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Effect of different crop management practices for better economic returns from *Kharif* onion

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Abstract

The present study was undertaken at the Agricultural Research Substation, Sumerpur-Pali to find out the effect of different fertilizer levels and crop geometry on *kharif* onion (*Allium cepa* L.) production. The experiment was laid out in split plot design with NPKS levels as main plot and crop geometry as subplot with three replications. Spacious crop geometry with highest dose of fertilizer (15 cm x 15 cm + 140 N: 80 P: 80 K: 40 S kg ha^{-1}) produced maximum plant height (98.20 cm), leaves plant^{-1} (20), bulb polar diameter (79.34 mm), equatorial diameter (85.10 mm), bulb weight (137.44 g) and harvest index (51.30) with huge quantity of split/multiplier bulbs (6.54 t ha^{-1}). Marketable yield (43.71 t ha^{-1}), gross return (₹ 5.25 lakhs), net return (₹ 4.25 lakhs) and B: C ratio (4.25) were higher in the closer crop geometry (10 cm x 10 cm) with highest dose of fertilizer, whereas maximum biological yield (126.75 t ha^{-1}) and total bulb yield (61.60 t ha^{-1}) were reported in the closest spacing with highest dose of fertilizer (7.5 cm x 7.5 cm + 140 N: 80 P: 80 K: 40 S kg ha^{-1}), which also produced the highest quantity (28.69 t ha^{-1}) of unmarketable bulbs. It is concluded that for maximum production of better quality of *kharif* onion bulb, the seedlings should be planted at 10 cm x 10 cm spacing with the highest level of fertilizer dose (140 N: 80 P: 80 K: 40 S kg ha^{-1}).

Keywords: *Allium cepa*, bolting, crop geometry, nutrient, polar diameter, productivity, split bulb

Introduction

Onion (*Allium cepa* L.) is extensively used for its precise flavour and pungency as spice crop not only for domestic utilization but also as overseas exchange earner. During the year 2020-21 India exported 15.78 lakhs MT of fresh onion worth ₹ 2826.5 crores (378.49 million USD million) (Anonymous 2021). India is the 2nd largest producer of onion in the world next only to China with 26.64 million tons produced from 1.62 million hectares area in 2021-22. Productivity of onion in India is very low *i.e.* 16.44 tons as compared to the China and other countries like, the Republic of Korea (66.15 t ha^{-1}), USA (56.13 t ha^{-1}), Netherlands (51.64 t ha^{-1}), Japan (46.64 t ha^{-1}) and Egypt (36.16 t ha^{-1}). Among onion growing states Maharashtra stands first followed by Karnataka, Gujarat, Bihar, Madhya Pradesh, Andhra Pradesh, Rajasthan, Haryana, Uttar Pradesh and Tamil Nadu. The estimated total area under onion in Rajasthan was about 74.61 thousand hectares, from which 1241.78 thousand tonnes were produced with 16.63 tons productivity in 2020-21 (Anonymous 2021). The reasons affecting onion production could be improper crop geometry and poor fertilizer application and implementation of unscientific agronomic management practices. Onions have a superficial, non branched root system in the top 25-30 cm of soil which is less effective than other crops at extracting soil nutrients (Brewster 2008). It was apparent from the available data that supplying of nitrogen, phosphorus and potassium with sulphur was helpful for obtaining more bulb yield with good quality. Existing literatures have shown that NPKS mineral nutrition alone or in combination had a major effect on the growth, maturity, productivity and quality of onion crop (Mazumder *et al*. 2019). The optimum fertilizer requirement for the crop is reported as 95 to 150 kg N, 13 to 57 kg P, and 42 to 133 kg K ha^{-1} for average yields of 10 to 30 t ha^{-1}(Amin *et al*. 2007; Lee *et al*. 2011; Mandal *et al*. 2020). Similarly, soil application of FYM @ 15 t ha^{-1} and NPK @125:100:100 kg ha^{-1} along with sulphur 40 kg ha^{-1} are appropriate to gain higher yield benefit in onion (Mandal *et al*. 2020). Nitrogen is necessary for growth and yield of onion but application of higher doses cause hindrance in bulb maturity (Aliyu *et al*. 2007). Phosphorus and potassium are needed for metabolic processes such as production and transport of carbohydrates and sugars, protein synthesis, imparting resistance to pests and diseases, activation of enzymes, reduced stalk and stem breakage and tolerance to stress conditions, storage quality, increased bulb size and bulb yield, but extra dose cause micro nutrient deficiency (Pachauri *et al*. 2005; El-Desuki *et al*. 2006). Sulphur is required in onion crop for typical aroma, pungency, oil content and is beneficial for other quality parameters (Meher *et al*. 2016; Mondal *et al*. 2020), additional dose is harmful for the crop due to antagonistic effects with different nutrients. Hence it is important to determine the precise dose of NPKS fertilizer for better economic returns from onion. On the other hand, optimal plant density is a pre-requisite for maximum yield, it avoids competition between plants for growth factors such as water, nutrient, CO_2, light and enables efficient use of available crop land without wastage (Awas *et. al*. 2010). Keeping this in view, the present study was carried out to find out the suitable crop geometry and doses of NPKS fertilizers and their combination for high production of quality bulbs of onion.

Materials and Methods

The research was carried out during August to November, 2020 at the Agricultural Research Substation, Sumerpur-Pali (Rajasthan). The experimental field is situated at 73° 05′ East longitude and 25° 09′ North latitude with an altitude of 272.0 m above MSL. The centre is grouped under arid region with a rainfall of 356.8 mm, RH 48.25% and means maximum temperature of 33° C and mear minimum tolerance of 19.5° C during experimentation. The experimental site had a soil pH of 8.2, EC 0.30 ds/m with 0.25 percent organic carbon. It has 28 kg P_2O_5 ha^{-1}, 139 kg K_2O ha^{-1}, 6.5 ppm S, 0.16 ppm Zn, 1.26 ppm Fe, 0.20 ppm Cu and 0.82 ppm Mn. The soil was 8, 30 and 62 percent clay, silt and sand respectively, which confer sandy-loamy soil texture. The 15 treatment combinations consisted of three levels of NPKS fertilizer (F_1 100 N: 40 P: 40 K: 20 S; F_2 120 N: 60 P: 60 K: 30 S; F_3 140 N: 80 P: 80 K: 40 S) kg ha^{-1}, and five crop geometries (S_1 7.5 cm x 7.5 cm, S_2 10 cm x 10 cm, S_3 12.5 cm x 12.5 cm, S_4 15 cm x 15 cm and S_5 12.5 cm x 10 cm). The plot size was 3 m × 90 cm on raised bed with drip irrigation and adjacent plots and blocks were 1.0 m and 1.5 m apart, respectively. Experimental data were collected from the middle rows of each plot leaving one plant at both ends of a row.

Full dose of well rotten FYM (25 t ha^{-1}), and treatment wise full dose of phosphorus, potash, sulphur, 1/3 of N were applied during land preparation and 50 days old Agri found Light Red variety seedlings were used for experimentation. The doses of nitrogen fertilizer as urea (46% N), phosphorus fertilizer as DAP (48% P_2O_5 + 18% N), potassium fertilizer as Muriate of Potash (60% K_2O) and sulphur as Sulfex Gold (Sulphur 80% w/w) were used. The rest of N was applied in two equal splits as top dress at 30 and 60 days after transplanting. All other advocated cultural practices including irrigation, gap filling, weeding, diseases and pest management concerning onion production were done as and when required. Transplanting of seedlings was carried during 28-29 July and harvesting was done during 13-15 November, when the leaves turned yellow and dried at the top with more than 50 per cent top leaf fall visible. The bulbs were kept on the open floor under foliage for curing for three days.

Observations on plant height, number of leaves, neck diameter were taken from ten randomly selected competitive plants in each treatment and replication at 15 days before harvesting. Plant height was measured from ground level to the tip of the longest leaf. The number of fully grown, green and photosynthetically active leaves were recorded. The neck diameter below the joint of leaf lamina was measured with the help of digital vernier caliper. After harvesting, bulb polar and equatorial diameters were measured using vernier caliper and expressed in millimeter. Root length was measured by the help of measuring scale and expressed in centimeter. Number of roots plant^{-1} and root weight were calculated by standard counting and weighing respectively. All the bulbs harvested plot wise were weighed after separating above ground portion. Total bulb yield, split bulb yield, unmarketable bulb, biological yield and marketable yield ha^{-1} were calculated from the yield obtained ha^{-1}. The TSS was determined by hand refractometer (ATAGO TC-1E) with a range of 0 to 32 °Brix and resolutions of 0.2 °Brix by placing 1 to 2 drops of clear juice on the prism, washed with distilled water and dried with tissue paper before next use. The refractometer was standardized against distilled water (0% TSS). The gross return was calculated from yield multiplied by average market rate during the period of investigation. Further, the net return was calculated by subtracting cost of each treatment from gross return. The benefit cost ratio was calculated by dividing net return to total cost of cultivation. The cost of cultivation included expenses incurred in land preparation, seedling transplanting, intercultural operation, fertilizer, crop protection measures, irrigation water and harvesting with labour charges.

Harvest index (%): The harvest index was calculated by dividing marketable bulb yield per hectare by total biological yield per hectare on fresh weight basis and it was expressed in percentage.

$$\text{Harvest index (\%)} = \frac{\text{Marketable bulb yield (t ha}^{-1}\text{)}}{\text{Total biological yield (t ha}^{-1}\text{)}} \times 100$$

Unmarketable bulbs (culls): Unmarkable bulbs were determined through subjective evaluation and recorded as the weight of diseased, decayed, insect attacked and abnormal bulbs including multiple bulbs, bolted bulb, thick necked bulbs, too small bulbs (below 30 g weight) too large bulbs etc. at harvest. Data on yield and quality parameters were collected from ten randomly selected plants of each unit plot and averaged. Data was analysed using Statistical Analysis System (SAS) software (Version 9.1) and differences among means were compared at $P< 0.05$.

Results and Discussion

Effect of crop geometry

Arithmetical examination of the data presented in Table 1 and Figure 1 showed that the plant growth factors were significantly influenced by crop geometry and increased with increase in spacing. The highest plant height (87.40 cm), leaves plant^{-1} (17.83), neck diameter (21.75 mm), bulb polar diameter (71.09 mm), equatorial diameter (73.94 mm), root length (10.23 cm), number of roots plant^{-1} (134.35), root weight plant^{-1} (6.17 g) were recorded in 15 cm × 15 cm spacing, closely followed by 12.5 cm x 12.5 cm and least value of all these growth attribute was recorded in closest spacing of 7.5 cm × 7.5 cm. Wider spacing led to enhanced vegetative growth due to extra availability of light, space and air contributing for more photosynthesis which might have been the cause for increased number of leaves and ultimately leaf area plant^{-1}, whereas in closer spacing there was inter-plant competition for growth factors (Mazumder *et al*. 2019). Similarly, widest crop geometry produced maximum plant height, number of leaf plant^{-1}, bulb diameter and individual bulb weight but the values of these parameters leaves decreased with declining plant geometry. Similar results were also reported by Jilani *et al.* (2010) and Ngullie and Biswas (2017). The maximum bulb weight (128.22 g) was recorded in 15 cm x 15 cm crop geometry followed by 12.5 cm x 12.5 cm spacing (81.21 g) and optimum bulb weight (69.43 g) 10 cm x 10 cm crop geometry while lowest bulb weight (50.08 g) was recorded at 7.5 cm x 7.5 cm spacing. The nearer crop geometry caused crop competition for water, nutrient and light thus resulting in small bulb size, while, the plants grown in wider crop geometry produced more green leaves and extra food which enhanced the bulb size and weight. Similar findings were also reported by Saud *et al*. (2013), Harris *et al*. (2016) and Amare *et al*. (2020) for onion crop. Bolting increased with increase in plant population and highest bolting (10.48%) was noticed with minimum crop geometry (7.5 cm x 7.5 cm), whereas least number of bolted plants (6.15%) was observed in 15 cm x 15 cm crop geometry. This could be attributed to comparative augmentation of crop competition for essential inputs and spacing, when crop geometry decreases, it enhances struggle for crop growth factors and physiological stress leading to premature bolting. The outcome of this finding is in concordance with those reported by Godara and Mehta (2013) and Walle *et al*. (2018) for onion crop. Total bulb yield and biological yield considerably increased with decrease in crop geometry, and highest bulb yield (59.20 t ha^{-1}) and biological yield (120.42 t ha^{-1}) were obtained in 7.5 cm x 7.5 cm crop geometry, which was significantly superior to that obtained under other wider crop geometries and the lowest biological yield (61.42 t ha^{-1}) was from the most sparsely populated plots (15 cm x 15 cm). The enhancement of total bulb yield and biological yield in closest crop geometry could be recognized to the larger leaf area or avoidance of wastage in light energy due to coverage by dense plant population that could increase photosynthetic rate per unit area resulting in more incorporation of stored food material in to leaves and bulbs. Spacious crop geometry caused higher yield per plant, although the nearer crop geometry produced higher yield per unit area due to increased plant density up to a certain limit (Walle *et al*. 2018). This is in agreement with the findings of (Jilani *et al*. 2010; Harris *et al*. 2016; Mahala *et al*. 2019).

The quantity of unmarketable bulbs increased significantly due to increasing plant population density (closer geometry) and the least quantity (2.30 t ha^{-1}) of unmarketable bulbs were obtained at 12.5 cm x 12.5 cm geometry followed by (3.29 t ha^{-1}) at 12.5 cm x 10 cm geometry, whereas highest unmarketable bulbs (28.69 t ha^{-1}) with lowest harvest index (25.33) was obtained at 7.5 cm x 7.5 cm geometry. The unmarketable bulbs obtained at 7.5 cm x 7.5 cm significantly exceeded those obtained at 10 cm x 10 cm, 12.5 cm x 12.5 cm, 15 cm x 15 cm and 12.5 cm x 10 cm crop geometry by about 558.17, 1247.39, 399.58 and 872.04 percent, respectively. Lowest harvesting index and additional quantity of unmarketable bulbs were obtained when the crop was planted at 7.5 cm x 7.5 cm distance, which could be attributed to decreased average bulb sizes, premature bolting, inferior quality bulb, and augmentation in the number of very small bulbs (cull bulbs) resulting in significantly reduced economic yield due to crop rivalry for growth factors. Previous studies (Harris *et al*. 2016; Walle *et al*. 2018) also reported that onions grown at close crop geometry resulted in large quantity of smaller and irregular shaped bulbs produced. Among the different crop geometries evaluated in this study, precisely populated plots (10 cm x 10 cm and 12.5 cm x 10 cm) had higher values of total soluble solids (13.25 °Brix and 12.92 °Brix), whereas the lowest values of total soluble solids (12.50 °Brix), was observed in plants grown in densely populated plots (7.5 cm x 7.5 cm). Similar results were also observed by Walle *et al*; (2018) Amare *et al*. (2020).

Marketable yield (41.03 t ha^{-1}), gross return (₹ 4.92 lakhs), net return (₹ 3.94 lakhs) and B: C ratio (4.02) were highest in 10 cm x 10 cm followed by 12.5 cm x 10 cm crop geometry, whereas highest biological yield (120.42 t ha^{-1}) and total bulb yield (59.20 t ha^{-1}) were reported in nearer crop geometry (7.5 cm x 7.5 cm) planting. This may be due closer spacing were the bulb size was small and was not preferred by the consumers and hence a huge quantity (28.69 t ha^{-1}) of bulbs was unmarketable. On the other hand, wider spacing (15 cm x 15 cm) produced large quantity (6.20 t ha^{-1}) of split/ multiplier bulbs that were not good for storing and had low consumer demand. Increasing the crop geometry from 7.5 cm x 7.5 cm to 10 cm x 10 cm raise the marketable bulb yield, gross return, net return and B: C ratio further by 34.48, 34.43, 47.01, and 47.25 per cent respectively, but further widening the crop geometry did not increase in yield and economic parameters. These results illustrate that plants grown at 10 cm x 10 cm spacing produced the highest marketable bulb yields and it is the suitable crop geometry for onion production. Similar results were also reported by Gebretsadik and Dechassa (2016) and Harris *et al*. (2016) for onion.

Effect of NPKS fertilizer levels

Vegetative growth characteristics were considerably affected by different levels of NPKS fertilizer (Table 1). The maximum plant height (79.11 cm), leaves plant^{-1} (16.05), neck thickness (19.07 mm), bulb polar diameter (63.84 mm), equatorial diameter (64.31 mm), root length (8.03 cm), number of roots plant^{-1} (129.64), root weight plant^{-1} (4.35) were obtained with a high rate of NPKS fertilizer (140 N: 80 P: 80 K: 40 S kg ha^{-1}) in F_3 treatment and followed by F_2 treatment (120 N: 60 P: 60 K: 30 S kg ha^{-1}) and lowest value of all these parameters was recorded in F_1 treatment (100 N: 40 P: 40 K: 20 S kg ha^{-1}). Application of adequate amount of NPKS leads to synthesis of more amounts of photosynthates used for the growth of vegetative parts and plant becomes vigorous and tall. Nitrogen causes better expansion of roots system in plants, which enhances the plant to absorb more water from the soil and amplify the uptake and utilization of additional necessary nutrients by increasing the root surface area. Moreover, phosphorus and potassium are essential for different biochemical functions in the physiological processes, like translocation of photosynthesis assimilates, respiration, opening and closing of stomata, osmotic regulation and as activator of enzymes (Resende and Costa 2014). It is apparent from data listed in Table 1 that the highest (8.74%) premature bolting was observed with lesser dose of fertilizer (100 N: 40 P: 40 K: 20 S kg ha^{-1}) whereas, least quantity (7.40 %) of bolting was observed in highest dose of fertilizer (140 N: 80 P: 80 K: 40 S kg ha^{-1}). Lower dose of nutrient enhance premature bolting by means of enhanced crop competition for nutrients. Inadequate nutrients increasing premature bulbs bolting have been also reported by Harris *et al*. (2016) in onion. It is revealed from the data presented in Table 2 and figure 1 that there is significant effect of different levels of NPKS fertilizer and caused a linear increase in bulb weight, bulb yield ha^{-1} and biological yield ha^{-1} of onion. Increasing the rate of NPKS fertilizer from F_1 treatment to F_2 treatment markedly increased in bulb weight (8.32%), bulb yield ha^{-1} (8.10%) and biological yield ha^{-1}(8.62%), whereas rising the rate from F_2 treatment to F_3 treatment increased bulb weight (4.12%), bulb yield ha^{-1} (3.65%) and biological yield ha^{-1} (4.75%). Therefore, addition of NPKS fertilizer above F_3 treatment may not increase the yield significantly. In the same way, (Sharma *et al.* 2017) recommended that applying 20 t ha^{-1} FYM and NPK @ 125-100-100 kg ha^{-1} for obtaining higher yield and economic attributes in onion. A gradual increase in the production of unmarketable and split bulbs was found when levels of NPKS fertilizer were increased (Table 2 & Figure 2). The lowest production of unmarketable (9.21 t ha^{-1}) and split bulbs (3.40 t ha^{-1}) was estimated with the dose of 100 N: 40 P: 40 K: 20 S kg ha^{-1} (F_1 treatment). These outcomes demonstrate the responsiveness of onion to NPKS fertilizers application and verify the results by different authors (Resende and Costa 2014), who report

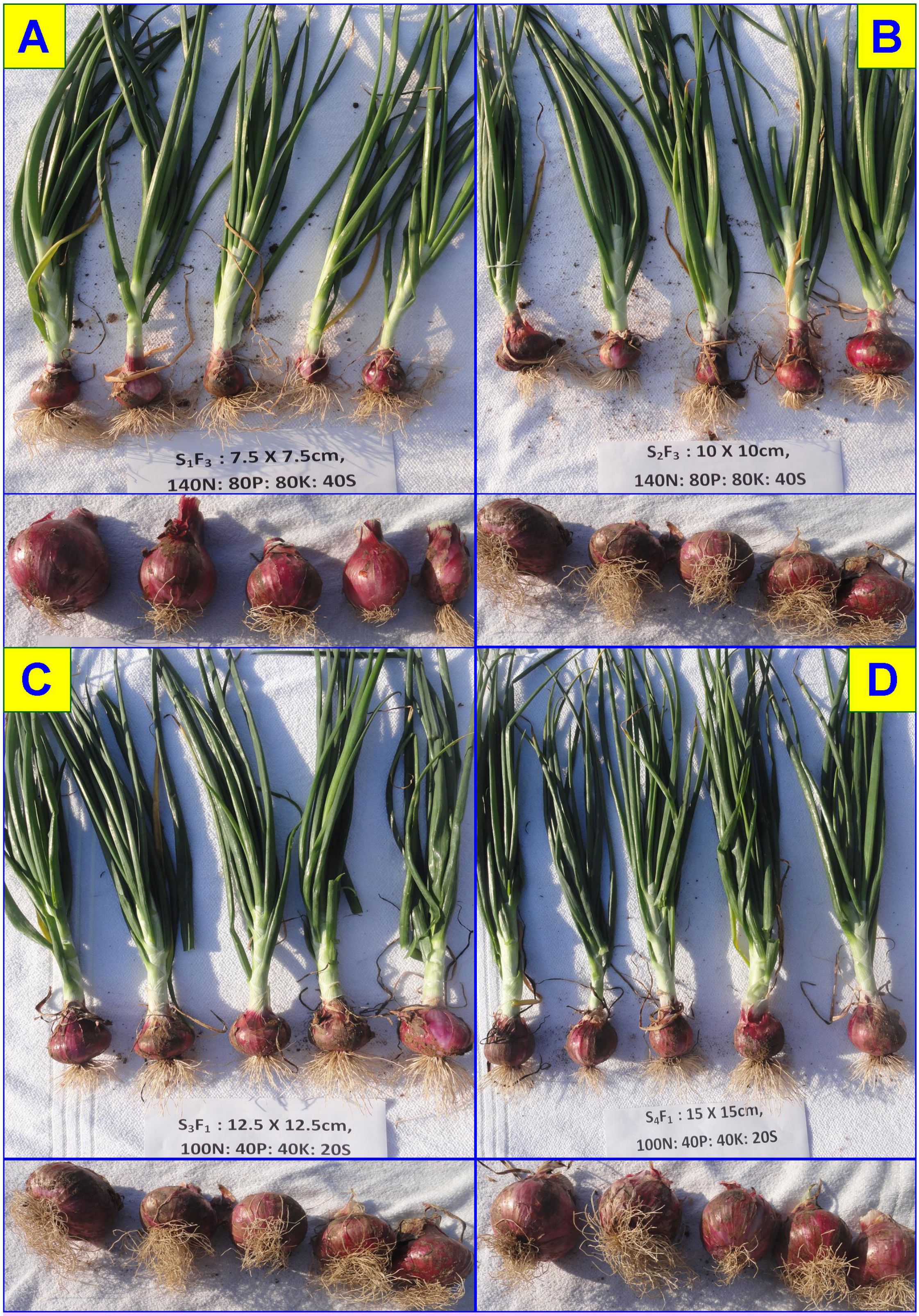

Fig. 1. Effect of crop geometry and NPKS fertilizer levels on yield parameters of onion

Fig. 2. Bulb splitting in wider crop geometry (15 cm x 15 cm)

that the nutrients contribute markedly to better yield of onion crop. Highest harvest index (44.93) obtained in F_2 treatment could be attributed to non-significant decline of marketable bulb yield (economic yield) in response to rising rate of NPKS levels from F_2 treatment to F_3 treatment which may have led to extravagant growth of vegetative parts (biological yield) at the expense of growth and development of bulbs. These results are in agree with those of Gebretsadik and Dechassa (2016) for onion. Data presented in Table 2 showed that NPKS combinations had significant effect on onion bulb quality parameters in terms of TSS. In this direction, the medium level of applied NPKS fertilizer (120 N: 60 P: 60 K: 30 S kg ha^{-1}) was more effective for higher TSS (13.0 °Brix). The influence of NPKS fertilizers on qualitative characteristics Jilani *et al*. (2003). The highest marketable bulb yield (36.04 t ha^{-1}), gross return, (₹ 4.32 lakhs), net return (₹ 3.32 lakhs) and B: C ratio (3.32) was recorded at F_3 treatment. Increasing the level of NPKS from F_1 treatment to F_2 treatment markedly increased marketable bulb yield (10.23%), gross return (10.08%), net return (12.81%) and B: C ratio (10.96%), however increasing the rate of NPKS from F_2 treatment to F_3 treatment undoubtedly increased marketable bulb yield further (4.19%), gross return (4.10%), net return (4.73%) and B: C ratio (2.47%) in diminishing pattern. Thus, F_3 treatment resulted in the production of optimum fresh marketable bulb yield with maximum gross return, net return and B:C ratio.

Interaction effect of crop geometry and levels of NPKS fertilizer

Data presented in Table 1 showed that different levels of NPKS fertilizer and crop geometry had considerable effect on onion vegetative growth parameters. In this way, the higher level of applied NPKS fertilizer (140 N: 80 P: 80 K: 40 S kg ha^{-1}) with widest crop geometry (15 cm x 15 cm) treatment S_4F_3 was more effective for all vegetative growth parameters, which was closely followed by treatment S_4F_2 (15 cm x 15 cm with 120 N: 60 P: 60 K: 30 S kg ha^{-1}) than those of other treatments and lowest NPKS levels (100 N: 40 P: 40 K: 20 S kg ha^{-1}) with closer crop geometry (7.5 cm x 7.5 cm) treatment S_1F_1 which had lowest values of growth parameters. The maximum plant height (98.20 cm), number of leaves $plant^{-1}$ (20), neck diameter (23.23 mm), bulb polar diameter (79.34 mm), equatorial diameter (85.10 mm), root length (11.44 cm), number of roots $plant^{-1}$ (140.04), root weight $plant^{-1}$ (6.50) were obtained in wider crop geometry with a high rate of NPKS in S_4F_3 treatment (15 cm x 15 cm + 140 N: 80 P: 80 K: 40 S kg ha^{-1}) followed by S_4F_2 treatment (15 cm x 15 cm + 120 N: 60 P: 60 K: 30

S kg ha^{-1}). The lowest plant height (53.44 cm), number of leaves plant^{-1} (8.50), neck diameter (11.79 mm), bulb polar diameter (46.35 mm), equatorial diameter (41.37 mm), root length (5.14 cm), number of roots plant^{-1} (106.03), root weight plant^{-1} (2.89) and leaf bulb ratio (0.94), were recorded with S_1F_1 treatment (7.5 cm x 7.5 cm + 100 N: 40 P: 40 K: 20 S kg ha^{-1}). These findings are in agreement with previous results (Islam *et al*. 2008; Barman *et al*. 2013; Kumara *et al*. 2018; Mahala *et al*. 2019). The decrease in bulb circumference in response to decreased crop geometry could be attributed to the availability of lower amount of photosynthate due to the increasing competition among plants (Ngullie and Biswas 2017). It is clear from data presented in Table 1 that the highest (11.44%) premature bolting was observed with closer crop geometry and lesser dose of nutrient combinations (7.5 cm x 7.5 cm +100 N: 40 P: 40 K: 20 S kg ha^{-1}), followed by S_1F_2 treatment (10.50%) whereas, least number (5.50 %) of bolted plants was observed in widest crop geometry with highest dose of nutrients (15 cm x 15 cm +140 N: 80 P: 80 K: 40 S kg ha^{-1}). These results might be due to inadequate space and nutrient shortage which creates crop antagonism and stress resulting in enhanced bolting. Opposite results were also reported by Hannaalla *et al*. (1991). Each increase in NPKS fertilizer level and spacing recorded increase in weight of bulb significantly and the highest bulb weight (137.44 g) was reported in S_4F_3 treatment, which was followed by (127.22 g) S_4F_2 treatment (Figure 1). Similarly, the combined effect of fertilizer doses and crop geometry had significant effect on growth and yield parameters of onion (Aliyu *et al.* 2008; Jilani *et al* 2009; Islam *et al*. 2015). It was evident that the closest spacing with highest dose of nutrients (7.5 cm x 7.5 cm + 140 N: 80 P: 80 K: 40 S kg ha^{-1}) produced maximum bulb yield (61.61 t ha^{-1}), biological yield (126.75 t ha^{-1}) and unmarketable bulb (29.26 t ha^{-1}) followed by (bulb yield (59.28 t ha^{-1}), biological yield (121.19 t ha^{-1}) and unmarketable bulb (28.45 t ha^{-1}) in S_1F_2 treatment (7.5 cm x 7.5 cm + 120 N: 60 P: 60 K: 30 S kg ha^{-1}). The lowest bulb yield (32.20 t ha^{-1}) and unmarketable bulb yield (2.25 t ha^{-1}) was reported in S_3F_1 treatment. This is due to increase in plant density which in turn contributed to enhanced bulb yield and biological yield but the bulb dimension and weight reduced resulting in increased unmarketable bulb yield considerably. Comparable results were also reported by Godara and Mehta (2013); Ngullie and Biswas (2017) for onion crop. Statistical analysis of the data presented in Table 2 showed that the quantity of split bulbs significantly increased in wider crop geometry with highest dose of nutrients S_4F_3 (15 cm x 15 cm +140 N: 80 P: 80 K: 40 S kg ha^{-1}). The maximum quantity of split bulb (6.54 t ha^{-1}) was recorded in S_4F_3 treatment closely followed by S_4F_2 treatment (6.51 t ha^{-1}), S_4F_1 treatment (5.54 t ha^{-1}) and the minimum quantity of split bulb (1.20 t ha^{-1}) was recorded in S_1F_1 treatment. Hence, the results of this study indicated that higher dose of NPKS fertilizers and wider crop geometry enhanced metabolic activities within plant, which improved vegetative growth and storage of large amount of metabolites in bulbs resulting in enhanced splitting of bulbs (Figure 2). Moreover, excess fertilization, irregular watering and temperature variations are all believed to influence split bulbs formation, which reduced their marketable demand (Boyhan *et al*. 2001).

The highest harvest index (51.30) was observed at wider crop geometry with highest dose of nutrients S_4F_3 (15 cm x 15 cm +140 N: 80 P: 80 K: 40 S kg ha^{-1}) closely followed by S_3F_2 treatment (51.26), S_3F_1 treatment (50.66), which increased the parameter by about 104.95 percent, 104.79 and 102.40 percent compared with the control (S_1F_1). Similar results were also reported by (Abdissa Yohannes *et al.* 2011) for onion. Among different treatments evaluated in this study the bulb TSS was insignificantly affected by different treatments and exactly populated plots (10 cm x 10 cm and 12.5 cm x 10 cm) with medium level of fertilizer (120 N: 60 P: 60 K: 30 S kg ha^{-1}) produced better quality of onion bulbs. Highest value of total soluble solids (13.50 °Brix and 13.24 °Brix) was observed in S_2F_2 and S_2F_3 treatments respectively, whereas the minimum values of total soluble solids (12.0 °Brix) was recorded with S_1F_1 treatment (7.5 cm x 7.5 cm + 100 N: 40 P: 40 K: 20 S kg ha^{-1}). Similarly, Khalil *et al*. (1988) deduced that, increasing application of fertilizers insignificantly enhanced quality parameters in mature onion bulbs. Marketable fresh bulb yield, gross return, net return increased non significantly and B:C ratio also increased appreciably with the increase in the rate of fertilizer levels with optimum crop geometry (Table 2). Thus, the highest marketable fresh bulb yield (43.71 t ha^{-1}), gross return, (₹ 5.25 lakhs), net return (₹ 4.25 lakhs) and B: C ratio (4.25) were recorded in S_2F_3 treatment (10 cm x 10 cm + 140 N: 80 P: 80 K: 40 S kg ha^{-1}), which was closely followed by S_2F_2 treatment (10 cm x 10 cm +120 N: 60 P: 60 K: 30 S kg ha^{-1}) with marketable fresh bulb yields (42.10 t ha^{-1}), gross return, (₹ 5.05 lakhs), net return (₹ 4.07 lakhs) and B:C ratio (4.16). The lowest marketable fresh bulb yield (28.36 t ha^{-1}), gross return (₹ 3.40 lakhs), net return (₹ 2.44 lakhs) and B:C ratio (2.55) were obtained in S_1F_1 treatment (7.5 cm x 7.5 cm +100 N: 40 P: 40 K: 20 S kg ha^{-1}) due to additional production (28.36 t ha^{-1}) of unmarketable bulbs. This shows that higher levels of NPKS with medium crop geometry improves marketability or decreases quantity of unmarketable onion bulbs through the positive role it plays in increasing average bulb weight. Widening the crop geometry tended to decrease the yield of unmarketable bulbs but linearly decreased the total bulb production, whereas closer crop geometry produced the highest unmarketable bulb (small sized and misshaped) yields due to the stiff inter plant competition for growth factors. In the widest crop geometry, production of significant quantity of extra large bulbs may contribute to the amount unmarketable bulb yield due to stumpy inter plant competition. These results are in accordance with the earlier findings (Lee *et al*. 2011; Barman *et al*. 2013; Kumara *et al*. 2018; Mahala *et al*. 2019).

Conclusion

The results showed that the different crop geometry and levels of NPKS fertilizer had significant effects on growth, yield and economic parameters of *kharif* onion individually, as well as in combination. Highest marketable bulb yield, gross return, net return and B:C ratio were obtained in the combination of optimal crop geometry with highest level of NPKS fertilizer treatments. Therefore, it could be concluded that onion variety Agrifound Light Red should be planted during the *kharif* season at optimum spacing of 10 cm x 10 cm with application of 140 N: 80 P: 80 K: 40 S kg ha^{-1} to attain maximum marketable bulb yield, gross return, net return and B:C ratio in sandy loam soil under arid climate conditions.

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