Indian Journal of Agricultural Sciences **94** (8): 858–863, August 2024/Article
https://doi.org/10.56093/ijas.v94i8.130077

Crop geometry and nutrient (N-P-K-S) management for *kharif* onion bulb (*Allium cepa*) crop

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Received: 10 November 2022; Accepted: 11 June 2024

ABSTRACT

The experiment was conducted during rainy (*kharif*) seasons of 2020 and 2021 at College of Agriculture (Agriculture University, Jodhpur, Rajasthan), Sumerpur, Pali, Rajasthan to find out the optimal quantity of N-P-K-S nutrients and appropriate crop geometry to maximize the productivity and bulb quality of onion (*Allium cepa* L.). The experiment was conducted in split-plot design (SPD) by means of 3 levels of N-P-K-S nutrients in main plots and 5 crop geometries under sub-plot, replicated thrice. Widest crop geometry (15 cm × 15 cm) with highest level of nutrients (140 N-80 P-80 K-40 S) resulted in highest tallness of plant (97.8 cm), maximum leaves (19/plant), root length (9.9 cm), number of roots/plant (139.8), average bulb weight (133.9 g) and harvest index (51.2). Saleable bulbs (43.6 t/ha), total income (6753.8 USD), net income (5462.6 USD) and Benefit: cost (B:C) ratio (4.23) was the highest in 10 cm × 10 cm geometry with highest level of N-P-K-S nutrients. Maximum biological production (125.8 t/ha), bulb production (61.8 t/ha) was observed at closest geometry (7.5 cm × 7.5 cm) with highest level of N-P-K-S nutrients. It was confirmed by experimentation, that the onion seedling should be transplanted at 10 cm × 10 cm geometry with 140 N-80 P-80 K-40 S kg/ha nutrients in medium fertile sandy loam soil in arid agro-climatic condition for maximum saleable good quality onion bulbs production.

Keywords: Biological yield, Harvest Index, Productivity, Pungency

Onion (*Allium cepa* L.) is the second most widely cultivated oldest food crop from the Amaryllidaceae family. It is enormously significant for flavour and pungency as vegetable, spice and medicinal value crop (Muhie 2022), for domestic consumption as well as highest foreign exchange earner product among the fresh agricultural produce in India. Through the year 2020–21 the country has sold 15 lakhs metric tonnes of onion bulbs to the world for the worth of 3784 USD lakhs (APEDA 2021). In the world, India is the second biggest grower of onion, after China and produced 266 lakhs tonnes of bulbs from 16 lakhs hectare areas during 2021–22. In comparison to the China and other major producing countries, onion productivity of India is extremely low i.e. 16400 kg/ha in comparison to the Egypt (36100 kg/ha), Japan (46600 kg/ha), Netherlands (51600 kg/ha), USA (56100 kg/ha) and Republic of Korea (66100 kg/ha).

Improved agro-techniques mainly balance nutrition and appropriate crop geometry may get better productivity and bulb quality. It is obvious from the available facts that application of NPK and sulphur nutrients was supportive in getting higher yield of super quality bulbs, however unbalanced dose of all these nutrients negatively influenced. Subordinate fertilization, especially P nutrient in tubers and bulb crop decreases yield up to 70% (Sandana *et al*. 2020). Optimal fertilizer requirement has been reported as a wide range of 95–150 kg Nitrogen, 13–57 kg Phosphorus, and 42–150 kg Potassium/ha (Khokhar 2019, Mazumder *et al*. 2019, Mandal *et al*. 2020) with productivity of 1000–3000 kg/ha. In addition to nutrition, suitable crop geometry is an important reason to determine onion productivity and marketability; it also minimizes crop competition for nutrients, water, CO_2, sunlight and facilitates proficient utilization of the field. Considering the above mentioned facts on importance of nutrient management and crop geometry a research trial was conducted with the hypothesis that balanced dose of N-P-K-S fertilization and appropriate crop geometry can improve productivity and bulb quality of onion.

MATERIALS AND METHODS

The experiment was conducted during rainy (*kharif*) seasons of 2020 and 2021 at College of Agriculture (Agriculture University, Jodhpur, Rajasthan), Sumerpur, Pali, Rajasthan. Average annual precipitation was 356.8 and 147 mm, relative humidity 48.25 and 55.75%,

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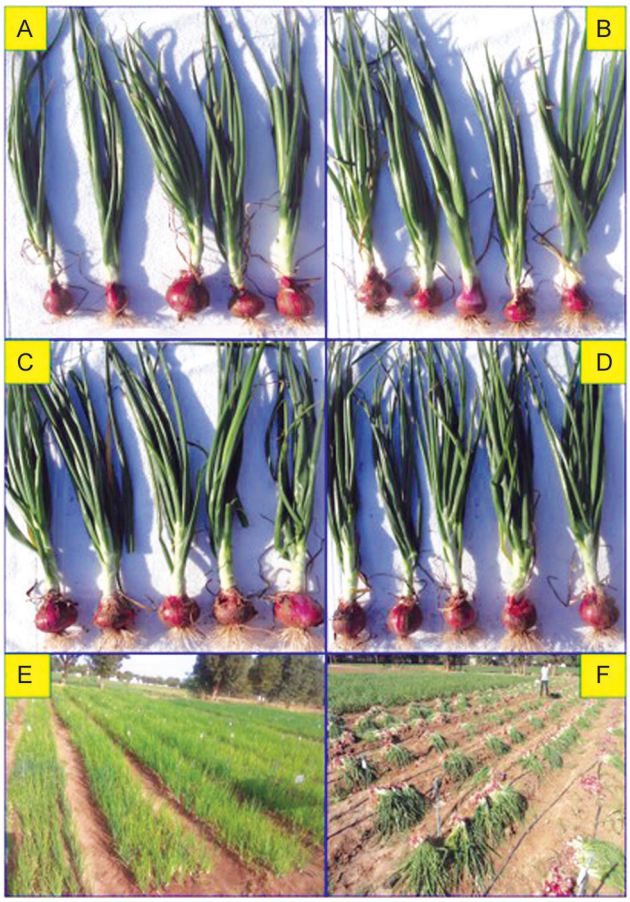
mean highest temperature of 33 and 47.5°C, minimum temperature 19.5 and 18.5°C during both the years of experimentation respectively. The physico-chemical properties of experimental field were as, *p*H=8.2; EC=0.30 ds/m; organic carbon=0.25%; N=74 kg/ha; P_2O_5=28.5 kg/ha, K_2O=139 kg/ha, S=6.50 mg/kg soil with sandy-loamy soil texture. The experiment was conducted in split-plot design (SPD) comprised of 15 treatment combinations with three levels of N-P-K-S nutrients (N_1, 100 N-40 P-40 K-20 S; N_2, 120 N-60 P-60 K-30 S; and N_3, 140 N-80 P-80 K-40 S kg/ha) in main plot and 5 types crop geometries (G_1, 7.5 cm × 7.5 cm; G_2, 10 cm × 10 cm; G_3, 12.5 cm × 12.5 cm; G_4, 15 cm × 15 cm and G_5, 12.5 cm × 10 cm) in sub-plot. The entire quantity of decomposed organic manure (25 t/ha), and whole quantity of PKS and 1/3rd of nitrogen were applied during land preparation. The rest 2/3rd of N was equally applied by top-dressing at 30 and 60 days of seedling transplanting. Harvesting was done on 13th–15th November at physiological maturity when 50% of their leaves were dried off. During both the years of experimentation, observations for growth and yield parameters were gathered from 10 randomly selected plants of each plot as per scientifically described standard methods and were averaged. Onion bulb yield in the form of saleable, unsalable, split bulb and biological yield were computed from the total yield obtained per ha by weighing methods. Bolting percentage was observed by plants showing flower scapes, was tallied and calculated as the ratio of bolters with total plants in the plot. The harvest index (%) on a fresh weight basis was worked out by means of a mathematical formula (economic yield/total biological yield × 100). The onion bulbs total soluble solid was observed with the help of a hand held refractometer (MASTER^{TM}) with a series of 0–32 °Brix. The total income was computed from marketable yield multiplied by mean selling price of 1-month duration at time of crop harvesting. The crop net income was worked out by subtracting treatment expenditure from total income and benefit cost (B:C) ratio was computed by dividing net income to total crop cultivation cost.

Statistical analysis: Results were evaluated by pooled data examination with help of SAS software (Version 9.1) for conducting analysis of variance (ANOVA) and variations among treatment means were compared at $P<0.05$. The significance of the difference between the pairs of means was evaluated by Duncan's new Multiple Range Test.

RESULTS AND DISCUSSION

Response to N-P-K-S nutrients levels: Results (Table 1) showed that the highest plant height (77.8 cm), number of leaves/plant (14.4), root length (7.8 cm), number of roots/plant (130.9) were obtained with a highest dose of N-P-K-S nutrients (140-80-80-40 kg/ha), which was at par with 120-60-60-30 kg/ha and minimum values of all these attributes was observed with 100 N-40 P-40 K-20 S kg/ha (Fig. 1). These results were in accordance with Walle *et al*. (2018) and Mondal *et al.* (2020) for onion bulb crop. Nutrients doses also had considerable effect on onion bulb bolting, and highest premature bolting (8.11%) was experienced with minimum dose of nutrients (100 N-40 P-40 K-20 S kg/ha) whereas, lowest bolting (7.36%) was reported with the quantity of 140 N-80 P-80 K-40 S kg/ha. These results were supported by Arolkar *et al*. (2021) in fennel (*Foeniculum vulgare* Mill.). Increasing the dose of N-P-K-S nutrients from 100-40-40-20 kg/ha to 120-60-60-30 kg/ha markedly boosted onion bulb weight (8.21%), bulb productivity (8.29%) and total biological productivity (8.92%), whereas increasing the dose from 120 N-60 P- 60 K-30 S kg/ha to 140 N-80 P-80 K-40 S kg/ha augmented in onion bulb weight (4.89%), bulb productivity (4.92%) and total biological productivity (5.59%) with decreasing trend (Table 2). Lowest harvest index (44.6) obtained with use of 140 N-80 P-80 K-40 S kg/ha could be qualified non-significant reduction of fresh saleable bulb yield in response to increasing of nutrients dose from 120-60-60-30 kg/ha to 140-80-80-40 kg/ha might be attributed to overdose or supra optimal supply of the nutrients which might have perform to unnecessary augmentation in vegetative growth and enlargement of bulbs. The obtained results agreed well with those of Sharma *et al.* (2017) for onion bulb crop. The maximum saleable yield (35.4 t/ha), total income, (5501.1 USD),



A, N_3G_1 (140N-80P-80K-40S kg/h + 7.5 cm × 7.5 cm); B, N_3G_2 (140N-80P-80K-40S kg/h + 10 cm × 10 cm); C, N_3G_3 (140N-80P-80K-40S kg/h + 12.5 cm × 12.5 cm); D, N_3G_4 (140N-80P-80K-40S kg/h + 15 cm × 15 cm); E, Experimental site (73° 05′ E and 25° 09′ N); F, Harvested onion crop

Fig. 1 Response of *kharif* onion to crop geometry and N-P-K-S nutrient levels.

Table 1 Effect of N-P-K-S nutrient levels and crop geometry on growth parameters and yield attributes of *kharif* onion (pooled mean + SEm)

Treatment	Growth parameter				Yield attributes			
	Plant height (cm)	No. of leaves/plant	Root length (cm)	No. of roots/ plant	Bulb/weight (g)	Bulb yield (t/ha)	Biological yield (t/ha)	Harvest index
N-P-K-S nutrient levels								
N_1	$65.46^{b}\pm2.20$	$11.28^{b}\pm0.60$	$6.95^{b}\pm0.25$	$122.27^{b}\pm2.43$	$73.36^{b}\pm6.42$	$39.57^{b}\pm2.23$	$73.19^{b}\pm5.36$	$44.64^{b}\pm2.62$
N_2	$73.20^{a}\pm2.30$	$13.09^{a}\pm0.61$	$7.42^{a}\pm0.36$	$117.08^{c}\pm2.06$	$79.38^{a}\pm6.73$	$42.85^{a}\pm2.32$	$79.72^{a}\pm5.80$	$44.93^{a}\pm2.58$
N_3	$77.83^{a}\pm3.00$	$14.43^{a}\pm0.77$	$7.80^{a}\pm0.30$	$130.99^{a}\pm1.93$	$83.26^{a}\pm7.29$	$44.96^{a}\pm2.57$	$84.18^{a}\pm6.16$	$44.62^{b}\pm2.54$
CV (%)	7.50	6.55	5.80	8.20	5.88	6.12	6.97	1.10
Level of significance	*	*	*	*	*	*	*	*
Crop geometry								
G_1	$58.52^{d}\pm1.83$	$9.46^{e}\pm0.40$	$5.90^{d}\pm0.10$	$110.91^{c}\pm1.86$	$49.47^{e}\pm1.01$	$58.47^{a}\pm1.03$	$118.73^{a}\pm2.28$	$25.49^{d}\pm0.10$
G_2	$69.21^{c}\pm1.67$	$11.25^{d}\pm0.44$	$6.78^{c}\pm0.07$	$121.75^{bc}\pm2.86$	$67.97^{d}\pm1.80$	$45.19^{b}\pm1.16$	$83.92^{b}\pm2.35$	$47.94^{c}\pm0.24$
G_3	$75.38^{b}\pm1.56$	$14.00^{b}\pm0.47$	$7.59^{b}\pm0.24$	$124.25^{b}\pm2.93$	$78.81^{b}\pm1.33$	$33.54^{d}\pm0.59$	$62.40^{d}\pm2.54$	$50.28^{a}\pm0.44$
G_4	$86.57^{a}\pm3.13$	$16.58^{a}\pm0.69$	$9.28^{a}\pm0.20$	$134.41^{a}\pm1.93$	$125.74^{a}\pm2.41$	$37.16^{c}\pm0.74$	$60.07^{d}\pm1.15$	$50.31^{a}\pm0.25$
G_5	$71.14^{c}\pm1.55$	$13.37^{c}\pm0.43$	$7.40^{b}\pm0.17$	$125.91^{b}\pm1.27$	$71.32^{c}\pm1.31$	$37.93^{c}\pm0.70$	$70.02^{c}\pm1.34$	$49.62^{b}\pm0.15$
CV (%)	5.33	5.70	4.50	6.70	3.40	5.33	5.72	0.64
Level of Significance	*	*	*	*	*	*	*	*
Interaction effect of N-P-K-S nutrient levels and crop geometry								
N_1G_1	$52.09^{l}\pm1.15$	$8.00^{i}\pm0.17$	$5.63^{g}\pm0.11$	$107.87^{e}\pm0.67$	46.56 ± 1.15	55.04 ± 0.57	110.70 ± 1.15	$25.10^{j}\pm0.05$
N_1G_2	$63.31^{ij}\pm1.52$	$9.63^{h}\pm0.31$	$6.62^{f}\pm0.12$	$119.37^{c}\pm0.66$	61.67 ± 1.14	41.01 ± 0.58	76.07 ± 1.16	$47.70^{g}\pm0.06$
N_1G_3	$69.73^{h}\pm1.15$	$12.63^{f}\pm0.19$	$7.03^{e}\pm0.11$	$123.87^{c}\pm0.68$	74.07 ± 1.17	31.52 ± 0.53	57.42 ± 1.34	$51.20^{a}\pm0.09$
N_1G_4	$76.65^{d}\pm1.07$	$14.13^{d}\pm0.22$	$8.59^{c}\pm0.09$	$135.87^{a}\pm0.70$	117.85 ± 1.12	34.83 ± 0.55	56.55 ± 1.15	$49.59^{d}\pm0.01$
N_1G_5	$65.50^{i}\pm1.06$	$12.00^{f}\pm0.57$	$6.87^{ef}\pm0.12$	$124.37^{c}\pm0.66$	66.63 ± 1.16	35.45 ± 0.64	65.22 ± 1.16	$49.59^{d}\pm0.05$
N_2G_1	$59.44^{k}\pm1.27$	$10.87^{g}\pm0.25$	$6.22^{g}\pm0.10$	$117.89^{cd}\pm0.94$	49.48 ± 0.86	58.49 ± 0.56	119.60 ± 1.44	$25.68^{i}\pm0.01$
N_2G_2	$71.04^{g}\pm1.55$	$12.74^{de}\pm0.42$	$6.93^{ef}\pm0.09$	$132.39^{b}\pm1.89$	68.71 ± 0.87	45.69 ± 0.61	83.86 ± 1.45	$48.61^{f}\pm0.04$
N_2G_3	$77.07^{d}\pm1.27$	$13.74^{de}\pm0.41$	$8.52^{c}\pm0.08$	$134.39^{b}\pm1.91$	80.28 ± 0.84	34.16 ± 0.43	62.53 ± 1.46	$51.08^{b}\pm0.04$
N_2G_4	$85.18^{b}\pm1.59$	$16.62^{b}\pm0.26$	$9.26^{b}\pm0.04$	$127.48^{bc}\pm1.92$	125.42 ± 0.81	37.07 ± 0.55	60.31 ± 1.42	$50.10^{c}\pm0.05$
N_2G_5	$73.28^{f}\pm1.29$	$13.49^{de}\pm0.26$	$7.35^{e}\pm0.09$	$130.39^{b}\pm1.77$	73.02 ± 0.78	38.84 ± 0.55	72.29 ± 1.46	$49.16^{e}\pm0.04$
N_3G_1	$64.01^{i}\pm0.99$	$10.50^{g}\pm0.31$	$5.84^{g}\pm0.07$	$106.98^{e}\pm0.07$	52.38 ± 1.25	61.89 ± 0.59	125.89 ± 0.86	$25.68^{i}\pm0.02$
N_3G_2	$73.29^{f}\pm1.14$	$12.38^{f}\pm0.01$	$6.80^{f}\pm0.06$	$113.48^{d}\pm0.14$	73.52 ± 1.26	48.87 ± 0.56	91.84 ± 0.85	$47.50^{h}\pm0.01$
N_3G_3	$79.32^{c}\pm1.08$	$15.63^{c}\pm0.34$	$7.23^{e}\pm0.09$	$114.48^{d}\pm1.10$	82.10 ± 1.28	34.93 ± 0.58	67.26 ± 0.85	$48.55^{f}\pm0.01$
N_3G_4	$97.88^{a}\pm1.11$	$19.00^{a}\pm0.02$	$9.98^{a}\pm0.07$	$139.89^{a}\pm0.09$	133.97 ± 1.24	39.59 ± 0.56	63.34 ± 0.84	$51.24^{a}\pm0.01$
N_3G_5	$74.64^{e}\pm1.51$	$14.63^{d}\pm0.29$	$7.98^{d}\pm0.08$	$122.98^{c}\pm0.32$	74.31 ± 1.30	39.51 ± 0.58	72.56 ± 0.89	$50.10^{c}\pm0.01$
CV (%)	5.33	5.70	4.50	6.70	3.40	5.33	5.72	0.64
Level of Significance	*	*	*	*	NS	NS	NS	*

Means in a column followed by the same letter(s) or without letter(s) are not significantly different at the 5% level by DMRT. *Significant at 5% level of probability. NS, Non-significant.

Treatment details are given under Materials and Methods.

net income (4209.8 USD) and B:C ratio (3.26) were observed with N-P-K-S @ 140-80-80-40 kg/ha, which was significantly superior to other lower levels. Increasing the dose of N-P-K-S nutrients from 100-40-40-20 kg/ha to 120-60-60-30 kg/ha markedly added to saleable fresh bulb yield by (9.94%), total income (10.03%), net income (12.82%) and B:C ratio (10.18%), conversely rising the dose of N-P-K-S nutrients from 120-60-60-30 kg/ha to 140-80-80-40 kg/ha undoubtedly increased in marketable fresh bulb yield further by 4.88%, total income 4.93%, net income 5.84% and B:C ratio 3.82% in declining pattern. Thus, application of 140 N-80 P-80 K-40 S kg/ha is appropriate dose for

production of best possible fresh saleable bulbs with highest total income, net income and B:C ratio and there is no need to augment the dose of the N-P-K-S nutrients over this level. Similar results were also reported by Walle *et al*. (2018), and Gererufael *et al*. (2020) for onion bulb crop and Wang *et al*. (2020) for rice crop.

Response to crop geometry: The highest plant height (86.6 cm), leaves/plant (16.6), root length (9.3 cm) and number of roots/plant (134.4) were observed with the plant geometry of 15 cm × 15 cm, which was significantly superior than all others, but crop geometry of 12.5 cm × 12.5 cm was closely followed, whereas, lowest values of all vegetative parameters were observed with crop geometry 7.5 cm × 7.5 cm (Fig. 1). Analogous effects were also observed by Ngullie and Biswas (2017) and Mazumder *et al.* (2019) in onion crop. Onion bulb weight was significantly affected

Table 2 Effect of N-P-K-S nutrient levels and crop geometry on physico-chemical attributes and economic parameters of *kharif* onion (pooled mean + SEm)

Treatment	Physico-chemical attributes			Economic parameters				
	Bolting per cent	Split bulb (t/ha)	Total soluble solids (ºBrix)	Saleable yield (t/ha)	Unsalable yield (t/ha)	Total income (USD)	Net income (USD)	Benefit cost ratio
N-P-K-S nutrient levels								
N_1	8.11^{a}±0.32	3.33^{c}±0.37	12.81±0.09	30.77^{c}±0.86	8.80^{c}±2.50	4765.11	3525.40	2.85^{c}
N_2	7.96^{b}±0.40	3.65^{b}±0.45	12.86±0.10	33.83^{b}±1.05	9.02^{b}±2.54	5242.91	3977.38	3.14^{b}
N_3	7.36^{c}±0.33	3.89^{a}±0.47	12.54±0.08	35.48^{a}±1.13	9.47^{a}±2.70	5501.18	4209.82	3.26^{a}
CV (%)	5.54	7.75	4.62	6.76	6.50	-	-	4.07
Level of significance	*	*	NS	*	*	-	-	*
Crop geometry								
G_1	10.04^{a}±0.21	1.27^{e}±0.03	12.26^{b}±0.12	30.27^{d}±0.70	28.20^{a}±0.43	4687.63	3422.10	2.70^{d}
G_2	8.19^{b}±0.04	3.68^{c}±0.08	13.09^{a}±0.11	40.22^{a}±1.03	4.96^{c}±0.16	6237.25	4971.72	3.92^{a}
G_3	7.13^{d}±0.08	3.95^{b}±0.05	12.72^{ab}±0.08	31.33^{c}±0.54	2.21^{e}±0.02	4855.50	3589.97	2.83^{c}
G_4	6.17^{e}±0.13	6.21^{a}±0.16	12.76^{ab}±0.07	30.23^{d}±0.67	6.93^{b}±0.06	4687.63	3422.10	2.70^{d}
G_5	7.52^{c}±0.21	3.01^{d}±0.08	12.84^{a}±0.10	34.75^{b}±0.64	3.19^{d}±0.03	5384.96	4119.43	3.25^{b}
CV (%)	5.20	5.47	2.67	5.74	5.94	-	-	2.35
Level of Significance	*	*	*	*	*	-	-	*
Interaction effect of N-P-K-S nutrient levels and crop geometry								
N_1G_1	10.60^{a}±0.07	1.20^{g}±0.01	12.24±0.11	27.79^{ef}±0.30	27.26^{ef}±0.86	4300.22	3060.52	2.47^{l}
N_1G_2	8.14^{c}±0.06	3.58^{d}±0.05	12.76±0.10	36.29^{c}±0.28	4.72^{de}±0.02	5617.40	4377.70	3.54^{c}
N_1G_3	7.39^{d}±0.06	3.80^{d}±0.01	12.76±0.12	29.39^{e}±0.26	2.13^{f}±0.02	4558.49	3318.79	2.67^{j}
N_1G_4	6.64^{e}±0.05	5.42^{b}±0.01	12.26±0.11	28.03^{ef}±0.27	6.79^{c}±0.01	4338.96	3099.26	2.50^{k}
N_1G_5	8.14^{c}±0.04	2.65^{f}±0.02	13.01±0.11	32.34^{d}±0.29	3.10^{e}±0.01	5010.47	3770.76	3.04^{e}
N_2G_1	10.26^{a}±0.13	1.31^{g}±0.12	13.28±0.20	30.70^{e}±0.21	27.78^{b}±0.01	4752.19	3486.66	2.76^{h}
N_2G_2	8.25^{c}±0.11	3.39^{de}±0.11	13.26±0.12	40.77^{b}±0.24	4.91^{de}±0.03	6314.74	5049.21	3.99^{b}
N_2G_3	7.13^{d}±0.12	3.88^{cd}±0.11	12.91±0.13	31.94^{d}±0.22	2.22^{f}±0.01	4945.90	3680.37	2.91^{f}
N_2G_4	6.13^{f}±0.10	6.52^{a}±0.12	12.28±0.10	30.21^{e}±0.22	6.86^{c}±0.01	4674.71	3409.18	2.70^{i}
N_2G_5	7.68^{d}±0.11	3.12^{e}±0.12	13.03±0.13	35.54^{c}±0.24	3.30^{e}±0.02	5501.18	4235.65	3.35^{d}
N_3G_1	9.25^{b}±0.01	1.28^{g}±0.01	12.74±0.16	32.33^{d}±0.59	29.55^{a}±0.01	5010.47	3719.11	2.88^{g}
N_3G_2	8.18^{c}±0.01	4.07^{c}±0.01	12.36±0.14	43.62^{a}±0.60	5.25^{d}±0.01	6753.80	5462.44	4.23^{a}
N_3G_3	6.88^{e}±0.02	4.17^{c}±0.01	12.86±0.17	32.66^{d}±0.58	2.27^{f}±0.01	5062.12	3770.76	2.92^{f}
N_3G_4	5.75^{g}±0.01	6.68^{a}±0.01	12.24±0.16	32.46^{d}±0.56	7.12^{c}±0.02	5036.29	3744.94	2.90^{f}
N_3G_5	6.75^{e}±0.01	3.26^{e}±0.01	12.49±0.15	36.35^{c}±0.57	3.16^{e}±0.02	5630.32	4338.96	3.36^{d}
CV (%)	5.20	5.47	2.67	5.74	5.94	-	-	2.35
Level of significance	*	*	NS	*	*	-	-	*

NS, Non-significant. Means in a column followed by the same letter(s) or without letter(s) are not significantly different at the 5% level by DMRT. *Significant at 5% level of probability.

Treatment details are given under Materials and Methods.

by crop geometry and highest bulb weight (125.7 g) was observed in 15 cm × 15 cm spacing pursued by 12.5 cm × 12.5 cm (78.8 g) and 10 cm × 12.5 cm (71.3 g) whereas, minimum bulb weight (49.4 g) was experiential in 7.5 cm × 7.5 cm. Closer geometry (7.5 cm ×7.5 cm) or higher plant density (169–177 plants/m) resulted in struggle among plants for ground spacing, consequently short bulb size, whereas, the plants grown in wider spacing or lower plant density (42–47 plants/m) produced more photosynthates which encouraged the bulb size (Amare *et al*. 2020). Highest premature bolting (10%) was reported under closest plant geometry, which was significantly higher than other crop geometry, whereas few numbers of bolted plants (6.1%) were found in 15 cm × 15 cm plant geometry. The results of these findings are in line with those reported by Walle *et al*. (2018) in onion bulb crop. Overall quantity of bulbs and biological yield significantly enhanced by way of reduce in crop spacing, and maximum bulbs (58.4 t/ha) and biological yield (118.7 t/ha) were produced at 7.5 cm × 7.5 cm, which was considerably higher from that produced under wider crop spacing and the minimum biological yield (60.0 t/ha) was produced from the most thinly planted plots. The least quantity of unsalable bulbs (2.2 t/ha) was produced in 12.5 cm × 12.5 cm planting spacing followed by 10 cm × 12.5 cm (3.1 t/ha), while maximum unsalable bulbs (28.2 t/ha) with least value of harvest index (25.4) were achieved in 7.5 cm × 7.5 cm crop geometry. Wider spacing is the major reason for producing more yields per plant, even if onions planted at closer spacing produce more bulbs in per ha area due to higher plant intensity up to a definite limit (Walle *et al*. 2018, Mahala *et al*. 2019). Accurately planted onion plots (10 cm × 10 cm and 12.5 cm × 10 cm) tended to have high quantity of total soluble solids (13.0°Brix and 12.8°Brix), while the minimum quantity of total soluble solid (12.2°Brix) was obtained from thickly planted onion plots (7.5 cm × 7.5 cm). Marketable yield (40.2 t/ha), total income (6237.2 USD), net income (4971.7 USD) and B:C ratio (3.92) were the highest at the precise spacing 12.5 cm × 12.5 cm, which was pursued by 10 cm × 12.5 cm, whereas uppermost biological yield (118.7 t/ha) and total bulb yield (58.4 t/ha) was produced in closest crop spacing (7.5 cm × 7.5 cm). Rising the crop spacing from 7.5 cm × 7.5 cm to 10 cm × 10 cm increased the saleable onion bulbs yield (32.87%), total income (33.06%), net income (45.28%) and B:C ratio (45.19%) and additional increase from 10 cm × 10 cm to 12.5 cm × 12.5 cm significantly decreased the saleable onion bulbs yield (22.10%), total income (22.15%), net income (27.79%) and B:C ratio (27.81%). Comparable effects were also reported by Walle *et al.* (2018) in onion bulb crop.

Response to N-P-K-S nutrient levels and crop geometry: Uppermost values of vegetative growth parameters were reported with more spacious planting geometry with highest level of N-P-K-S nutrients i.e. 140 N-80 P-80 K-40 S kg/ha + 15 cm × 15 cm, which was followed by 120 N-60 P-60 K-30 S kg/ha + 15 cm × 15 cm and lowest value was recorded with 100 N-40 P-40 K-20 S kg/ha + 7.5 cm × 7.5 cm treatment (Table 1 and Fig. 1). Results were having harmony with the findings of Mahala *et al.* (2019). Highest premature bolting (10.6%) was reported in closer plants geometry with lowest dose of N-P-K-S nutrients i.e. 100 N-40 P-40 K-20 S kg/ha + 7.5 cm × 7.5 cm, followed by 120 N-60 P-60 K-30 S kg/ha + 7.5 cm × 7.5 cm whereas, minimum quantity (5.7%) of bolted onion plants were observed in wider planting geometry with uppermost dose of N-P-K-S fertilizers (140 N-80 P-80 K-40 S kg/ha + 15 cm × 15 cm). Each increase in level of N-P-K-S nutrients and crop geometry non-significantly enhance the solitary weight of bulb and premier bulb weight (133.9 g) was found in 140 N-80 P-80 K-40 S + 15 cm × 15 cm treatment, which was followed (125.4 g) by 120 N-60 P-60 K-30 S + 15 cm × 15 cm. It was apparent that the closest plant spacing with highest level of fertilizer (140N-80 P-80 K-40 S + 7.5 cm × 7.5 cm) produced highest bulb yield (61.8 t/ha), onion crop biological yield (125.8 t/ha) and unsalable bulb (29.5 t/ha) closely pursued by 120 N-60 P-60 K-30 S + 7.5 cm × 7.5 cm treatment and lowest bulb yield and unmarketable bulb was reported in 100 N-40 P-40 K-20 S + 12.5 cm × 12.5 cm treatment. The highest quantity of split bulb was recorded in 140 N-80 P-80 K-40 S + 15 cm × 15 cm treatment (6.6 t/ha) which was closely followed by 120 N-60 P-60 K-30 S + 15 cm × 15 cm; 100 N-40 P-40 K-20 S + 15 cm × 15 cm and the lowest quantity of split bulb was recorded in 100 N-40 P-40 K-20 S + 7.5 cm × 7.5 cm treatment (1.2 t/ha). The maximum harvest index (51.2) was produced at spacious geometry with uppermost dose of N-P-K-S (140 N-80 P-80 K-40 S + 15 cm × 15 cm) and closely followed by 100 N-40 P-40 K-20 S + 12.5 cm × 12.5 cm (51.2) and 120 N-60 P-60 K-30 S + 12.5 cm × 12.5 cm (51.0), which increased the parameter by about 104.14, 103.98 and 103.51%, respectively compared with the control (100 N-40 P-40 K-20 S + 7.5 cm × 7.5 cm). Bulb TSS content was non-significantly influenced by application of N-P-K-S nutrient levels and crop geometry. Aanalogous, findings were also reported by Walle *et al*. (2018) and Amare *et al*. (2020). The highest saleable fresh bulb yield (43.6 t/ha), total income, (6753.8 USD), net income (5462.4 USD) and B:C ratio (4.23) were recorded with the application of 140 N-80 P-80 K-40 S + 10 cm × 10 cm treatment, which was narrowly followed by 120 N-60 P-60 K-30 S + 10 cm × 10 cm and lowest values was obtained from 100 N-40 P-40 K-20 S + 7.5 cm × 7.5 cm treatment due to additional production (27.2 t/ha) of unsalable bulbs. These findings are in harmony with the previous findings of Mahala *et al*. (2019).

Based on the present research findings, it can be concluded that increase in onion productivity and bulb quality by application of balanced dose of N-P-K-S nutrients and adequate crop geometry may be a better option in terms of utmost utilization of available ground space with minimum fertilizer wastage. Therefore, it could be recommended that onion seedlings for *kharif* season should be transplanted at spacing of 10 cm × 10 cm along with application of 140 N-80 P-80 K-40 S kg/ha to attain highest saleable yield and higher income.

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