Indian J. Hort. 68(3), September 2011: 312-317

A novel technique to apply irrigation water at sub-surface from existing surface drip irrigation system in grapevine: Effect on yield, nutrient content and water use efficiency

Jagdev Sharma[*] and A.K. Upadhyay[**]
National Research Centre for Grapes, Manjri Farm, Pune 412 307, Maharashtra

ABSTRACT

Improving water use efficiency is the key to sustaining grape production especially in hot and dry tracts of Maharashtra. For this, a novel technique using hollow PVC pipes to directly apply irrigation water at sub-surface (22.5 cm depth) in the root zone from the already laid down surface drip irrigation system was compared with surface drip irrigation method for three consecutive cropping and six pruning seasons. Application of irrigation water using sub-surface irrigation technique produced significantly higher yield, brix yield (TSS × yield/100), bunch weight, pruned biomass and nutrient content compared to corresponding surface drip irrigation level at 50 and 75% levels of recommended irrigation level. New sub-surface irrigation technique at 75% irrigation level produced yield and brix yield equivalent to 100% surface drip irrigation level, thereby leading to significantly higher water use efficiency. The average benefit-cost ratio was higher for new sub-surface irrigation technique at 75% recommended irrigation level (1.74) compared to surface drip irrigation at 100% recommended irrigation level (1.67). To further economise on the cost of the implementation of this novel sub-surface irrigation technique during 2005-2006, waste plastic bottles used for mineral water were used instead of PVC pipe at 50% irrigation level with similar results.

Key words: Drip irrigation, sub-surface irrigation, grape.

INTRODUCTION

Grape cultivation in India is mostly concentrated in the semi-arid regions, where potential evapo-transpiration is much higher than the annual precipitation. Water is the main factor limiting the quality and yield in arid zones (Fanizza and Riccardi, 5). Major grape growing regions of India suffer from water scarcity at one or the other time. The problem has been further compounded by increased pressure on use of groundwater and reduced and erratic rainfall over the years in major raisin (dried grapes) producing regions. Presently, growers transport irrigation water in tankers from distant places during summers to these grape-growing regions to keep the vineyards alive. The cost of one tanker of water (10,000 l) could be as high as Rs. 1,200 during the drought years (Anon, 1) depending on the distance of transportation. Although the growers have installed drip irrigation system to cope up with water scarcity problems, considerable soil moisture is lost through evaporation even in surface drip irrigated crops (Bonachela *et al.*, 3; Castel, 4). For maximizing irrigation water use efficiency, the water should be directly applied in the root zone to minimize evaporation losses. Sub-surface drip irrigation (SDI) systems offer many advantages over other types of irrigation systems for specialty crop production, including water savings, improved trafficability and a drier canopy (Steele *et al.*, 13) by reducing evaporation losses.

The scientific information on subsurface irrigation or the method for application of water directly in the root zone in grapes and its feasibility is meager especially in Indian soil-climatic conditions and under saline irrigation. Further, almost all the vineyards in India are surface drip irrigated. Changing the irrigation system to conventional sub-surface irrigation will involve huge expenses. To economise on the cost of cultivation and utilizing existing surface drip irrigation technique under such situations, a novel technique was devised involving the use of PVC pipes (30 cm length) placed directly below the drippers, so that the irrigation water can be directly applied in the root zone at 22.5 cm depth. In the light of the above, two experiments were conducted to study the effect of application of drip irrigation water directly in the grapevine root zone at 22.5 cm depth on field grown grapevines using PVC pipe and waste plastic bottles to improve water use efficiency compared with surface drip irrigation method.

MATERIALS AND METHODS

First experiment was conducted on Tas-A-Ganesh vines (*Vitis vinifera* L.) for three consecutive cropping and six pruning seasons on a heavy black cotton type

[*]Corresponding author's E-mail: jsharmagrape@yahoo.com

soil exhibiting swelling and shrinkage properties the Research Farm of NRCG, Pune during the period 2002-2005. Before the start of the experiment the vines were raised under uniform management practices for two years till the framework was developed on Y-trellis system. The experiment was conducted under double pruning and single cropping system for consecutive three years using four vines as a unit for recording observations. Each treatment was replicated six times. Total rainfall was 270 mm in the first year, 200 mm in the second year and 500 mm during the third year of experimentation whereas the pan evaporation was 1304, 1162 and 1260 mm, respectively (Table 1). Vines were irrigated at three-irrigation levels, *viz.* 50, 75 and 100% level of the predetermined (recommended) surface drip irrigation for the region (Sharma *et al.*, 10) and 50 and 75% irrigation applied through subsurface irrigation technique (Table 2). The drip water from the

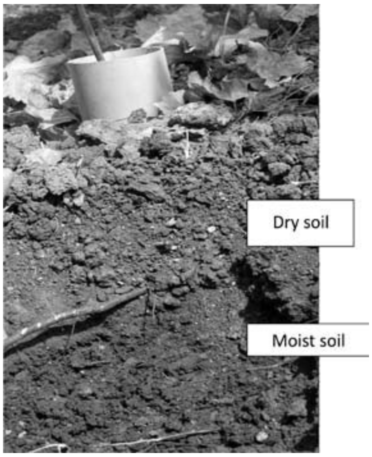

Fig. 1. Upper dry soil layer as a result of application of water directly in the root zone with the help of micro-tube attached to dripper and hollow pipe.

Table 1. Pan evaporation between the foundation pruning and harvest and irrigation applied.

Growth stage	First year (April 2002 to March 2003)		Second year (May 2003 to March 2004)		Third year (April 2004 to March 2005)	
	Pan evaporation (mm)	Irrigation* applied (mm)	Pan evaporation (mm)	Irrigation* applied (mm)	Pan evaporation (mm)	Irrigation* applied (mm)
0-40 days	317.9	133.6	197.2	82.8	286	120
41-60 days	38.4	5.4	69.3	9.7	71	9.9
60-120 days fruit pruning	318.4	44.6	175.6	24.6	190	14.3
0-40 days	158.5	66.6	177.0	74.3	143	60.1
41-55 days	54.36	7.6	66.5	9.3	61	8.5
56-105 days	168.2	70.6	178.37	74.9	155	64.9
106-harvest	248.4	104.3	297.80	125.1	315	132.3
Total	1304.16	432.6	1161.77	400.7	1220	410

*100% irrigation level (Recommended level for surface drip irrigation)

already laid down surface drip irrigation system was applied at 22.5 cm depth through hollow PVC pipe (30 cm length and 6.25 cm in diameter) with the help of micro-tube attached to emitters/drippers (4 lph). Sixteen holes were made in the lower 15 cm portion of the PVC pipes across the cross-section of the pipe from both the directions to facilitate lateral movement of water out of PVC pipe in the root zone of the vines (Fig. 1). The vines were irrigated with saline water from open well (8.30-8.35 pH and 1.70-1.80 dS/m electrical conductivity) after plantation and also during the years of experimentation. The vines received 50% of the annual N, P, K as direct soil application. Remaining nutrient dose was applied

Table 2. Irrigation treatment details.

Treatment No.	Detail
T1	50% of recommended irrigation level through surface drip
T2	50% of recommended irrigation level below surface at 22.5 cm depth
T3	75% of recommended irrigation level through surface drip
T4	75% of recommended irrigation level below surface at 22.5 cm depth
T5	100% of recommended irrigation level through surface drip

Fig. 2. Empty plastic water bottles used for applying the water in the root zone of the vines. The incidence of the weeds was also reduced as result of application of irrigation water below surface.

as fertigation. A maximum of 60 bunches per vine were retained after the fruit pruning.

Pruned biomass on fresh weight basis was recorded after each pruning. The gravimetric soil moisture was recorded during the ripening stage after 24 hours after irrigation. Water use efficiency was measured in terms of brix yield (kg/ha) / total quantity of irrigation water applied (mm). Brix yield was calculated by the formulae: Brix yield = (Yield × TSS / 100). Bunch weight was calculated as yield per vine/bunch number per vine at the time of harvest. Petiole nutrient content was determined after harvest by sampling all the petioles on a cane. The tissue samples were washed as per standard procedure, oven dried at 70°C and then ground to 0.5 mm fraction using a Cyclotec sample mill (Foss Tecator make). The powdered fraction was digested in HNO_3 : $HClO_4$ (3:1) and analysed for phosphorus and potassium content (Jackson, 7). The nitrogen content in plant sample was estimated according to modified Kjeldahl procedure as described by Jackson (7). Year-wise data were pooled and statistically analysed using randomised block design. Data on nutrients having significant differences among the treatments at harvest stage has been reported.

Another experiment was conducted during the 2005-2006 cropping season by using empty plastic (mineral water) bottles instead of hollow PVC pipe with the objective to make use of cheaper material for below surface application of water. One set of vines (15 vines) were irrigated using surface drip at 50% level of the recommended irrigation level, while in the other set of vines irrigation was applied below surface at 22.5 cm depth as per earlier experiment. The treatments were imposed 10 days after fruit set on Tas-A-Ganesh vines grafted on 110R rootstock and the data were statistically analyzed using 't test'.

RESULTS AND DISCUSSION

The pooled data with respect to yield and yield attributes are given in the Table 3. The lowest yield was recorded under treatment T1 (50% of the recommended irrigation level through surface drip). The other treatments produced significantly higher yield than T1. Sub-surface irrigation at 50% of the recommended irrigation level (T2) produced significantly higher yield compared to T1 and was on par with treatment T3 (75% of the recommended irrigation level as surface drip). Similarly treatment T4 (75% of recommended irrigation at subsurface) produced significantly higher yield compared to T3 and was on a par with T5 (100% of the recommended irrigation level through surface drip). Treatment effect on brix yield also showed similar trend. Sub-surface irrigation at 50 and 75% of the recommended irrigation level produced significantly higher brix yield than the corresponding surface drip irrigation levels. Treatment T4 also produced brix yield equivalent to T5 (Table

Table 3. Effect of treatments on water use efficiency, yield and yield attribiutes of Tas-A-Ganesh vines during 2002-2005 (three years pooled data) and average trunk girth at the end of experiment.

Treatment	Yield (tonne/ha)	Brix yield (tonne/ha)	WUE (kg yield/ha -mm irrigation)	Benefit : cost ratio	Bunch weight (g)	Average trunk girth (cm)	Pruning weight (kg/vine on fresh weight basis)	
							Foundation pruning season	Fruit pruning season
T1	11.57	2.48	11.80	1.31	152	14.61	1.33	1.19
T2	13.91	2.99	14.25	1.53	174	16.94	1.95	1.74
T3	13.61	3.21	11.53	1.54	171	16.08	1.83	1.62
T4	15.77	3.76	13.52	1.74	187	17.93	2.11	2.05
T5	14.76	3.75	11.32	1.67	195	17.75	2.22	1.90
CD (P = 0.05)	1.088	0.194	0.483		5.85	0.78	0.217	0.126

3). The lowest average bunch weight (152.08 g) and pruned biomass were recorded under T1 treatment. The difference with respect to average bunch weight between T3 (171 g) and T4 (187 g) was significant. The pooled data showed though small but significantly higher bunch weight in case of treatment T5 than T4. However, in two out of three years there was no significant difference in bunch weight between these two treatments. Higher bunch weight during the first year in case of T5 was due to less number of bunches recorded compared to T4.

Vine trunk girth was measured at the end of experiment. Sub-surface irrigation increased the vine trunk girth significantly over the surface drip irrigation at 50 as well as 75% of the recommended irrigation level (Table 3). Least trunk girth (14.61 cm) was recorded with 50% of the recommended irrigation level under surface drip irrigation (T1). Increased rates of irrigation increased the vine trunk girth significantly. The treatments T5 and T4 did not differ significantly with respect to trunk girth. The improved yield as a result of sub-surface irrigation (22.5 cm depth) at 50 and 75% level of irrigation was supported by significantly higher bunch weight, pruned biomass weight and increased stem/trunk girth. The reduced irrigation levels reduced the above parameters significantly. Southy and Jooste (12) found a high positive correlation between yield and cane mass on a relatively saline soil.

Water use efficiency (WUE) was measured in terms of brix yield (kg/ha) / irrigation water (ha-mm). Significantly higher water use efficiency than surface drip irrigation method was obtained with the novel method of sub-surface irrigation (22.5 cm depth) in all the three years at same level of irrigation (Table 3). Though the highest WUE was recorded with sub-surface irrigation at 50% of the recommended irrigation level (T2), however, the brix yield was significantly lower compared to higher irrigation levels, i.e., T3, T4 and T5. Sub-surface irrigation at 75% of the recommended irrigation level resulted in higher water use efficiency (13.52 kg/ha-mm) compared to irrigation 100% surface drip irrigation level (11.32 kg/ha-mm).

Moisture content of the soil at 0-7.5 cm depth in case of sub surface irrigation was significantly lower than conventional surface drip irrigation at different distances from the drip point, whereas moisture content was significantly higher at 7.5-22.5 cm depth (Table 4). The superiority of new method of irrigation over conventional surface drip was due to reduction in soil evaporation from the surface layer as is evident from the soil moisture data. Various research workers under varied soil and climatic conditions have reported considerable evaporation losses from surface drip irrigation. Evaporation from the emitter zones in drip irrigated olive orchards ranged from 4 to 12% for a mature (36% ground cover) and from 18 to 43% of ET for a young orchard (5% ground cover), depending on the fraction of soil surface wetted by the emitters (Bonachela *et al.*, 3). Soil evaporation in Clementine trees orchards (cv. Clementina de Nules) subjected to differential drip-irrigation ranged from about 50% of evapo-transpiration in months with frequent rainfall to 8-30% in rainless months (Castel, 4).

The irrigation method also affected the petiole nutrient concentrations (Table 4). Treatments involving the sub-surface irrigation (T2 and T4) increased K and P concentration in the petioles compared to corresponding surface drip irrigation levels (T1 and T3). Treatment T4 resulted in significant increase in petiole N, P and K content over T5 (conventional - 100% irrigation through surface drip). Nutrient uptake is affected by both method of placement of fertilizers and moisture status of the soil. The increased petiole nutrient content was partly due to application of the nutrients directly in the root zone along with irrigation water (fertigation) since 50% of the NPK dose was applied as fertigation. Grapevines are sensitive to salinity. Both treatments, T5 and T4 showed reduction

Table 4. Nutrient concentration at harvest and soil moisture content at ripening stage under surface drip and sub-surface irrigation.

Treatment	Element					15 cm away from the drip point		30 cm away from the drip point	
	N %	P %	K %	Cl^- %	Na %	0 to 7.5 cm depth	7.5 to 22.5 cm depth	0 to 7.5 cm depth	7.5 to 22.5 cm depth
T1	0.58	0.21	0.91	0.83	1.00	30.27	28.67	15.90	15.41
T2	0.67	0.30	1.22	0.71	0.95	15.55	31.65	14.45	18.92
T3	0.61	0.26	1.16	0.71	1.14	31.48	30.97	15.55	19.65
T4	0.65	0.39	1.37	0.64	0.97	15.97	32.15	14.30	21.72
T5	0.56	0.33	0.90	0.64	1.14	32.27	31.63	15.85	21.18
CD (P = 0.05)	0.073	0.049	0.221	0.035	0.13	1.47	0.79	0.82	0.68

in chloride concentration in petioles compared to rest of the treatments. Treatment T4 showed reduction in the Na concentration in the petioles. These results indicate the possibility of improving the nutrient use efficiency by adopting sub-surface method of irrigation. Further, the weed incidence was also reduced in the treatments receiving irrigation below soil surface during the present study (Fig. 3, data not shown). Grattan *et al.* (6) also observed reduction in weed incidence with the application of irrigation through sub-surface method.

In a separate experiment during 2005-2006 cropping season, instead of PVC pipe cheaper material, *viz.* empty mineral water plastic bottles were used in the same way 10 days after fruit set for sub-surface irrigation. Sub-surface irrigation at 50% of the recommended irrigation level resulted in significant increase in yield and bunch weight compared to surface drip method (Table 5). The superiority of sub-surface method of irrigation using different technologies in different crops has also been demonstrated by many workers (Matouk *et al.*, 8; Oron *et al.*, 9; Wunderer and Schmuckenschlager, 14; Sharma *et al.*, 11). Sub-surface micro-irrigation technique using clay pipes was particularly effective in improving yields, crop quality and water use efficiency for a range of crops grown under different climatic conditions. Good results were also obtained with below surface irrigation when poor quality irrigation water was used (Batchelor *et al.*, 2). Moisture distribution under subsurface drip irrigation is better adjusted to the root pattern in order to counteract osmotic effects of the soil salinity in comparison to conventional drip irrigation (Oron *et al.*, 9).

Fig. 3. Holes were made in the lower portion of the hollow pipe to facilitate the lateral movement of the irrigation water.

Benefit-cost ratio calculated based upon farm gate price of Rs. 20 per kg grapes and considering the additional expenditure involved and the life of the PVC pipe (Rs. 4,377 per year/ha) considering the life of the PVC material in the new subsurface method subsurface excluding the cost of 25% amount of irrigation water and electricity etc. was highest in the treatment T4 (1.74) followed by T5 (Table 3). The benefit-cost ratio was least in the case of treatment T1 (1.31). The cost involved in this technique could be reduced by using the waste plastic bottles.

Subsurface irrigation at 75 per cent of the recommended irrigation level, suggested a saving of 25 per cent of irrigation water. This saving is highly important particularly in areas where the irrigation water has to be transported during the stress period to keep the vines alive. New method of water application does not require major changes in the already laid down surface drip system. The results of the present experiment showed that application of water through this novel technique was superior to surface method of irrigation in terms of higher yield/mm of applied irrigation (water use efficiency).

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Table 5. Effect of application of drip irrigation water at subsurface (22.5 cm) after fruit set using plastic bottles on yield and yield parameters during 2005-2006.

Sl. No.	Yield per vine (kg)		TSS (°Brix)		Bunch wt. (g)	
	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface
1	12.50	10.67	21.2	21.6	229	195
2.	12.75	11.30	21.5	21.6	209	195
3.	13.00	11.08	21.7	21.5	247	195
4	12.52	10.56	21.4	21.6	241	193
5	12.85	11.06	21.6	21.9	239	195
6.	11.95	9.56	21.4	21.6	216	189
7.	12.56	9.56	21.7	21.8	247	162
8.	11.78	9.40	21.9	21.3	213	182
9.	12.01	10.52	21.5	21.6	221	180
10.	11.68	9.52	21.6	21.8	211	185
11.	11.91	9.80	21.5	21.6	219	184
12.	12.72	10.84	21.7	21.4	254	203
13.	11.68	9.40	21.5	21.7	222	184
14.	11.06	9.87	21.7	21.8	214	157
15.	11.85	10.21	21.6	22.0	234	184
Mean	12.19	10.22	21.57	21.65	227.7	185.3
t value	8.75**		-1.34 (NS)		8.54**	

**Significant ($p = 0.05$); NS = Non significant

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Received: April, 2009; Revised: March, 2011;
Accepted : July, 2011