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Effect of different irrigation and fertigation levels on fruit quality parameters in sweet orange (*Citrus sinensis* L. Osbeck) cv. Phule Mosambi

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Abstract
Water and nutrient use efficiency are primary requirements for optimum and sustained citrus productivity. The interactive effect of irrigation and fertigation levels on fruit quality parameters of 10-year-old sweet orange (*Citrus sinensis* L. Osbeck) cv. Phule Mosambi was studied in factorial randomized block design with nine treatment combinations and control with surface irrigation and band placement of conventional fertilizers. The interaction effects in the treatment T_1 (I_1F_1) i.e. irrigation level I_1-100% etc. through drip along with fertigation level F_1-100% RD through WSF recorded significantly the maximum juice, optimum TSS, higher ascorbic acid, reducing sugars, non-reducing sugars, total sugars and A grade fruit yield. There was also a significant influence of T_1 (I_1F_1) on per cent A grade fruit yield.

Keywords: Fertigation, irrigation studies, sweet orange, quality parameters

Introduction
The citrus is a leading fruit crop of World. The sweet orange (*Citrus sinensis* L. Osbeck) is one of the most important fruit crop amongst the citrus group in India and particularly in Maharashtra state. In India, the important citrus fruits grown are mandarins, sweet oranges and acid lime sharing 40.60 per cent, 26.00 per cent and 25.10 per cent, respectively of total citrus fruit production in country. Andhra Pradesh ranks first in area (82.89 thousand ha) and production (2003.10 thousand MT) whereas, Maharashtra ranks second in area (55.20 thousand ha) and production (684.80 thousand MT) [2].
Sweet orange is a rich source of sugars, acids, polysaccharides and many phytochemicals such as vitamin C and carotenoids which provide health benefits against various diseases including cardiovascular and cancer diseases. Since sweet orange contains natural antioxidants, this citrus fruit clears the body of free radicals, thus increasing pH levels of body making them lead a healthier and energetic life and free of disease.
As a perennial evergreen tree, citrus requires water and nutrients round the year for higher orchard efficiency (Davies and Albrigo) [5]. The shortage of water and nutrients in any stage of the crop reduces the yield and quality of the fruits drastically. Moreover, the substantial loss of nutrients from plant root zone through deep percolation and surface runoff under traditional methods of irrigation and fertilization causes the pollution of water in surface and ground water sources of the region, which is a threat to human life (Hanson *et al.*) [9]. The use of water and nutrients through drip irrigation (DI) in concurrence with plant demand, therefore, could be one of the potential options for sustainable citrus production.
In the present investigation, different irrigation and fertigation regimes were used to study the influence of water and nutrients on fruit quality of sweet orange cv. Phule Mosambi.

Material and Methods
A two-year field trial was conducted during 2017 and 2018 at the research farm of All India Coordinated Research Project on Fruits, Department of Horticulture, MPKV, Rahuri, situated between $19^0$20' and $19^0$57' N latitude and $74^0$82' and $74^0$19' E longitude with an altitude of 531 above MSL in the scarcity zone of Ahmednagar district in Maharashtra. The pattern of rainfall is erratic and the region comes under semi-arid climate having irrigation facility. The experiment was conducted on 10 years old sweet orange (*Citrus sinensis* L. Osbeck) cv. Phule Mosambi budded on Rangpur lime rootstock (*Citrus limonia* Osbeck) planted at a distance of 6 x 6 m. The soil of experimental site was medium black with pH of 8.12 and EC of 0.21 dSm^{-1}. *Ambia bahar* crop was taken in sweet orange wherein the water stress was induced in the month of November-December.

The sweet orange orchard with 60 trees was selected for ten treatments under the study. Each treatment was replicated thrice having two plants in each replication. The experiment was laid out in factorial randomized block design comprising two factors of irrigation and fertigation with each having three levels and a control. In this investigation nine treatments included three irrigation levels (I) *i.e.*, I_1-irrigation at 100% ETc., I_2 - irrigation at 80% ETc. and I_3- irrigation at 60% ETc. with three fertigation levels (F) *i.e*., F_1- 100% of recommended dose (RD) through water soluble fertilizers (WSF), F_2- 80% of RD through WSF and F_3- 60% of RD with WSF through drip irrigation. The treatments combinations tested were T_1 -I_1F_1-Drip irrigation at 100% of ETc with 100% of RD through WSF, T_2 -I_1F_2-Drip irrigation at 100% of ETc with 80% of RD through WSF, T_3 -I_1F_3- drip irrigation at 100% of ETc with 60% of RD through WSF, T_4-I_2F_1- drip irrigation at 80% of ETc with 100% of RD through WSF, T_5-I_2F_2- drip irrigation at 80% of ETc with 80% of RD through WSF, T_6-I_2F_3- drip irrigation at 80% of ETc with 60% of RD through WSF, T_7-I_3F_1- drip irrigation at 60% of ETc with 100% of RD through WSF, T_8-I_3F_2- drip irrigation at 60% of ETc with 80% of RD through WSF, T_9-I_3F_3- drip irrigation at 60% of ETc with 60% of RD through WSF and T_{10}- Control - surface irrigation as per the farmer practice with conventional fertilizers at 100% RDF as band placement. The recommended dose of fertilizer (RDF) for sweet orange in the region is 800 g N: 300 g P_2O_5: 600 g K_2O + 20 kg FYM + 15 kg neem cake/plant/year that was used for fertigation with water soluble fertilizers (WSF) in treatments while band placement of conventional fertilizers (BPF) were used for control. The application of fertilizers for band placement was done with urea, single super phosphate and muriate of potash while water soluble fertilizer grades like urea, urea phosphate (12:61:0), potassium phosphate (0:52:34) and sulphate of potash (0:0:50) were used for fertigation. The fertigation was done at fortnightly interval with 18 splits for each of the levels i.e. 100% (F_1), 80% (F_2) and 60% (F_3) of RD through WSF in four main stages comprising 5 splits of 40% each of N, P_2O_5 and K_2O during January to March in first stage, 5 splits each of 30% N and P_2O5 and 10% of K_2O during April and May in second stage, 4 splits each of 20% of N and P_2O5 and K_2O during June and July in third stage and 4 splits each of 10% N and P_2O_5 and 30% K_2O during August and September in fourth stage. All standard package of practices was followed during the experiment *viz.*, weeding, pest and disease management etc. Irrigation duration for delivery of water to different treatments was controlled with the help of control valve at the inlet of each treatment plot. Each plant in the treatment plot was irrigated with double lateral spaced at 90 cm apart each having 6 emitters of 4 L h^{-1} discharge rate. Irrigation was given on alternate day on the basis of daily crop-evapotranspiration rate (ETc) computed from the reference evapotranspiration (ETr) with the help of Phule Jal mobile application depicting the real time ETr values of the orchard and the crop coefficient (Kc) as suggested by Allen *et al.* [1] and modified by Petillo and Castel [18] from the equation ETc = ETr x Kc. The net irrigation requirement was computed from the formula, $V = [(ETr-R_e) \times Kc \times A \times F] / Eu$ where, V = volume of water applied to each plant per day (mm^3); ETr = Reference evapotranspiration at the irrigation level (mm/day); Kc = Crop coefficient (as per crop stage); A = canopy area of tree (m^2) and F = wetting factor under canopy *i.e.*, 70% of canopy area]; R_e was taken as the effective rainfall (mm/day) for the day and *Eu* was the taken as 90% emission uniformity.

The juice was expressed as weight of juice out of the total fruit weight in percent and the titratable acidity was estimated by titrating juice with 0.1 N NaOH by using the method as suggested by AOAC [3]. The total soluble solids (TSS) of the sweet orange fruit juice was recorded by using hand refractometer (Erma, Japan) having range of 0-32 °Brix. The ascorbic acid, reducing sugars, non-reducing sugars and total sugars were estimated by the standard method described by Ranganna [20]. The Grade A, B and C fruits in percent were calculated with the help of citrus fruit size category as given by Ladaniya [14] and the total number of fruits in various grades were expressed in percent grade A, B or C out of total fruits.

Results and Discussion

The effect of different irrigation and fertigation levels and their interactions showed a significant increase in juice (%). The data as per Table 1 shows that the irrigation level I_1-100% ETc recorded significantly the maximum juice content (47.54%), lowest TSS (9.57 ^{0}B), maximum ascorbic acid (58.26 mg 100 ml^{-1} of juice) and highest reducing sugars (4.09%), non-reducing sugars (2.64%) and total sugars (6.73%). The fertigation level F_1 with 100% RD through WSF showed maximum juice content (46.48%), lowest TSS (9.64^{0}B), maximum ascorbic acid (57.81 mg 100 ml-1 of juice), highest reducing sugars (4.00%), non-reducing sugars (2.61%) and total sugars (6.60%) which was observed to be at par with F_2 having fertigation level of 80% of RD through WSF in case of juice and ascorbic acid content. The effect of irrigation and fertigation as individual and that of interaction on titratable acidity was observed to be non-significant.

The interaction effects of different irrigation and fertigation levels on juice content, TSS, ascorbic acid, reducing sugars, non-reducing sugars and total sugars were found to be significant. The treatment T_1 (I_1F_1) having irrigation level I_1-100% ETc through drip along with fertigation level F_1-100% RD through WSF recorded significantly the maximum juice (48.52%) and ascorbic acid content (59.89 mg 100 ml^{-1} of juice) than rest of the treatment combinations which was found to be statistically at par with T_2 (I_1F_2) having irrigation at 100% of ETc and fertigation level of 80% of RD through WSF, T_4 (I_2F_1) having irrigation at 80% ETc with fertigation level of 100% of RD through WSF and T_5 (I_2F_2) having irrigation at 80% of ETc and fertigation at 80% of RD through WSF. The higher soil water and nutrients availability might be the reason for higher juice and ascorbic acid content in sweet orange. Similar results were obtained by Shirgure *et al.* (2001) [22] and Shirgure *et al.* (2004) [21] in acid lime, Desai *et al.* (2014) [6] in Kinnow mandarin, Panigrahi and Srivastava (2017) [17] in citrus, Kuchanwar *et al.* (2017) [13] in Nagpur mandarin and Goramnagar *et al.* (2017) [8] in acid lime.

Table 1: Effect of irrigation and fertigation levels on fruit quality parameters in sweet orange Pooled Mean

Treatment	Juice (%)	TSS (^{0}Brix)	Titratable acidity (%)	Ascorbic acid (mg 100 ml^{-1} of juice)	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)
Irrigation Levels (I)							
I_1	47.54	9.57	0.49	58.26	4.09	2.64	6.73
I_2	46.44	9.78	0.45	57.82	4.05	2.41	6.46
I_3	42.89	10.46	0.4	53.53	3.73	1.96	5.69
SE (m) +	0.2	0.05	0.03	0.21	0	0.02	0.02
CD at 5%	0.59	0.14	NS	0.64	0.01	0.07	0.06
Fertigation Levels (F)							
F_1	46.48	9.64	0.47	57.81	4.00	2.61	6.60
F_2	46.33	9.87	0.45	57.4	3.97	2.31	6.28
F_3	44.06	10.31	0.41	54.4	3.9	2.1	6.00
SE (m) +	0.20	0.05	0.03	0.21	0.00	0.02	0.02
CD at 5%	0.59	0.14	NS	0.64	0.01	0.07	0.06
Interaction (I X F)							
T_1 -I_1F_1	48.52	9.42	0.52	59.89	4.15	3.03	7.17
T_2 -I_1F_2	48.07	9.47	0.5	59.39	4.10	2.51	6.61
T_3 -I_1F_3	46.05	9.83	0.45	55.5	4.04	2.38	6.41
T_4 -I_2F_1	47.77	9.56	0.48	59.15	4.07	2.47	6.53
T_5 -I_2F_2	47.54	9.63	0.46	58.92	4.07	2.43	6.5
T_6 -I_2F_3	44.01	10.14	0.42	55.4	4.02	2.35	6.36
T_7 -I_3F_1	43.15	9.94	0.43	54.39	3.79	2.33	6.11
T_8 -I_3F_2	43.4	10.5	0.40	53.9	3.76	1.98	5.74
T_9 -I_3F_3	42.11	10.96	0.38	52.31	3.65	1.58	5.23
SE (m) +	0.34	0.08	0.06	0.37	0.01	0.04	0.04
CD at 5%	1.02	0.25	NS	1.10	0.02	0.11	0.11
T_{10}-Control	44.84	10.30	0.41	55.34	3.82	2.16	5.98

The interaction effect of different irrigation and fertigation levels on TSS was found to be significant. The treatment T_1 (I_1F_1) having irrigation level I_1-100% etc. through drip along with fertigation level F_1-100% RD through WSF recorded the minimum TSS 9.42 ^{0}B than rest of the treatment combinations. The treatment T_9 (I_3F_3) having irrigation at 60% ETc with fertigation level of 60% of RDF through WSF recorded significantly the highest TSS 10.96 ^{0}B. The increase of water stress under the lower irrigation levels caused a significant increase in TSS. Yakushiji *et al.* (1998) [24] showed that water stress leads to an increase in TSS, which is not as a result of dehydration of the fruit, but rather as a result of the osmo-regulatory response caused by the lack of water. This agrees with Koo and Smajstrla (1984) [12] who elaborated that irrigation and fertigation reduce the total soluble solids. These results are in conformity with Holzapfel *et al.* (2001) [10], Shirgure *et al.* (2003) [23], Ghosh and Pal (2010) [7] in sweet orange, Panigrahi and Srivastava (2011) [16] in Nagpur mandarin, Nagaz *et al.* (2015) [15] in sweet orange and Amina *et al.* (2018) [4] in *Citrus reticulata* Blanco.

The interaction effects between different irrigation and fertigation levels on reducing sugars (%), non-reducing sugars (%) and total sugars (%) were found to be significant. The treatment T_1(I_1F_1) comprising irrigation level I_1-100% ETc through drip along with fertigation level F_1-100% RDF through WSF recorded significantly maximum reducing sugars (4.15%), non-reducing sugars (3.03%) and total sugars (7.17%) as compared to the rest of the treatment combinations. The occurrence of these results might be due to the fact that higher NPK fertilization results in higher sugar accumulation. The results are in conformity with those of Ghosh and Pal [7] in sweet orange cv. Mosambi and Karuna *et al.* (2017) [11] in Kinnow mandarin.

The interaction effect of irrigation and fertigation on per cent A grade yield as tabulated in Table 2 shows that the treatment T_1 i.e. I_1 F_1, drip irrigation at 100% ETc and fertigation with 100% of RD recorded the highest A grade fruit yield (21.35%) in pooled result followed by T_2 i.e. I_1F_2. This result is in agreement with Pratima and Sharma [19] in kiwifruit.

Table 2: A, B and C grade yield (%) of sweet orange during *Ambiabahar* as influenced by different levels of irrigation and fertigation Pooled Mean

Treatments	A grade (%)	B grade (%)	C grade (%)
Irrigation Levels (I)			
I_1	20.64	39.37	39.99
I_2	19.84	38.12	42.04
I_3	17.67	30.21	52.12
SE (m) +	0.17	0.37	2.21
CD at 5%	0.49	1.09	6.56
Fertigation Levels (F)			
F_1	20.17	37.66	42.17
F_2	19.7	36.2	44.09
F_3	18.28	33.83	47.89
SE (m) +	0.17	0.37	2.21
CD at 5%	0.49	1.09	NS
Interaction (I X F)			

T_1 -I_1F_1	21.35	40.62	38.03
T_2 -I_1F_2	21.23	40.15	38.62
T_3 -I_1F_3	19.35	37.33	43.32
T_4 -I_2F_1	20.91	39.53	39.56
T_5 -I_2F_2	20.42	38.89	40.69
T_6 -I_2F_3	18.19	35.93	45.88
T_7 -I_3F_1	18.24	32.84	48.92
T_8 -I_3F_2	17.47	29.56	52.97
T_9 -I_3F_3	17.29	28.23	54.47
SE (m) +	0.29	0.64	3.83
CD at 5%	0.85	NS	NS
T_{10}-Control	17.98	31.1	50.92

Conclusion

The treatment T_1 (I_1F_1) i.e. - irrigation level-100% ETc through drip along with fertigation level-100% RD through WSF was found to be superior with respect to fruit quality parameters as it recorded significantly the maximum juice, optimum TSS, higher ascorbic acid, reducing sugars, non-reducing sugars, total sugars and A grade fruit yield. Therefore, the sweet orange orchard can be irrigated with 100% etc. through drip along with fertigation level-100% RDF through WSF for optimum quality parameters in fruits.

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