86.52	155.73	190.12	95.3
N_4 : 75% N inorganic + 25 % N organic	214.2	73.7	0.99	5.21	7.01	3.89	2.92	85.23	150.47	185.47	94.2
N_5 : 50% N inorganic + 50 % N organic	208.1	72.4	0.90	5.15	6.96	3.80	2.90	83.61	149.86	182.38	93.8
SEm ±	4.2	2.4	0.08	0.18	0.14	0.08	0.07	2.36	2.51	3.99	3.1

Canopy spread ceased when crop attained maximum vegetative growth in either different plant densities or nutrient levels. Owing to decline in vegetative growth non significant variation in canopy spread at harvest was observed. Leaf area index was significantly higher with high plant density by 56.0-140.7, 14.5-34.6, 14.2-26.5 and 12.8-34.7 % at 30, 60, 90 DAS and harvest, respectively, over medium and lower plant densities. Modarris *et al.* (1998) and Tollenaar *et al.* (1994) also reported similar findings. Under high plant density, more number of plants per unit area was responsible for higher LAI. Dry matter accumulation decreased with increase in plant density from 66,666 to 1,00,000

Table 2. Influence of plant density and nutrient management on crop growth rate, relative growth rate, net assimilation rate and leaf area ratio of QPM

Treatment	CGR (g day-1)			RGR (mg g^{-1} day^{-1})			NAR (g m^{-2} day^{-1})			LAR (cm^2 g^{-1})		
	30-60 DAS	60-90 DAS	90 DAS - harvest	30-60 DAS	60-90 DAS	90 DAS - harvest	30-60 DAS	60-90 DAS	90 DAS - harvest	30-60 DAS	60-90 DAS	90 DAS - harvest
Plant Density (Plants ha^{-1})												
P_1 : 66,666	2.85	2.28	1.29	114.06	18.11	7.24	10.81	2.94	1.86	106.49	61.76	39.37
P_2 : 83,333	2.64	2.22	1.48	111.90	19.39	8.74	9.37	3.13	2.30	121.75	61.93	38.21
P_3 : 1,00,000	2.51	2.27	1.48	111.37	20.88	9.03	8.05	3.34	2.43	139.72	62.58	37.19
SEm ±	0.07	0.08	0.19	1.05	0.75	0.07	0.31	0.11	0.20	3.53	1.33	0.62
CD (5 %)	0.02	NS	NS	NS	2.16	NS	0.91	0.31	NS	10.22	NS	NS
Nutrient management												
N_1 : 100 % RDF	2.74	2.21	1.51	112.32	19.14	8.95	9.57	3.01	2.36	119.04	63.43	38.10
N_2 : 125 % RDF	2.70	2.37	1.32	113.13	19.79	7.50	9.34	3.16	1.99	125.48	62.57	39.41
N_3 :100% N inorganic + 25 % N organic	2.68	2.31	1.43	112.46	19.71	8.32	9.44	3.11	2.20	121.34	63.48	38.11
N_4 : 75% N inorganic + 25 % N organic	2.73	2.18	1.46	112.38	19.07	8.74	9.15	3.13	2.28	126.33	60.76	38.47
N_5 : 50% N inorganic + 50 % N organic	2.49	2.21	1.36	111.92	19.58	8.19	9.54	3.27	2.15	121.08	60.21	38.20
SEm ±	0.09	0.10	0.24	1.35	0.96	0.10	0.40	0.14	0.26	4.55	1.72	0.80
CD (5 %)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

plants/ha. The highest dry matter accumulation of 3.1, 94.9, 163.2 and 194.3 g/plant was recorded at 30, 60, 90 DAS and harvest, respectively, under lower plant density. This was probably because of less competition among plants for resources viz., space, nutrients, moisture, light, etc. under low densities (Choudhary and Singh, 2006).

The different growth parameters viz., crop growth rate (CGR), net assimilation rate (NAR) and leaf area ratio (LAR) were significantly influenced at early period of growth (30-60 DAS) by plant densities however; nutrient management did not produce significant differences. Decrease in values of these growth parameters was observed with advancement of crop growth under different plant population (Table 2). CGR and NAR were significantly higher at low plant density (66,666 plant ha^{-1}) during 30-60 DAS interval whereas higher RGR and significantly the highest LAR were noted under higher plant density (1,00,000 plant ha^{-1}) during 60-90 and 30-60 DAS, respectively. But the magnitude of increase at lower plant density was more (34.3%) than that of CGR (13.5%) over higher plant density during 30-60 DAS. Amanullah *et al.* (2008) also reported higher LAR with higher plant density. The higher CGR at lower plant density could be attributed to better utilization of growth factors such as space, nutrients and moisture leading to better synthesis and accumulation of photosynthates while on the other hand at higher plant density there was more competition. It is interesting to note that in the early period of observation (30-60 DAS) NAR recorded was higher (10.81 g m^{-2} day^{-1}) with low plant density while it was maximum (3.34 and 2.43 g m^{-2} day^{-1} at 60-90 DAS and 90 DAS – harvest, respectively) with higher plant density at later stage. The probable reason might be the less competition for resources under lower plant density during initial stage which lead to more accumulation of photosynthates consequently resulted in more NAR whereas, more LAI under high plant density (Table 2) helped to maintain high net assimilation rate during later stages. The higher values of RGR (20.88 mg g^{-1} day^{-1}) and LAR (139.72 cm^{-2} g^{-1}) with 1,00,000 plant ha^{-1} might be due to increased light interception owing to increased LAI and more number of erect upper leaves and photosynthetic activity during the grain filling period. Nutrient management practices did exhibited non-significant effect on different growth parameters, indicating no hindrance in nutrient supply during vegetative growth period.

Yield

Grain, cob and stover yields of maize were found to be increased with increase in plant density from 66,666 to 1,00,000 plant ha^{-1} (Table 3). Yogananda *et al.* (1999) and Bangarwa *et al.* (1988) also

Table 3. Yield of QPM as affected by plant density and nutrient management

Treatment	Yield (q ha^{-1})		
	Grain	Cob	Stover
Plant Density (Plants ha^{-1})			
P_1 : 66,666	57.67	84.68	142.0
P_2 : 83,333	65.49	92.79	154.6
P_3 : 1,00,000	69.90	99.79	169.1
SEm ±	1.95	3.62	2.80
CD (5 %)	5.01	10.48	8.12
Nutrient management			
N_1 : 100 % RDF	64.58	92.34	156.0
N_2 : 125 % RDF	66.85	96.70	161.3
N_3 : 100% N inorganic + 25 % N organic	65.28	92.90	158.1
N_4 : 75% N inorganic + 25 % N organic	62.56	90.06	150.9
N_5 : 50% N inorganic + 50 % N organic	62.50	90.01	150.0
SEm ±	2.52	4.67	3.62
CD (5 %)	NS	NS	NS

reported increase in grain and stover yield, respectively, with each successive increase in plant density. High plant density produced 4.41 and 12.23 q ha^{-1} more grain,7.00 and 15.51 q ha^{-1} more cob and 14.45 and 27.08 q ha^{-1} more stover yields than to medium and low plant densities, respectively. This clearly indicates that reducing both inter and intra row spacing attributed to more number of plants

Table 4. Effect of plant density and nutrient management on economics of cultivation of QPM

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	Output-input ratio
Plant Density (Plants ha^{-1})				
66,666	25305	56965	31660	2.29
83,333	25605	64289	38684	2.56
1,00,000	25905	68865	42960	2.71
Nutrient Management				
100 % RDF	21545	63607	42062	2.95
125 % RDF	22882	65834	42952	2.88
100% N inorganic + 25 % N organic	26545	64317	37772	2.42
75% N inorganic + 25 % N organic	26199	61607	35408	2.35
50% N inorganic + 50 % N organic	30852	61498	30645	1.99

* Minimum support price of maize (2010-11) Rs.840/q
* Selling price of stover Rs. 60/q

and cobs per unit area consequently led to higher grain yield over the normally followed geometry of 60 cm x 25 cm, whereas, more plant height and more leaf area index may be the reasons for higher stover yield at higher plant density. Nutrient practices failed to bring significant effect on yield attributes and hence yield.

Economics

Gross return, net return and output-input ratio in general, varied significantly with plant population and nutrient management practices but nutrient management practices did not exhibit significant effect on gross return (Table 4). The maximum gross (68,865 ha^{-1}) and net (42,960 ha^{-1}) return was obtained with higher plant density which was statistically at par with 83,333 plants ha^{-1}.Similarily output-input ratio was the highest (2.71) at higher plant population. It could be attributed to more grain and stover yield with higher plant density. Carrillo *et al.* (1995) also observed significant increase in net return and B:C ratio with increase in plant density from 66 to 130 thousand ha^{-1}. Crop receiving 125 % RDF exhibited significantly more net return (42,952 ha^{-1}) while output: input ratio was recorded significantly higher (2.95) for 100 % RDF which was due to high grain and stover yield obtained under this treatment. The lower net return and output: input ratio recorded under treatment having equal amount of nitrogen through inorganic and organic was due to the high cost of cultivation.

Conclusion

Quality Protein Maize variety HQPM-1 may be grown at plant density of 83,333 plants ha^{-1}. Application of 120:60:40 kg $N:P_2O_5:K_2O$ ha^{-1} in the form of either inorganics or combination with organics is adequate for obtaining higher yield in *tarai* region of Uttarakhand. But the inorganic sources of nutrients are more economical and hence can be used.

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