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Effect of fertigation pattern and planting geometry on growth, yield and water productivity of tomato (*Solanum lycopersicum*)

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ABSTRACT

Field study was conducted on a sandy loam soil during 2012-13 and 2013-14 in per-humid region of India to investigate the effects of fertigation patterns and planting geometries on crop growth, yield and water productivity (WP) of tomato (*Solanum lycopersicum* L.) hybrid variety Swarna Sampada. Three fertigation patterns, viz. almost uniform dose per fertigation event (FP1), higher dose during initial stage of crop (FP2) and higher dose during mid-stage of crop (FP3) in combination with 4 planting geometries, viz. rectangular planting geometry with row-to-row and plant-to-plant spacing of 50 cm × 75 cm (S1) and three triangulated paired row (60 cm between paired row) planting geometries 40 cm × 70 cm (S2), 40 cm × 50 cm (S3) and 40 cm × 30 cm (S4) were evaluated in a split plot design replicated thrice. Effect of fertigation pattern was non-significant on crop growth. Whereas crop growth was negatively impacted by the higher plant densities (40 000 and 66 600 plants/ha under S3 and S4, respectively). The fertigation pattern FP3 recorded significantly highest average tomato yield of 79.2 tonnes/ha than those of FP1 and FP2. Triangulated planting geometries S2 and S3 recorded significantly higher fruit yield of tomato than S1 and S4 planting geometries. Higher WP of 13.4 kg/m^3 recorded in FP3 in comparison to rest of the two fertigation patterns. Results revealed that fruit yield of tomato responded well when higher percentage of recommended dose is applied during mid-stage (10 to 16th week after transplanting) of the crop growth period. Triangulated arrangements of planting (S2 and S3) appeared to be the most effective in terms of fruit yield and WP of drip irrigated tomato. However, S2 may be preferred among all the planting geometries due to lesser plants/ha consequently requiring lesser inputs.

Key words: Drip irrigation, Fertigation pattern, Planting geometry, Tomato, Water productivity

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops cultivated and consumed in India and in most part of the world. Abdel-Mawgoud *et al*. (2007) observed that plant spacing and fertilization schedule is the two most important parameters that affect the tomato fruit yield. The tomato plant spacing recommendations available in literature are suitable for furrow or other surface irrigation systems. These recommendations are less suitable for cultivating tomatoes with drip system.

Optimal planting geometry depends on soil wetting area achieved under drippers and plant properties, viz. extent of root zone, canopy spread and competition for nutrient and light etc. Planting geometry also affects quality of the produce (Tabasi *et al*. 2013). In most of the crop, the increase in yield can be achieved through increasing the planting density (Bodunde *et al*. 1996, El-Hendawy *et al.* 2008). Further, research reports also showed that greater plant densities resulted in reduced yields because of competition between plants (Mohamed 1999, Griesh and Yakout 2001). This necessitates a site and location specific assessment of the impact of different planting densities and planting geometries on crop yield and quality.

The other important management practice is fertilizer application. Fertigation, application of fertilizer through irrigation water, is the most promising and effective way to apply the fertilizer and is gaining popularity among the farmers. Many researchers reported that the fertigation is an efficient method of fertilizer application with savings in the consumption of fertilizers up to 50 % (Miller *et al*. 1976, Rajput and Patel 2001). Drip irrigation is capable of applying small amounts of water where it is needed and to apply it with a high degree of uniformity and frequency. These features make it potentially much more efficient than other irrigation methods (El-Hendawy *et al*. 2008). However, scheduling of fertilizer application in proper quantity and time is crucial to get the optimum yields. It is logical that nutrient needs of the plant are not uniform throughout the cropping season and apart from fertigation frequency, correct rate of fertilizer application to the crop during specific period is crucial (Coock and Sanders 1991). These specific periods can be, vegetative stage (initial), flowering, fruit-setting and fruit growth (mid) and harvest (late). The fertilizer schedule has to be adjusted according to these crop growth stages (DeValerio 2015).

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Adequate levels of nutrients are vital to increase the production and yield of tomato. Researchers investigated the impact of fertigation doses on tomato yield and quality but with uniform application of fertilizer in each fertigation event throughout the crop growing season. Information on impact of varying rates of fertilizer application as per the crop growth stage is seriously lacking. Also, very little work seems to have been undertaken to standardize the planting geometry and population density of drip irrigated tomatoes. This research was undertaken to investigate the effects of different planting geometries and growth-stage linked fertigation patterns on growth, yield and water productivity of the drip irrigated tomatoes.

MATERIALS AND METHODS

Field experiments were carried out at the research farms of ICAR, Research Complex for Eastern Region located at Ranchi Centre ($23^0$16' N - 50^0 85' E and 629 m amsl), Jharkhand during last week of October to first week of April for two years (2012-13 and 2013-14). The soil in experimental plot was deep, well drained, sandy loam comprising 70.8 % sand, 16.4 % silt and 12.8 % clay (Table 1). The soil had acidic reaction (pH=5.46) and the bulk density was 1.59 g/cm^3.

The experiment was laid out with 4 planting geometries (S1, S2, S3 and S4) of tomato hybrid variety Swarna Sampada (F_1) (Table 2) to get the different levels of plant population per ha with three fertigation patterns FP1, FP2, FP3 to have different dose of fertilizer at different time during crop growth period (Table 3).

Unlike conventional systems of fertigation, the fertigation events were scheduled to apply different amounts of fertilizer in accordance with the plant growth stage. The recommended fertilizer was distributed over several fertigation events with varying quantities per application in a specific fertigation pattern. Three fertigation patterns (FP1, FP2 and FP3) resulting from varying fertigation levels per application are presented in Fig 1. In the fertigation pattern FP1 almost uniform quantity of fertilizer was applied at every event, FP2 applied higher dose of fertilizer at initial stage (6th to 11th week) as per crop growh while FP3 applied higher fertilizer during middle stage of crop growth (10th to 16th week). Crop response to different fertigation patterns was evaluated. No fertgaion was applied after 18th week. The recommended dose of fertilizer for tomato (120:60:60 kg of NPK/ha) was applied in the three experimental main plots as per the pattern wise schedules provided in Table 3. Combination of urea ($CO(NH_2)_2$) and water soluble fertilizer (19:19:19) was used to get the desired level of the fertigation dose per schedule maintaining the total seasonal dose at recommended level.

Table 1 Physical and chemical properties of the soil (top 30 cm) in experimental plot

Physical						Chemical					
Sand (%)	Silt (%)	Clay (%)	θ_{FC} (%)	θ_{WP} (%)	BD (g/cc)	pH	EC (ds/m)	OC (%)	Available Nutrient (kg/ha) N	P	K
65.9	21.7	12.4	30.6	12.7	1.59	5.46	0.031	0.41	229.03	13.14	455.88

*θ_{FC}–field capacity and θ_{WP} - wilting point, BD-bulk density, EC-electrical conductivity, OC-organic carbon, N-nitrogen, P-phosphorous, K-potassium.

Table 2 Spacing between plants (cm) in different planting geometries for tomato crop

Geometry name	RR	PP*	BPR	Planting geometry	Plant population	Plant density (plants/m^2)
S1	50	75	50	Rectangular paired row	26600	2.7
S2	40	70	60	Triangulated paired row	28500	2.9
S3	40	50	60	Triangulated paired row	40000	4.0
S4	40	30	60	Triangulated paired row	66600	6.7

* RR-row-to-row, PP-plant-to-plant, BPR-between paired rows.

Table 3 Week wise fertiliser dose applied (kg/plot*) per fertigation event in tomato

FP1			FP2			FP3		
Week	WSF^	Urea	Week	WSF	Urea	Week	WSF	Urea
1-6	0.946	0.390	1-6	1.136	0.466	1-6	0.380	0.156
7-16	1.136	0.466	7-8	1.516	0.623	7-9	0.760	0.313
17-18	0.946	0.390	9-11	1.896	1.896	10-12	1.516	0.623
			12-13	0.760	0.760	13-16	1.896	0.780
			14-18	0.380	0.380	17-18	1.136	0.460

^WSF: Water soluble fertilizer, *Plot size of 600 m^2.

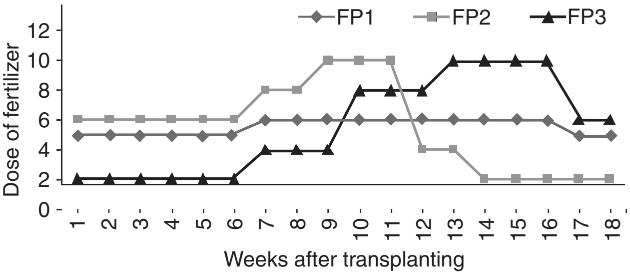

Fig 1 Fertigation schedule of tomato for total fertilizer dose of 120:60:60 NPK kg/ha.

The experiment was laid out in split plot design with fertigation levels as main plots (having plot size of 600 sq m) and treatments on planting arrangements in sub-plots. Each treatment was replicated three times. Water was applied using 12 mm diameter lateral with 2.4 l/h in-line drippers at a spacing of 40 cm between two emitters. Irrigation was applied every alternated day throughout the growing season. Tomato seedlings were transplanted in the last week of October and last harvesting of crops were done till first week of April during both the years of experimentation. A total rainfall of 77.6 and 109 mm recorded during the crop cultivation period in 2012-13 and 2013-14, whereas 593 mm irrigation each was applied in both the years of experimentation.

Reference crop evapotranspiration (ET_0) was estimated from pan evaporation (E_p) ($ET_0 = E_p \times K_p$). Pan evaporation data was collected from the field meteorological observatory located at about 150 m away from the experimental site. The actual crop evapotranspiration was estimated by multiplying reference crop evapotranspiration with crop coefficient ($ET_c = ET_0 \times K_c$) (Doorenbos and Pruitt 1992). Where, K_c is the crop coefficient. The K_c values of 0.6, 1.0 and 0.75 at initial, middle and maturity stages, respectively (Allen *et al*. 1998). Net irrigation water requirement was determined based on the difference between ET_c and effective rainfall. The effective rainfall was estimated using dependable rainfall method as suggested in FAO CROPWAT model. Irrigation water productivity (IWP) (tonnes/ha/cm) was determined as $(Y/I_r) \times 100$ (Kanber *et al*. 1992). Where, Y is fruit yield (tonnes/ha) and I_r is the irrigation water applied (cm). Fertigation was done using a 19 mm (3/4 inch) diameter ventury fertigation system having injection rate of 70.8 l/h at inlet and outlet pressures of 1.0 and 0.2 kg/cm^2, respectively. Fertigation was done at weekly interval.

Soil moisture in the experimental plots was monitored weekly. Data on crop height was recorded at 30, 60 and 90 days after transplanting. The matured tomato fruits were manually picked for 7 and 9 times during the cropping seasons of 2012-13 and 2013-14, respectively, and weight of fresh tomato fruits was recorded under each sub plot. Water productivity was worked out by dividing tomato yield (kg) with the quantity of water applied (m^3) through irrigation during the cropping season. Data collected from the experiment were subjected to statistical analysis of variance. Significant differences among the treatment means were separated using the Duncan multiple range test (DMRT).

RESULTS AND DISCUSSION

Soil moisture dynamics

Soil moisture in the root zone of tomato plants monitored weekly over the crop growing season. For most part of the cropping period, soil moisture content at 20 cm below the soil surface, averaged over the fertigation treatments, was in the range of 23.5 to 28.9%, which is slightly less than the field capacity of the soil (Fig 2). The lower amounts of irrigation and comparable canopy cover under different geometry treatments maintained almost uniform moisture content across all the planting geometries during initial stage (1st to 7th weeks). As the crop progressed the amount of water applied also increased leading to slight increase in the soil moisture after 8th week after transplantation in all the planting geometry treatments. The seasonal average soil moisture content was 27.0, 26.5, 25.9 and 25.7% under the planting geometries S1, S2, S3 and S4, respectively. Geometries with denser plant population (S3 and S4) recorded the lower moisture levels at 20 cm depth highlighting the fact that there is increasing competition for water at higher plant densities. Higher plant density leads to moisture stress in the crop root zone.

Soil moisture in the root zone remained almost uniform with slight variation at deeper depths. Average moisture content in the soil profile was in the range of 21.6 to 28.0 % depending on the soil depth and planting geometries. The profile averaged (top 60 cm) soil moisture content at 11th WAT was 26.1, 27.0, 26.2 and 22.8 % under planting geometries of S1, S2, S3 and S4, respectively. The moisture content of the S1 treatment was slightly on higher side throughout the soil profile. Increased evapotranspiration was due to increased number of plants and denser canopies, which might be responsible for lower soil moisture contents in the treatments with denser plant populations. The treatments with plant population of 66 600 plant stand/ha (S4) showed lesser moisture levels in the plant root zone.

Plant growth

During early stage of the plant growth, effect of fertigation pattern as well as planting geometries was not

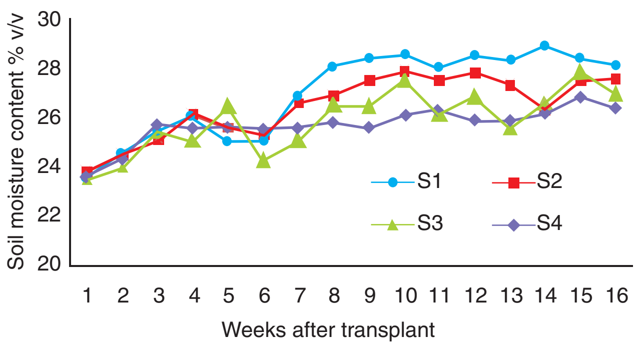

Fig 2 Soil moisture dynamics under different planting geometries.

significant. At 12th week after transplanting (WAT) the significant effect of plating geometry was observed on the plant height while the effect of fertigation pattern was statistically non-significant. This implies that varying the rate of fertilizer applied as per crop growth stage will not impact the crop growth significantly. The planting geometries having denser plant population (S3 and S4) resulted in reduced plant growth compared to the planting arrangements with lesser plant population (S1 and S2). The competition for water and nutrients in the plant root zone resulted in reduced plant growth under high density plantations. Tuan and Mao (2015) reported that treatment with lowest plant density had the maximum fruit weight (91.4 g), whereas the lowest fruit weight 85.5 g was recorded in highest plant density. Highest plant height of 68.4 and 71.3 cm was observed during 2012-13 and 2013-14, respectively under S1 planting geometry in combination with FP2 fertigation pattern, however, the difference in the plant heights observed under S1 and S2 were not significant.

Fruit yield of tomato/plant

Pooled data revealed that yield/plant was significantly influenced by the fertigation pattern (Table 4). The yield per plant obtained under FP1 and FP3 were significantly higher than FP2, in which higher dose of fertilizers are given in early stage of crop. FP1 and FP3 recorded an average yield of 2.36 and 2.47 kg/plant. It indicates that higher percentage of fertilizer dose at the mid stage of the crop growth (flowering and fruit development, 10th to 16th WAT) was better for tomato yield/plant in comparison to applying higher dose of fertilizer in early stage of crop growth. The yield/plant was also significantly influenced by planting geometry. Planting geometry having lower plant population of 26 600 plants/ha (S1) and 28 500 plants/ha (S2) recorded significantly higher yield/plant during both the years of experimentation. Highest yield (pooled and averaged over the fertigation patterns) of 2.65 and 2.52 kg/plant was observed in S1 (rectangular) in and S2 (triangular) plant geometries, respectively. Yields per plant were significantly reduced at higher planting densities of 40 000 plants/ha (S3) and 66 600 plant/ha (S4). The findings obtained in this study were in good agreement to those reported by Tuan and Mao (2015) and Ali (1997) who found that low plant density gave the highest fruit weight compared to high plant density. This may due to the fact that competition for air, water, nutrient etc. is less in low planting density than at high planting density.

Fruit yield of tomato/ha

Average tomato fruit yields obtained for 2012-13, 2013-14 and pooled data (2012-14) under different fertigation patterns (averaged over planting geometries) and under different planting geometries (averaged over fertigation patterns) are presented in Table 5.

Tomato yield was significantly affected by planting geometry and fertigation pattern. It is evident that the marketable yield varied widely from 63.3 to 80.7 tonnes/ha depending on the treatments and experimental years. The fertigation pattern FP3 recorded significantly higher average tomato yields of 79.2 tonnes/ha than FP1 and FP2. Yields obtained under FP3 were 19.5 % higher than that of FP1 in pooled data of 2012-14. This highlights the fact that application of higher fertigation dose during 10th to 16th week after transplanting gives better yields in case of tomato.

The effect of planting geometry on the tomato yields was also significant. Triangulated planting geometries S2 and S3 recorded significantly higher fruit yield of tomato than S1 and S4 planting geometries in in pooled data of 2012-14. Difference in yields obtained under the treatment S2 and S3 were non-significant ($P<0.05$). However, S2 (28 500 plants/ha) may be best treatment among all planting geometries because it requires relatively less input due to lesser plant density and yielding significantly higher yield. Pooled data shows that the highest average yield of 76.9

Table 4 Effect of planting geometry and fertigation pattern on tomato yield (kg/plant) in 2012-14

Treatment	2012-13	2013-14	Pooled (2012-14)
	Yield (t/ha)		
Fertigation pattern			
FP1	2.44a	2.29a	2.36a
FP2	2.13b	2.01b	2.07b
FP3	2.33a	2.60a	2.47a
LSD (P = 0.05)	0.13	0.48	0.24
Planting geometry			
S1	2.50a	2.55a	2.52a
S2	2.60a	2.70a	2.65a
S3	2.13b	2.21b	2.17b
S4	1.99b	1.73b	1.86b
LSD (P = 0.05)	0.18	0.34	0.19
FP × S	NS	NS	NS

Means with different alphabetic suffix are significantly different at $P<0.05$.

Table 5 Effect of fertigation patterns and planting geometries on tomato yield (t/ha) in 2012-14

Treatment	2012-13	2013-14	Pooled (2012-14)
	Yield (t/ha)		
Fertigation pattern			
FP1	63.3b	69.4a	66.3b
FP2	66.6b	66.7b	66.7b
FP3	80.7a	77.7a	79.2a
LSD (P = 0.05)	12.3	8.9	8.4
Planting geometry			
S1	63.3b	64.2b	63.7a
S2	77.9a	75.9a	76.9b
S3	72.6a	78.4a	75.5b
S4	67.1b	66.6b	66.8a
LSD (P = 0.05)	10.7	8.3	7.3
FP × S	NS	NS	NS

Means with different alphabetic suffix are significantly different at $P<0.05$.

tonnes/ha was obtained with triangular planting geometry having plant population of 28 500 plants/ha (S2) which was 20.7 % higher than S1. The treatment S1 having rectangular plating arrangement and lowest plant population produced the lowest yield of 63.7 tonnes/ha. Significant interaction effect of fertigation pattern and planting geometry was not observed in any of the experimental year as well as in pooled data analysis.

Relationship between yield and plant population

Relationship between plant population and tomato yield under the best performing fertigation pattern (FP3) is presented in Fig 3. It is observed that the scanty plant stand resulted in lower tomato yields. Tomato yield increased with increase in plant population and reached a maximum value when the plant population is in the range of 28 500 to 40 000 plants/ha. At higher plant population there was considerable decrease in the marketable yield of tomatoes. This finding highlights the need to optimize the plant population and density to get better yields. Taun and Mao (2015) showed that the tomato yields decreased with increasing plant density from 25 974 to 35 714 plants/ha.

Water productivity

Irrigation water productivity worked out as the ratio between total tomato production and the seasonal irrigation water use is presented in Table 6. The water productivity varied from 10.7 to 13.6 kg/m^3 across the treatments and experimental years. Considering the average yields of pooled analysis, fertigation pattern that applied higher dose of fertilizer at the mid stage of crop development stage (FP3) showed highest water productivity of 13.4 kg/m^3 (Table 6). Among the planting geometries, S2 and S3 planting geometries with plant populations of 28 500 and 40 000 plants/ha resulted in higher water productivities than S1 and S4. Since, the quantity of water applied through drip was same across all the treatments the water productivity observed the similar pattern as that of tomato yield/hectare.

This study was conducted to develop more efficient fertigation program for tomato, considering growth-stage specific nutrient requirements. The study demonstrated that the drip systems being used for vegetable crops can be made more effective for tomato production by optimizing the effects of fertigation pattern and planting geometry. These two were found to be significant determinants of overall yield and irrigation water productivity of drip irrigated tomato. Planting geometries with triangulated paired row having moderate plant populations (28 500 and 40 000 plants/ha) showed significantly higher tomato yields than rest of the two planting geometries. Moreover, moderate planting density (28 500 plants/ha) may be preferred among all the planting geometries/densities due to lesser plants per hectare consequently requiring lesser inputs invested. Growth stage based variable application of water soluble fertilizers performed better over the almost uniform dose at every fertigation event. Application of higher percentage of recommended dose of fertilizer during 10th to 16th week after transplanting resulted in increased tomato yield. This research highlights the need to vary the fertigation amount at every application in accordance with the crop growth stage.

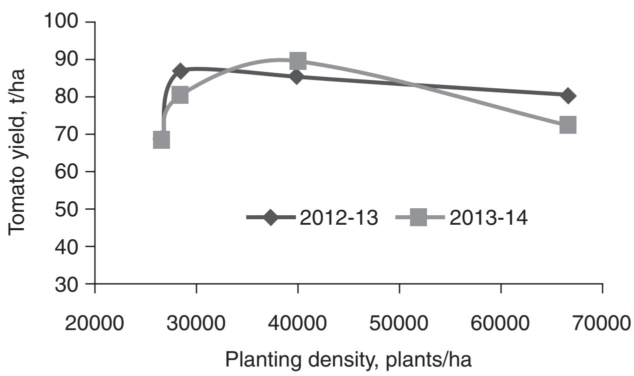

Fig 3 Relationship between plant population and tomato yield as observed under FP3 fertigation pattern in 2012-13 and 2013-14

Table 6 Water productivity (kg/m^3) of tomatoes as affected by planting geometry and fertigation patterns during 2012-14

Treatment	2012-13	2013-14	Pooled (2012-14)
	Water productivity (kg/m^3)		
Fertigation pattern			
FP1	10.7	11.7	11.2
FP2	11.2	11.2	11.3
FP3	13.6	13.1	13.4
Planting geometry			
S1	10.7	10.8	10.7
S2	13.1	12.8	13.0
S3	12.2	13.2	12.8
S4	11.3	11.2	11.3

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