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Effect of planting density and fertigation on physical quality of fruit, fruit retention and yield in processing varieties of tomato

Ch. Shanmukhi, P Soman, MLN Reddy and AVD Dorajee Rao

Abstract
The Abhinav variety recorded the highest fruit diameter (5.44 cm), fruit weight (116.41g) and fruit yield per hectare (119.78 tonnes). Planting density at 60 cm x 60 cm (S_2) recorded significantly the highest fruit diameter (5.42 cm) and fruit weight (1123.98 g) followed by 75 cm x 40 cm (S_3) (5.35 cm) (114.04 g). The lowest fruit diameter (5.21 cm) and fruit weight (106.51 g) was recorded by the planting density at 120 cm x 40 cm (S_3). Application of 180N: 90P: 90K kg per ha (F_3) recorded the highest fruit diameter (5.37 cm), fruit weight (107.55g) and fruit yield per hectare (131.61 tonnes) followed by 150N: 75P: 75K kg per ha (F_2). The lowest fruit diameter (5.27 cm), fruit weight (106.21g) and fruit yield per hectare (87.76 tonnes) was recorded by the application of 120N: 60P: 60K kg per ha (F_1). Among interaction combinations, the highest fruit weight was recorded by the combination of variety Abhinav + 60 cm x 60 cm (S_2) + 180N: 90P: 90K kg per ha (142.86 g).

Keywords: tomato, fruit weight, fruit length, fruit diameter, fruit retention, planting density, fertigation

1. Introduction
Tomato is a self-pollinated annual crop belongs to the family Solanaceae. Tomatoes were consumed either fresh or as processed products. Tomato is a number one processing vegetable. Tomato is important for health and rich in several good compounds. It is also believed that it gives protection from or reduces the risk of contracting chronic degenerative diseases. The significant feature of this vegetable is its consistent consumption all over the world, used in many forms, from fresh to processed types. Spacing of tomato plants is an important component for healthy productive plants. The correct tomato plant spacing is dependent upon which variety of tomato is being grown. Spacing tomato plants any closer will reduce air circulation around the plants this may result in disease and also reduces the number of branches which ultimately reduces the final yield of the crop.Tomato is an important crop grown and fertigated in open fields. Fertigated tomatoes yielded more, had higher dry matter and improved quality parameters (size, firmness and soluble sugars) compared to conventionally irrigated and fertilized crops. Fertigation doubled the number of fruits. Improved nutrient availability provided by fertigation was considered to be one of the important factors causing the increase in yield. This research was undertaken to investigate the effects of different planting densities and growth-stage linked fertigation patterns on physical quality of fruit, fruit retention and yield in processing varieties of tomato.

2. Details of the experiment
A field experiment on the "effect of planting density and fertigation on growth, flowering and yield in processing varieties of tomato (*Solanum lycopersicum*L.)" was conducted with an objective of finding out the most suitable variety, planting density and fertigation level at the research farms of Jain Irrigation Systems Ltd., located at Chhittoor, in Andhra Pradesh. The total plot of experiment was 1.5 acre (6075 m2).

Experimental Design: Factorial Randomized Block Design (FRBD)

Number of Factors	:	3
Factor-I (Varieties)	:	2
Factor-II (Spacings)	:	3
Factor-III (Fertigations)	:	3
Factor 1	:	Tomato Variety (V)
V_1	:	Alankar
V_2	:	Abhinav
Factor 2	:	Plant Spacing (S)

S_1	:	120 cm x 40 cm
S_2	:	60 cm x 60 cm
S_3	:	75 cm x 40 cm
Factor 3	**:**	**Fertigation level**
F_1	:	120: 60: 60 NPK kg ha $^{-1}$
F_2	:	150: 75: 75 NPK kg ha $^{-1}$
F_3	:	180: 90: 90 NPK kg ha $^{-1}$

Total number of treatment combinations: 18

The details of treatment combinations are as detailed below.

T_1: $V_1S_1F_1$ Alankar+120 cm x 40 cm+120 kg: 60 kg: 60 kg NPK per hectare

T_2: $V_1S_1F_2$Alankar+120 cm x 40 cm+150 kg: 75 kg: 75 kg NPK per hectare

T_3: $V_1S_1F_3$Alankar+120 cm x 40 cm+180 kg: 90 kg: 90 kg NPK per hectare

T_4: $V_1S_2F_1$ Alankar+60 cm x 60 cm+120 kg: 60 kg: 60 kg NPK per hectare

T_5: $V_1S_2F_2$Alankar+60 cm x 60 cm+150 kg: 75 kg: 75 kg NPK per hectare

T_6: $V_1S_2F_3$Alankar+60 cm x 60 cm+180 kg: 90 kg: 90kg NPK per hectare

T_7: $V_1S_3F_1$Alankar+75 cm x 40 cm+120 kg: 60 kg: 60 kg NPK per hectare

T_8: $V_1S_3F_2$Alankar+75 cm x 40 cm+150 kg: 75 kg: 75 kg NPK per hectare

T_9: $V_1S_3F_3$Alankar+75 cm x 40 cm+180 kg: 90 kg: 90 kg NPK per hectare

T_{10}: $V_2S_1F_1$ Abhinav+120 cm x 40 cm+120 kg: 60 kg: 60 kg NPK per hectare

T_{11}: $V_2S_1F_2$Abhinav+120 cm x 40 cm+150 kg: 75 kg: 75 kg NPK per hectare

T_{12}: $V_2S_1F_3$Abhinav+120 cm x 40 cm+180 kg: 90 kg: 90 kg NPK per hectare

T_{13}: $V_2S_2F_1$Abhinav+60 cm x 60 cm+120 kg: 60 kg: 60 kg NPK per hectare

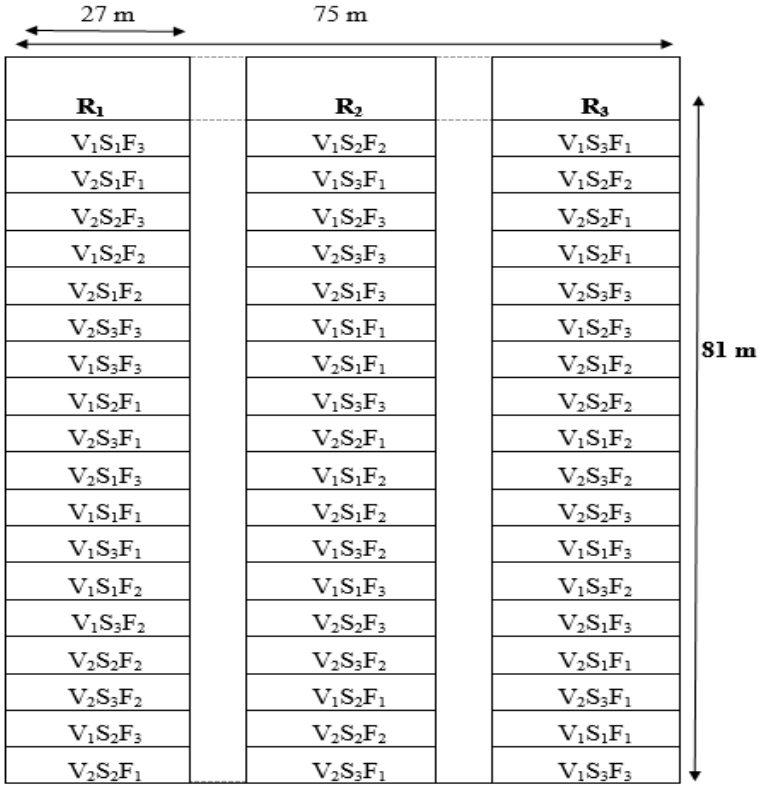
T_{14}: $V_2S_2F_2$Abhinav+60 cm x 60 cm+150 kg: 75 kg: 75 kg NPK per hectare

T_{15}: $V_2S_2F_3$Abhinav+60 cm x 60 cm+180 kg: 90 kg: 90 kg NPK per hectare

T_{16}: $V_2S_3F_1$Abhinav+75 cm x 40 cm+120 kg: 60 kg: 60 kg NPK per hectare

T_{17}: $V_2S_3F_2$Abhinav+75 cm x 40 cm+150 kg: 75 kg: 75 kg NPK per hectare

T_{18}: $V_2S_3F_3$Abhinav+75 cm x 40 cm+180 kg: 90 kg: 90 kg NPK per hectare



Field layout of experiment

Number of plants sampled to get the data from each treatment was 10.

Nutrient status of different fertilizers

Fertilizer	Nutrient (%)
Urea	46% N
Sulphate of Potash (0:0:50)	50% K_2O, 17.50% S
Potassium-nitrate (13:0:45)	13% N, 45% K_2O
19:19:19	19% N, 19% P, 19% K
Mono-Ammonium Phosphate (12-61-0)	12% N,61 % P_2O_5
Single superphosphate	16 to 20% P_2O_5,18 to 21 % Ca,11 to 12% S

The distance between two drip lines is 1.2 m and the plants are planted on raised beds of 15 cm height, 1 m width and 27 m length. The fertilizer application is through drip lines which are soluble in water. Fertigation is given every alternate day, with the given doses for different treatments at different stages of plant growth. The fertilizers used in fertigation are mentioned in the above table.

Effect of spacing in drip fertigated tomato on yield and fruit quality here the entire Plot is divided first into TWO- 1) Variety 1 and 2.) Variety 2. And each of these are further divided into 9 sub-blocks. (3 crop spacings x 3 replications.) Each of these will read as $V_1S_1R_1$-------etc. and V_2S_1 R_1--- etc. For this experiment a layed drip lines at every 1.2 m. all plots same. We will them make changes in planting pattern at the

time of transplanting. One fertigation unit at filter station. There are 3 major plots, F1, F2 and F3- the three levels of fertigation treatment. Within each fertigation level we have 2 Varieties and 3 replications. Here again the Lateral spacing is 1.2 meter. But each of the Fertigation level will have separate sub main. One Fertigation unit (1 inch Ventury but connected to three submain valves).
So design and installed the system accordingly.

3. Results and Discussion

3.1 Fruit length (cm)

The data on fruit length (Table 1) revealed that there were no significant differences due to variety, planting density, fertigation level and their interactions except, variety x fertigation. Both the varieties, Abhinav and Alankar exhibited longer fruits with the application of F_3:180N: 90P: 90K kg per ha and F_2 150N: 75P: 75K kg per ha. The shortest fruits were produced by these varieties in combination of F_1: 120N: 60P: 60K kg per ha. This might be due to more availability of nutrients to plants, better vegetative growth and metabolism, more synthesis of proteins, fats and carbohydrates that may have favourably influenced the yield attributes. Similar findings were also reported by Singh and Sharma (2001) [1] and Mishra *et al.* (2004) [2].

3.2 Fruit diameter (cm)

The data on fruit diameter (Table 2) revealed that there were significant differences due to variety, planting density and some of their interactions. Among the varieties Abhinav recorded the highest fruit diameter (5.43 cm). Planting density at 60 cm x 60 cm (S_2) recorded significantly the highest fruit diameter (5.42 cm) which was on par with 75 cm x 40 cm (S_3) (5.35 cm). The lowest fruit diameter was recorded by the planting density at 120 cm x 40 cm (S_1) (5.21 cm). It may be due to less competition among plants for growth factors in wider spacing as reported by Singh (2004). Application of 180N: 90P: 90K kg per ha (F_3) recorded the highest fruit diameter (5.37 cm) followed by 150N: 75P: 75K kg per ha (F_2) (5.35 cm). The lowest fruit diameter (5.27 cm) was recorded by the application of 120N: 60P: 60K kg per ha (F_1). This might be due to more availability of nutrients to plants, better vegetative growth and metabolism, more synthesis of proteins, fats and carbohydrates that may have favourably influenced the fruit diameter. Similar findings were also reported by Singh and Sharma (2001) [1] and Mishra *et al.* (2004) [2]. However, there was no significance difference regarding fertigation, Variety x planting density and planting density x fertigation.

3.3 Fruit weight (g)

Significant differences with respect to fruit weight (Table 3) were observed due to variety, planting density and some of their interactions. Among the varieties Abhinav recorded the highest fruit weight (116.41 g). Planting density at 60 cm x 60 cm (S_2) recorded significantly the highest fruit weight (123.98 g) which was followed by 75 cm x 40 cm (S_3) (114.04 g). The lowest fruit weight was recorded by the planting density at 120 cm x 40 cm (S_1) (106.51 g). This could be due to increased uptake of more nutrients and build up of sufficient photosynthates enabling the increase in size of fruits (length and breadth and weight), ultimately leading to increased size of fruits. These results are in conformity with the findings of Ganesan and Subbiah (2005) [4]. On the other hand too short time from fruit set to maturity and shorter intervals between pickings in wider row orientation could have discouraged the attainment of maximum fruit size and hence, the size and weight of fruits lagged behind in those orientations as compared to 60 cm x 60 cm. As regards to the level of fertigation, the highest dose of fertigation (F_3) has been proved always better and thus maintaining the best quality fruits as compared to the application of F_1 and F_2 levels.

3.4 Fruit retention percentage

Significant variations were observed in fruit retention percentage due to variety, planting density, fertigation combinations and some of their interactions (Table 4). Among the varieties, Abhinav recorded the highest fruit retention percentage per cluster (78.16%). Planting density at 120 cm x 40 cm (S_1) recorded significantly the highest fruit retention percentage per cluster (93.41%) which was followed by planting density at 60 cm x 60 cm (S_2) (73.20%). The lowest fruit retention percentage per cluster was recorded by the planting density at 75 cm x 40 cm (S_3) (67.39%). Application of 180N: 90P: 90K kg per ha (F_3) recorded the highest fruit retention percentage per cluster (79.02 %) was followed by 150N: 75P: 75K kg per ha (F_2) (78.46 %) whereas the lowest fruit retention percentage per cluster (72.96 %) was recorded by the application of 120N: 60P: 60K kg per ha (F_1). The interaction effect of variety x planting density was found significant. This might be due to more availability of nutrients to plants, better vegetative growth and metabolism, more synthesis of proteins, fats and carbohydrates that might have favourably influenced the fruit retention percentage.

3.5 Fruit yield per hectare (tonnes)

The fruit yield per hectare (Table 5) exhibited significant differences due to variety, planting density, fertigation level and their interactions. Among the varieties Abhinav recorded the highest fruit yield ha^{-1} (119.78 tonnes). Planting density at 75 cm x 40 cm (S_3) recorded significantly the highest fruit yield ha^{-1} (131.61 tonnes) which was followed by60 cm x 60 cm (S_2) (104.12 tonnes). The lowest fruit yield ha^{-1} was recorded by the planting density at 120 cm x 40 cm (S_1) (93.45 tonnes). This might be due to higher plant population per unit area at narrow spacing. A positive correlation was reported between stand density and yield and negative one between stand density and individual plant productivity. These results are in agreement with Charlo *et al.* (2007) [5]. Application of 180N: 90P: 90K kg per ha (F_3) recorded the highest fruit yield ha^{-1} (131.61 tonnes) followed by 150N: 75P: 75K kg per ha (F_2) (109.82 tonnes). The lowest fruit yield ha^{-1} (87.76 tonnes) was recorded by the application of 120N: 60P: 60K kg per ha (F_1).

The effect of variety, planting density and fertigation level was found significant on the fruit yield ha^{-1}. As it is observed in case of growth and flowering parameters, the fruit yield was found to be highest in case of Abhinav compared to Alankar establishing the superiority of the genotype. However, there was significant difference between these three levels of planting density or population density with respect to fruit yield ha^{-1}.

Fertigation with the highest fertiliser dose made significant difference at all the population levels as compared to the lowest fertiliser doses. The additional dose of nutrients beyond the medium level resulted in a significant increase in the fruit yield ha^{-1}. However, an examination of interactions between planting density and fertigation level at per hectare level revealed that enhanced fertigation dose boosted the yield significantly from the lowest level 120N: 60P: 60K to higher level 180N: 90P: 90K kg per ha. Manoj *et al.* (2013) [6] reported similar results on tomato var. Azad T-6.

Table 1: Fruit length (cm) as influenced by variety, planting density and fertigationin processing tomato

Planting density (B)	Fertigation (C)	Variety (A)		
		Alankar	**Abhinav**	***Mean***
S_1 (120cm x 40 cm) (2.08 plants per m^2)	F_1 (120N:60P:60K)	5.80	5.83	5.81
	F_2 (150N:75P:75K)	5.73	6.18	5.95
	F_3 (180N:90P:90K)	6.16	6.33	6.24
	Mean	5.89	6.11	*6.00*
S_2 (60 cm x 60 cm) (2.78 plants per m^2)	F_1 (120N:60P:60K)	6.03	6.03	6.03
	F_2 (150N:75P:75K)	6.10	6.21	6.15
	F_3 (180N:90P:90K)	6.73	6.30	6.51
	Mean	6.28	6.18	*6.24*
S_3 (75 cm x 40 cm) (3.33 plants per m^2)	F_1 (120N:60P:60K)	5.88	5.96	5.95
	F_2 (150N:75P:75K)	6.33	6.28	6.30
	F_3 (180N:90P:90K)	6.07	6.33	6.20
	Mean	6.11	6.19	*6.15*
For Comparing varieties (A) and Fertigation (C)				
F_1 (120N:60P:60K)		5.90	5.94	*5.92*
F_2 (150N:75P:75K)		6.05	6.22	*6.13*
F_3 (180N:90P:90K)		6.32	6.32	*6.32*
Mean		*6.09*	*6.16*	*6.12*
Factors		*S Em±*		CD at 5%
Variety (A)		-		*NS*
Planting density (B)		-		*NS*
Fertigation (C)		-		*NS*
A x B		-		*NS*
B x C		-		*NS*
A x C		0.09		0.27
A x B x C		-		*NS*

Table 2: Fruit diameter (cm) as influenced by variety, planting density and fertigation in processing tomato

Planting density (B)	Fertigation (C)	Variety (A)		
		Alankar	**Abhinav**	***Mean***
S_1 (120cm x 40 cm) (2.08 plants per m^2)	F_1 (120N:60P:60K)	5.15	5.34	5.25
	F_2 (150N:75P:75K)	5.05	5.03	5.04
	F_3 (180N:90P:90K)	5.17	5.51	5.34
	Mean	5.12	5.29	*5.21*
S_2 (60 cm x 60 cm) (2.78 plants per m^2)	F_1 (120N:60P:60K)	5.49	5.42	5.46
	F_2 (150N:75P:75K)	5.27	5.47	5.37
	F_3 (180N:90P:90K)	5.17	5.74	5.45
	Mean	5.31	5.54	*5.42*
S_3 (75 cm x 40 cm) (3.33 plants per m^2)	F_1 (120N:60P:60K)	5.36	5.33	5.34
	F_2 (150N:75P:75K)	4.91	5.91	5.41
	F_3 (180N:90P:90K)	5.52	5.11	5.31
	Mean	5.26	5.45	*5.35*
For Comparing varieties (A) and Fertigation (C)				
F_1 (120N:60P:60K)		5.33	5.36	*5.27*
F_2 (150N:75P:75K)		5.08	5.47	*5.35*
F_3 (180N:90P:90K)		5.28	5.45	*5.37*
Mean		*5.23*	*5.43*	*5.33*
Factors		*S Em±*		CD at 5%
Variety (A)		0.03		0.10
Planting density (B)		0.04		0.12
Fertigation (C)		-		*NS*
A x B		-		*NS*
B x C		-		*NS*
A x C		0.06		0.17
A x B x C		0.10		0.31

Table 3: Fruit weight as influenced by variety, planting density and fertigation in processing tomato

Planting density (B)	Fertigation (C)	Variety (A)		
		Alankar	**Abhinav**	***Mean***
S_1 (120cm x 40 cm) (2.08 plants per m^2)	F_1 (120N:60P:60K)	93.58	98.73	96.15
	F_2 (150N:75P:75K)	106.31	109.93	108.12
	F_3 (180N:90P:90K)	119.46	111.09	115.27
	Mean	106.45	106.58	*106.51*
S_2 (60 cm x 60 cm) (2.78 plants per m^2)	F_1 (120N:60P:60K)	111.57	113.17	112.37
	F_2 (150N:75P:75K)	118.28	117.59	117.93

	F_3 (180N:90P:90K)	140.41	142.86	141.64
	Mean	123.42	124.54	*123.98*
S_3 (75 cm x 40 cm) (3.33 plants per m^2)	F_1 (120N:60P:60K)	88.76	108.62	100.38
	F_2 (150N:75P:75K)	104.02	112.00	106.32
	F_3 (180N:90P:90K)	137.13	133.72	135.42
	Mean	109.97	118.11	*114.04*
For Comparing varieties (A) and Fertigation (C)				
F_1 (120N:60P:60K)		104.45	107.96	106.21
F_2 (150N:75P:75K)		103.05	112.04	107.55
F_3 (180N:90P:90K)		132.33	129.22	107.55
Mean		113.28	116.41	*114.84*
Factors		*S Em+*		CD at 5%
Variety (A)		1.04		3.01
Planting density (B)		1.28		3.68
Fertigation (C)		-		*NS*
A x B		-		*NS*
B x C		2.22		6.38
A x C		1.81		5.21
A x B x C		3.14		9.02

Table 4: Fruit retention (%) as influenced by variety, planting density and fertigation in processing tomato

Planting density (B)	**Fertigation (C)**	**Variety (A)**		
		Alankar	**Abhinav**	***Mean***
S_1 (120cm x 40 cm) (2.08 plants per m^2)	F_1 (120N:60P:60K)	96.66	73.21	84.93
	F_2 (150N:75P:75K)	97.64	98.93	98.28
	F_3 (180N:90P:90K)	98.52	95.56	97.04
	Mean	97.60	89.23	*93.41*
S_2 (60 cm x 60 cm) (2.78 plants per m^2)	F_1 (120N:60P:60K)	65.93	66.37	66.15
	F_2 (150N:75P:75K)	69.69	80.71	75.20
	F_3 (180N:90P:90K)	80.16	76.39	78.27
	Mean	71.92	74.49	*73.20*
S_3 (75 cm x 40 cm) (3.33 plants per m^2)	F_1 (120N:60P:60K)	66.18	75.56	70.87
	F_2 (150N:75P:75K)	69.69	61.71	65.70
	F_3 (180N:90P:90K)	54.39	76.83	65.61
	Mean	63.42	71.36	*67.39*
For Comparing varieties (A) and Fertigation (C)				
F_1 (120N:60P:60K)		74.50	71.42	*72.96*
F_2 (150N:75P:75K)		77.88	79.04	*78.46*
F_3 (180N:90P:90K)		74.02	84.03	*79.02*
Mean		*75.46*	*78.16*	*76.81*
Factors		*S Em+*		CD at 5%
Variety (A)		0.06		0.18
Planting density (B)		0.07		0.22
Fertigation (C)		0.07		0.22
A x B		-		*NS*
B x C		0.13		0.38
A x C		0.11		0.31
A x B x C		0.19		0.55

Table 5: Fruit yield (tonnes) per ha as influenced by variety, planting density and fertigation in processing tomato

Planting density (B)	**Fertigation (C)**	**Variety (A)**		
		Alankar	**Abhinav**	***Mean***
S_1 (120 cm x 40 cm) (2.08 plants per m^2)	F_1 (120N:60P:60K)	66.11	79.83	72.97
	F_2 (150N:75P:75K)	75.62	125.83	100.73
	F_3 (180N:90P:90K)	77.22	136.09	106.66
	Mean	72.98	113.92	93.45
S_2 (60 cm x 60 cm) (2.78 plants per m^2)	F_1 (120N:60P:60K)	97.09	86.41	91.75
	F_2 (150N:75P:75K)	102.87	113.90	108.39
	F_3 (180N:90P:90K)	106.28	118.19	112.23
	Mean	102.08	106.17	104.12
S_3 (75 cm x 40 cm) (3.33 plants per m^2)	F_1 (120N:60P:60K)	84.06	113.05	98.56
	F_2 (150N:75P:75K)	108.36	132.31	120.33
	F_3 (180N:90P:90K)	179.45	172.43	175.94
	Mean	123.96	139.26	131.61
For Comparing varieties (A) and Fertigation (C)				
F_1 (120N:60P:60K)		82.42	93.10	87.76
F_2 (150N:75P:75K)		95.61	124.02	109.82
F_3 (180N:90P:90K)		120.98	142.24	131.61

Mean	99.67	119.78	109.73
Factors	*S Em*±		CD at 5%
Variety (A)	2.77		7.97
Planting density (B)	3.39		9.76
Fertigation (C)	3.39		9.75
A x B	4.80		13.80
B x C	5.88		16.90
A x C	4.80		13.80
A x B x C	8.31		23.91

Conclusions

The fruit yield ha^{-1} was found to show a different trend *i.e.* the highest fruit yield ha^{-1} was recorded at the closest spacing only unlike the case of number of fruits per plant which was highest at the widest spacing. Even though an individual plant yielded more at wider spacing, due to less number of plants per unit area, the net yield per unit area had been worked out to be lower compared to the case where there was more number of plants per unit area yielding lesser weight of fruits per plant *i.e.* closer spacing. However, the var. Abhinav recorded the highest fruit yield per plant, fruit yield per plot and per ha. Similarly F_3 level of fertigation recorded significantly superior to the lowest level of fertigation. The best quality heavier fruits with greater length and diameter as well as more number of fruits with higher fruit retention were recorded from the variety Abhinavin combination with fertigation level 180N: 90P: 90K kg per ha as compared to Alankar. This combination of variety spacing and fertigation level is now incorporated into the guidelines to farmers in Chittoor district.

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