DOI : 10.5958/0974-0112.2020.00066.3

Indian J. Hort. 77(3), September 2020: 461-468

Effect of irrigation levels on yield and quality of Cabernet Sauvignon vines of wine grapes under semiarid tropics of India

Ajay K. Upadhyay*, Jagdev Sharma, Ajay K. Sharma, Ravindra U. Mulik, Jinal Lodaya and Satisha Jogaiah

ICAR-National Research Centre for Grapes, Manjari Farm, Solapur Road, Pune 412 307, Maharashtra

ABSTRACT

To improve quality of wine grapes, it is necessary to strike balance between vegetative and reproductive growth. Thus, developing irrigation schedule becomes important in managing vine vigour, which in turn helps in reducing the berry size, which is one of the main requirements for wine making. A three year (2010-11 to 2012-13) study was conducted to develop irrigation schedule for Cabernet Sauvignon, wherein six treatments with various replenishment rates based upon pan evaporation at different crop growth stages were compared. All the treatments proved similar statistically in respect of yield and yield related parameters. Lower values of tartaric: malic acid ratios were observed in T1 and T6 treatments than others. Treatment T6 showed highest water use efficiency (84.30 kg of grapes/ mm) of irrigation water applied. The irrigation water applied was least in T6 treatment (209.7 mm) apart from 192 mm rainfall. Even though least irrigation was provided to vines till harvesting in treatment T6, nevertheless moisture stored in the soil profile was sufficient to meet the crop need. Thus, irrigation schedule (T6) with minimal irrigation has been found to produce fairly good yield and quality grapes, which can be comparable with other treatments providing higher quantity irrigation to vines.

Key words: *Vitis vinifera*, water use efficiency, must quality, anthocyanins, phenols.

INTRODUCTION

About 94 per cent of total grape production is cultivated in the states of Maharashtra and Karnataka (Adsule *et al.,* 1). Primarily, India is a table grape producing country; however, wine grape cultivation has been started for last 25 years. Wine grape cultivation in India falls under hot climate, a category based on average growing season temperature (Jones, 10). Tropical viticulture suffers from conditions like continuous vegetative growth due to lack of dormancy. Further, moisture and temperature are the important abiotic stresses affecting the vineyard productivity. Under these growing conditions, viticulture practices include double pruning with single fruiting season in a year. First pruning in March – April is called as foundation pruning and the second pruning from September to October is known as fruit pruning.

Cabernet Sauvignon is one of the wine varieties considered to be adapted to intermediate to hot climate conditions. It is envisaged that climate change is likely to bring hotter growing season with less rainfall. Such events will accentuate both water and salt stresses, leading to early mortality of vines. According to Chaves *et al.* (3), large proportion of vineyards are located in regions with seasonal drought where soil and atmospheric water deficits, together with high temperatures, exert large constraints in yield quality and commercial life of vines. In vineyards under Mediterranean conditions it is now a common practice to manage the water deficit during final phases of grape development (Williams and Matthews, 23). However, in Australia, for example, most common practice is to apply less water early in the season (McCarthy *et al.,* 14). Both of these practices have shown to benefit wine, in one case reducing the berry size by limiting available water and in the other one by limiting the potential for growth.

Matthews *et al.* (13) showed that the growth of berries was inhibited more, and the concentration of flavonoids in berries and resultant wine increased more when water deficits were imposed before veraison than after veraison. Kennedy *et al.* (12) concluded that post veraison water deficits inhibited fruit growth only. Water deficit also appears to beneficially influence fruit composition in ways that are, at least in part, independent of berry size (Roby *et al.,* 19). Later on, Castellarin *et al.* (2) found that water deficit can enhance accumulation of anthocyanins by stimulating the expression of genes encoding their biosynthesis.

A key to improve wine grape quality in irrigated vineyards is to achieve an appropriate balance between vegetative and reproductive developments. Thus, irrigation becomes important in managing vigour

Corresponding author's E-mail: ajay.upadhyay@icar.gov.in

and at the same time helping in reducing the berry size. However, developing production technologies will necessitate first looking into the moisture stress issues, which is the major factor in grape production under Indian conditions. No systematic research has been carried out on irrigation water requirement for wine grape varieties to produce suitable berries for quality wine production. Developing irrigation schedule based on crop growth stage and weather conditions will help in improving wine grape quality. Keeping in view the importance of irrigation water requirement based on phenological stages of wine grapes, the present study was conducted to standardize irrigation schedule for Cabernet Sauvignon vines raised on 110R rootstock.

MATERIALS AND METHODS

The experiment was initiated at ICAR-NRC for Grapes in 2010 on three year old Cabernet Sauvignon vines raised on 110R rootstock. The plantation distance in vineyard was 2.4 × 1.2 m. The soil of the experimental site is heavy textured exhibiting swelling shrinkage characteristics with about 40% clay content. The $EC_{(1:2)}$ of soil ranged from 0.5 to 0.542 dSm^{-1} with available nutrient content of 142-216 ppm N, 19.42-46.24 ppm P, 423-953 ppm K and 805-926 ppm Na. The vines were irrigated with water having EC-1.62 dSm^{-1}; pH-8.87; Ca^{2+} -42.4 ppm; Mg^{2+} -67.56ppm; Na^{+} -206.31 ppm; Cl^{-} -223.65 ppm; HCO_3^{2-} - 488 ppm, SO_4^{2-} - 125.14 ppm and 37.0 ppm NO_3^{-}-N. The vines were uniformly fertilized on per hectare basis with 125 kg P_2O_5, 300 kg K_2O, 100 kg N and FYM @ 15 ton on dry weight basis. Six treatments (irrigation schedule based on crop growth stage and recorded open pan evaporation) were imposed on vines raised under uniform management conditions. The experiment was conducted as randomized block design with four replications. In the third year, another schedule was added after obtaining results of preliminary trial on withholding irrigation after fruit pruning, wherein total number of treatments was increased to seven by modifying treatment T6 by withholding irrigation from 91 days after fruit pruning up to the harvest. Details of treatments are given in Table 1. The total pan evaporation data for the experimental period is given in Fig.1. The pan evaporation was recorded with Class A pan evaporimeter. Recorded total pan evaporation in 2010-11, 2011-12 and 2012-13 was 1289.19 mm, 1427.27mm and 1476.69 mm, respectively. Total rainfall recorded during the growing years 2010-11, 2011-12 and 2012-13 was 594 mm, 533.5 mm and 192 mm, respectively. The treatments were imposed after adjusting for the total rainfall in the schedule.

Ten vines in each replication were selected to record the data on various aspects. The collected bunches were stored at low temperature (20-22°C) to remove the field heat. For recording the data on bunch weight and berries per bunch, at random 50 bunches were selected and average was noted. Fifty berries were collected from different sides and upper, mid and down side of bunches and utilized for berry weight, length and diameter. The nutrient content in the petioles was analysed after washing, oven drying at 70°C and grinding in 'Cyclotec' sample mill (Foss Tecator make). Nitrogen in the petioles was estimated by Kjeldahl method using Gerhardt semi-automatic distillation apparatus (VAPODEST 30). A part of petiole samples were digested in block

Table 1. Details of applied treatments during both the pruning seasons

Growth Stage	T 1	T 2	T 3	T 4	T 5	T 6	T 7
Foundation Pruning/ Back Pruning							
Shoot growth (1-40 days)	45*	45	60	30	30	30	30
Fruit bud differentiation (41-60 days)	15	15	15	15	15	15	15
Cane maturity and Fruit bud development (61-120 days)	15	15	15	15	15	15	15
121days - fruit pruning	30	15	15	15	15	15	15
Fruit Pruning/ Forward Pruning							
Shoot growth (1-40 days)	45	45	60	30	30	30	30
Bloom to Shatter (40-55 day)	15	30	15	30	30	30	30
Berry growth and development stage I (56-90 days)	45	30	30	30	15	15	15
Berry growth and development stage II (91-106 days)	45	30	30	30	15	15	--
Ripening to Harvest (106-145 days)	45	15	15	15	30	15	--
Rest period (20 days after harvest)	15	-	15	-	15	--	--

*Based on per cent replenishment of actual pan evaporation (1mm = 10000L/ha)

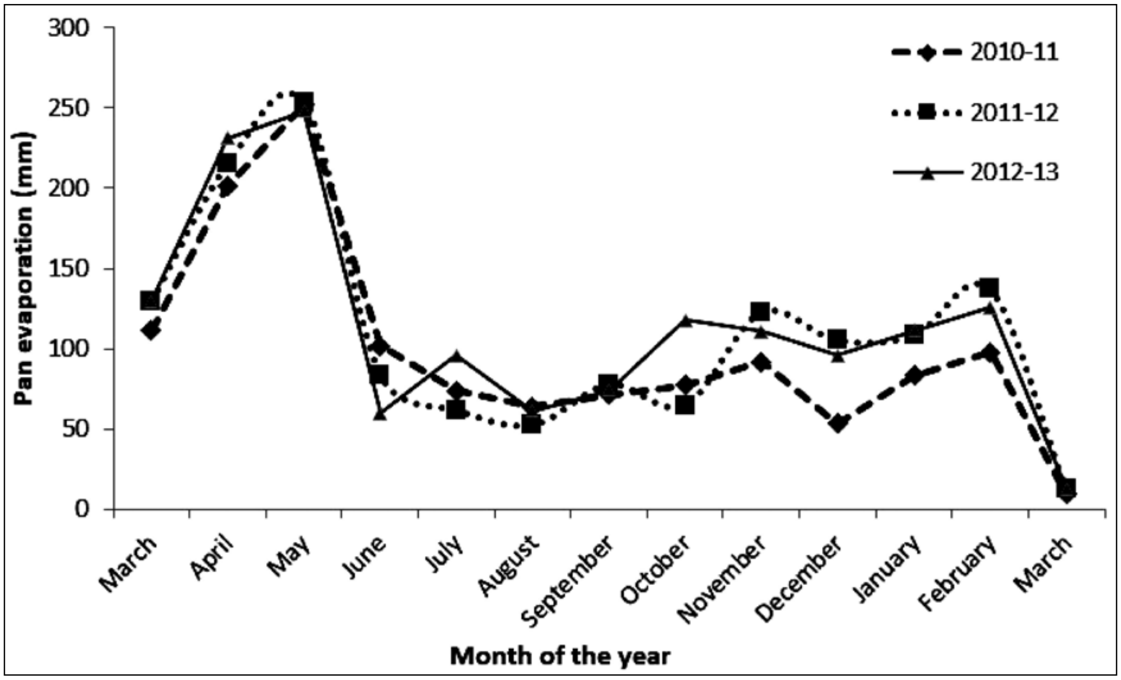

Fig. 1. Pan evaporation (mm) during experiment period.

digester in H_2SO_4: H_2O_2 mixture for estimation of K, and Na. An atomic absorption spectrophotometer (Perkin Elmer Analyst 100) was used to estimate K and Na in emission mode. The chloride in the tissue extract was determined by using flow injection system (Skalar make San system).

The fresh fruits were macerated in cheese cloth and the resultant must was centrifuged and the supernatant was analysed for TSS (hand held refractometer with temperature compensated to 20 °C); acidity (titration of juice against 0.1N NaOH using phenolphthalein as indicator)

For the analysis of organic acids, sugars and phenolic compounds, the fruit samples were stored at -20°C. These stored samples were utilized for analysis of different parameters by using HPLC. The analysis of organic acids (Tartaric acid and malic acid) was done with Agilent technologies 1260 series HPLC system with Diode array detector (DAD) at wave length of 214 nm and band width of 4.0. The column used was Agilent Zorbax eclipse plus C 18 (4.6 ×100 mm 5um). The separation was done with mobile phase of A- 95 % Acidified water with orthophosphoric acid (pH 2.0) and B- 5 % absolute methanol with flow rate of 0.8ml/min. Column temperature was 25° C. The injection volume was 10μl and total run time was 7 minutes. The HPLC analysis of glucose and fructose was done with Agilent technologies 1260 series system with Evaporative Light Scattering Detector (ELSD) in isocratic mode. The injection volume was 10 μ L and total run time was 6 min. Total phenolic, content was estimated with Folin-Ciocalteu reagent by using gallic acid as standard phenolic compound (Slinkard and Singleton, 22).

RESULTS AND DISCUSSION

The data recorded on yield and yield attributing parameters including TSS and acidity in berries are presented in Table 2. For first six irrigation treatment (T1 to T6), the data were pooled and statistically analysed. Significant recorded among the treatments in respect of all parameters for entire duration of study. Highest bunch weight (66.91g) was recorded in T3, while it was lowest (62.66 g) in T1. The highest bunch number (61.51) was recorded in T1 followed by T4 (60.39), while lowest number of bunches (56.51) was recorded in T5. The pooled yield data under different irrigation schedules ranged from 12.58 to 13.52 t/ha, registering its highest value with T3, without showing any significant difference. TSS and acid contents in the berries were found within the limit which is needed for wine making. TSS in the berries ranged from 22.34 - 22.54°B having acidity in the range of 0.60 - 0.61 per cent.

During the course of third year (2012-13) based upon earlier preliminary studies, another treatment T7 was added, wherein no irrigation was provided 91 days after pruning. During this year, bunch weight varied from 75.03 to 79.13 g, being highest

Table 2. Effect of irrigation treatments on yield, bunch and berry quality.

Treatments	Three years pooled data (2010-2013)					2012-13				
	Bunch wt. (g)	Bunch No.	Yield (t/ha)	TSS (°B)	Acidity (%)	Bunch wt. (g)	Bunch No.	Yield (t/ha)	TSS (°B)	Acidity (%)
T1	62.66	61.51	13.10	22.51	0.61	77.65	72.75	18.59	22.61	0.69
T2	64.30	59.39	13.20	22.34	0.60	75.03	70.50	18.38	22.44	0.69
T3	66.91	59.69	13.52	22.54	0.60	78.50	72.75	19.26	22.46	0.69
T4	64.16	60.39	13.20	22.52	0.60	75.10	67.50	17.77	22.70	0.69
T5	65.08	56.51	12.70	22.44	0.60	78.50	64.50	17.29	22.71	0.69
T6	63.73	57.23	12.58	22.45	0.61	77.53	68.25	17.67	22.56	0.70
T7	-	-	-	-	-	79.73	66.25	18.91	22.30	0.70
CD (*p*=*0.05*)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SEm±	2.38	2.12	0.51	0.19	0.01	3.54	4.87	1.14	0.37	0.13

in newly introduced treatment i.e. T7. Bunches per vine ranged from 64.50 to 72.75 and highest bunch count was noticed in T1 and T3 (equal in both), while in T7 (new treatment), only 66.25 bunches per vine were recorded. Highest yield (19.26 t/ha) was recorded in T3 followed by T7 (18.91 t/ha), while it was lowest (17.29 t/ha) was observed in T5. Though non-significant, berries of T5 contained highest TSS (22.71 °B), whereas it was lowest (22.3 °B) in T7. The final increases in sugar are mostly driven by berry dehydration rather than sugar production (Prichard and Verdegaal, 17). Junquera *et al.* (11) also observed the significant effect of irrigation on berry composition. Acidity was found within range of 0.69 to 0.70 per cent.

The contents of sodium and potassium in berry (skin and juice) play an important in deciding quality of wine grapes. Sodium content in juice was much higher than skin, while juice contained lower potassium than skin in all the treatments (Table 3). In case of juice, the sodium content varied from 52.19 ppm in T4 to 55.19 ppm in T3. All treatments had 0.13 per cent K content in juice except T4 where it was 0.12 percent. In case of skin, lowest sodium content (22.25 ppm) was found in T3 followed by T2, while highest Na was found in skin of berries collected from T4. Berry skin collected from T1 contained highest K (0.32 per cent) followed by T3 and T6 (0.31 per cent), while T5 was found with lowest K content (0.27 per cent). Intrigliolo *et al.* (9) found lower potassium concentrations in berry collected from rainfed than irrigated vines. However, non-significant differences were recorded among the treatments (Table 3). The effects of deficit irrigation on berry and wine quality depend on the climatic conditions during the growing season, soil type, grapevine variety and timing of application (Santos *et al.,* 20). Petiole analysis at fruit bud differentiation stage during foundation pruning season and full bloom stage during fruit pruning season for their nutritional status did not show significant difference between the treatments.

Biochemical constituents in must from various treatments are presented in Table 4. Anthocyanin content in the must ranged from 1.76 to 1.81 mg/g. Though non-significant, highest anthocyanin content was observed in T3 (1.81 mg/g) which was followed by T1, T2 and T4. Highest phenol content (22.42 mg/L) was observed in T5 followed by T6 (22.41 mg/L), while T2 had the lowest content of phenols (21.07 mg/L). Roby *et al.* (19) reported a direct effect of water deficit on skin proanthocyanidin and anthocyanin contents. Indeed, a water-deficit treatment typically increases the skin to pulp ratio in the berries, when compared with well-watered grapevines (Roby *et al.,* 19), increasing the amount of skin tannins and anthocyanins. Tartaric and malic acids are main organic acids contained by grape

Table 3. Na and K content in juice and skin of Cabernet Sauvignon grape berry.

Treatment	Juice		Skin	
	Na (ppm)	K (%)	Na (ppm)	K (%)
T1	54.00	0.13	23.63	0.32
T2	52.94	0.13	22.38	0.29
T3	55.19	0.13	22.25	0.31
T4	52.19	0.12	29.50	0.29
T5	52.81	0.13	26.50	0.27
T6	53.75	0.13	22.50	0.31
SEm±	2.69	0.01	3.30	0.03
CD (*p*=*0.05*)	NS	NS	NS	NS

Table 4. Effect of irrigation treatments on must quality.

Treatment	Total Anthocyanin (mg/g)	Total Phenols (mg/L)	L-Tartaric Acid (g/L)	Malic Acid (g/L)	Ratio (Tartaric to Malic acid)	Glucose - Fructose ratio
T1	1.79	22.01	6.74	3.46	1.95	0.99
T2	1.79	21.07	6.67	3.31	2.02	0.93
T3	1.81	22.33	6.41	3.37	1.90	0.94
T4	1.79	22.10	6.78	2.87	2.36	0.95
T5	1.77	22.42	6.61	3.12	2.12	0.95
T6	1.76	22.41	7.57	3.40	2.23	0.99
SEm±	0.03	2.38	0.15	0.07	0.06	0.04
CD (p=0.05)	NS	NS	0.31	0.14	0.14	NS

berries. Grape grown in hot conditions contains more tartaric acid than malic acid. Treatment T6 had with highest tartaric acid content (7.57 g/L) which was followed by T4 (6.78 g/L), while lowest content (6.41 g/L) was recorded in T3. Malic acid content was also minimum (2.87 g/L) in T4 while must from T1 contained highest malic acid (3.46 g/L). The ratio of organic acid has own role in deciding quality and stability of wines during storage as pH is influenced not only by content of organic acids, but ratio of tartaric to malic acid also decides pH of particular must. As tartaric acid is stronger acid, its increase in concentration will result in lower wine pH (Picariello *et al.,* 16). The deficit irrigation has resulted in more tartaric to malic acid ratio and highest ratio was found in T4 (2.36) closely followed by T6 (2.23), whereas it was lowest in T3 (1.90). Deficit irrigation causing moderate water deficits typically reduces malic acid concentrations by one third of a fully watered vine. Due to water deficit, increased tartaric to malic acid ratio was noted by Prichard *et al.* (18). Infact, in T3 and T1, applied irrigation water was maximum compared to other treatments. Hence, lower values of tartaric: malic acid ratio were observed, whereas it was higher in other treatments, where deficit irrigation was applied.

Berry growth is less sensitive to water deficits than vegetative growth. However, water deficits depending on the timing and severity, can significantly reduce berry size (Prichard and Verdegaal, 17). The solute composition of fruit at harvest is sensitive to vine water status throughout its development. Moderate water deficits can increase the rate of sugar accumulation resulting in an earlier harvest. If deficits are severe and/or the vine is carrying a large crop, sugar accumulation is generally slowed resulting in delayed harvest. In terms of concentration, grape composition was scarcely affected by the irrigation volume. The effect of berry weight, metabolic activity, and solute concentration partly compensated for one another, which resulted in few differences in phenol concentrations. Different proteomic and transcriptomic studies in grape berries from vines subjected to water stress reported an effect on the metabolic pathway of secondary metabolites (Grimplet *et al.*, 8; Deluc *et al.*, 5). Glucose and fructose are major sugars in grapes. The ratio of sugars was ranged from 0.93 to 0.99. However, non-significant differences were noted among the treatments. Coombe and Dry (4) noted no differences for pH and total acidity; however, values reached were within the optimal range at harvest in all seasons studied and for all treatments. Mercer *et al.* (15) also recorded non-significant differences in the brix levels noted between the treatments either analysed at harvest or during postharvest, when they studied effects of irrigation reductions from around 110 mm per year down to around 20 mm per year in Sauvignon Blanc on three different rootstocks.

Grapevine is generally considered a ‘drought-avoiding’ species, with an efficient stomatal control over transpiration (Schultz, 21). Total irrigation water application in each treatment is given in Fig. 2. The water use efficiency was lowest across all the treatments during 2010-11 and increased in following years, being highest during 2012-13 (Fig. 3). Highest WUE was recorded in T6 followed by T4, T5 and T2 in second and third years of the experimentations. The irrigation schedule treatment T6 with lowest irrigation water application of 185.82 mm during 2010-11, 196.11 mm during 2011-12 and 209.7 mm during apart from total rainfall of 594, 533.5 and 192 mm, respectively, was found sufficient to provide yield and quality equivalent to other higher irrigation treatments. Based upon the results of three years, T6 treatment showed highest water use efficiency of 84.3 kg of grapes/ mm of irrigation water applied in 2012-13, and 67.2

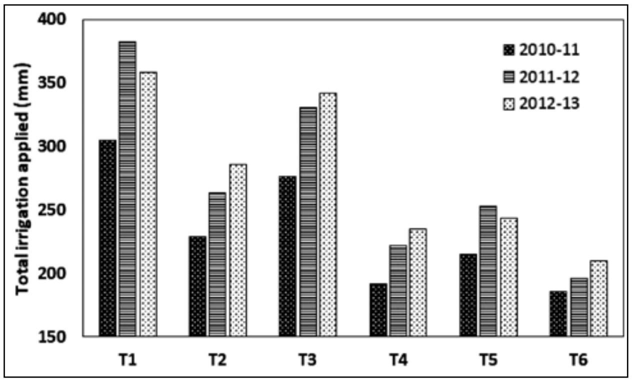

Fig. 2. Year wise application of irrigation water in different treatments

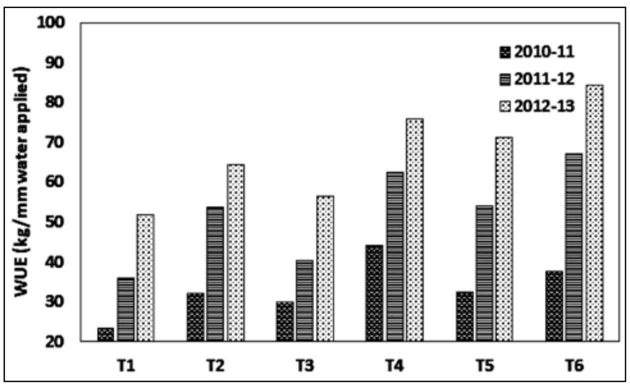

Fig. 3. Effect of treatments on water use efficiency of Cabernet Sauvignon

kg of grapes/mm of irrigation water applied in 2011-12. The irrigation water application was least in T6 treatment across all the years of experimentation. Photosynthetic rates generally decline at lower pre-dawn water potentials than stomatal conductance, when grapevines are subjected to moderate water deficits. As a consequence, intrinsic water use efficiency (A/g_s or WUE_i) is usually higher in vines under deficit irrigation (mild to moderate water deficits) than under well-watered conditions. This is reflected in a lower water use and higher WUE by the crop, an important aim of deficit irrigation strategies in vineyards (Chaves *et al.,* 3). Computing WUE as yield/vine evapo-transpiration (ETc) as suggested by Fereres and Soriano (7), observed that while a moderate water stress can improve WUE, more severe and prolonged water stress, as recorded in the rain-fed vines, can be even detrimental to the vineyard WUE. Further, the soil moisture status below the dripper was least in case of T6 treatment as compared to other treatments. However, all treatments were at par (Table 5). With regard to soil moisture status at 0.30 m and 0.60 m away from the dripper showed non-significant differences among the treatments. This clearly implied that in treatment T6, with least irrigation water application, the moisture stored in the soil profile is sufficient to meet the crop need.

Production of quality grapes demands optimum irrigation water availability throughout the season. Though moisture stress affects vine growth, vigour, yield and must quality of wine grapes, moisture stress at some stages of berry growth (especially after veraison) is useful to improve grape and must composition. Identification of stages at which vines can be supplied with minimum or no irrigation helps in saving the irrigation water considerably without compromising on yield and quality of berries. Data of present study clearly showed water use efficiency can be maximized by regulated deficit irrigation based at different phenological stages of vines. Different parameters showed non-significant differences among the treatments. It means at par quality grapes can be produced by applying need based irrigation calculated by measured pan evaporation. On the basis of present results, it may be concluded that by adopting irrigation schedule as per treatment T6 (least irrigation water application ranging from), yield and quality of the Cabernet Sauvignon grapes can be produced which match with grapes produced from treatments with higher water application. However, there is a possibility of further reduction in irrigation water application as stated by results of treatment T7 in third year. It needs to be further explored.

ACKNOWLEDGEMENT

The authors are thankful to the Director, ICAR-NRC for Grapes for supporting the research project and providing necessary guidance for the execution of the project.

Table 5. Soil moisture content (%) at harvest.

Treatments	Below dripper (upto 0.60m)	0.30m away from dripper (upto 0.60m)	0.60m away from dripper (upto 0.60m)
T1	36.51	24.20	22.28
T2	34.42	22.53	21.97
T3	35.55	23.02	20.49
T4	35.27	22.41	21.14
T5	35.18	22.72	19.41
T6	33.31	22.13	20.31
SEm±	1.63	1.25	0.89
CD (*p=0.05*)	NS	NS	1.90

REFERENCES

1. Adsule, P.G., Sharma, A.K., Upadhyay, A., Sawant, I.S., Jogaiah, S., Upadhyay, A.K. and Yadav D.S. 2012. Grape research in India: A review. *Prog. Hort.* **44**: 180-93.

2. Castellarin, S.D., Pfeiffer, A, Sivilotti, P., Degan, M., Peterlunger, E. and Di Gaspero, G. 2007. Transcriptional regulation of anthocyanin biosynthesis in ripening fruits of grapevine under seasonal water deficit. *Plant Cell Environ.* **30**:1381-99.

3. Chaves M.M., Santos T.P., Souza C.R., Ortuño M.F., Rodrigues M.L., Lopes C.M., Maroco J.P. and Pereira J.S. 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. *Annal Appl. Biol.* **150**: 237–52.

4. Coombe, B.G. and Dry, P.R. 2002. *Viticulture*, vol. 2: Practices. Winetitles, Adelaide, Australia, pp 376.

5. Deluc, L.G., Quilici, D.R., Decendit, A., Grimplet, J., Wheatley, M.D., Schlauch, K.A., Mérillon, J.M., Cushman, J.C. and Cramer, G.R. 2009. Water deficit alters differentially metabolic pathways affecting important flavour and quality traits in grape berries of Cabernet Sauvignon and Chardonnay. *BMC Genom.* **10**: 212.

6. Dry, P. and Loveys, B.R. 1998. Factors influencing grapevine vigour and the potential for control with partial root zone drying. *Australian J. Grape Wine Res.* **4**:140–48.

7. Fereres, E. and Soriano, M.A. 2007. Deficit irrigation for reducing agricultural water use. *J. Exp. Bot*. **58**:147–59.

8. Grimplet, J., Wheatley, M.D., Jouira, H.B., Deluc, L.G., Cramer, G.R. and Cushman, J.C. 2009. Proteomic and selected metabolite analysis of grape berry tissues under well-watered and water-deficit stress conditions. *Proteomics*, **9**:2503–28.

9. Intrigliolo, D.S., Perez, D., Risco, D.S., Yeves, A. and Castel, J.R. 2012. Yield components and grape composition responses to seasonal water deficits in Tempranillo grapevines. *Irrig. Sci.* **30**:339–49.

10. Jones, G.V. 2006. Climate and Terroir: Impacts of Climate Variability and Change on Win". P 247. **In**: Fine Wine and Terroir - The Geoscience Perspective. R.W., Macqueen and L.D. Meinert, Geoscience Canada Reprint Series Number 9, Geological Association of Canada, St. John's, Newfoundland.

11. Junquera, P., Ramo´N Lissarrague, J., Jime´Nez, L., Linares, R. and Baeza, P. 2012. Long-term effects of different irrigation strategies on yield components, vine vigour, and grape composition in cv. Cabernet-Sauvignon (*Vitis vinifera* L.). *Irrig. Sci*. **30**:351–61.

12. Kennedy, J.A., Matthews, M.A. and Waterhouse, A.L. 2002. Effect of maturity and vine water status on grape skin and wine flavonoids. *American J. Enol. Vitic*. **53**:268–74.

13. Matthews, M.A., Ishii, R., Anderson, M.M. and O'mahony, M. 1990. Dependence of wine sensory attributes on vine water status. *J. Sci. Food. Agric*. **51**:321–35.

14. McCarthy, M.G., Loveys, B.R. and Dry, P.R. 2000. Regulated Deficit Irrigation and Partial Root zone Drying as Irrigation Practices – *Water Reports 22* Rome: FAO.

15. Mercer, J., Dryden, G., Neal, M. and Green, S. 2016. Maximising irrigation savings in grape vines and the effect on yield and wine quality. SFF Project 03/100 and Extension. http://www.fruition.net.nz/wp-content/uploads/2016/08/Maximising-irrigation-savings-in-grape-vines-and-the-effect-on-yield-and-wine-quality.pdf.

16. Picariello, L.; Rinaldi, A.; Martino, F.; Petracca, F.; Moio L. and Gambuti, A. 2019. Modification of the organic acid profile of grapes due to climate changes alters the stability of red wine phenolics during controlled oxidation. *Vitis*. 58(special issue): 127-133.

17. Prichard, T.L. and Verdegaal, P.S. 2001. Effects of water deficits upon wine grape yield and quality. http://cecentralsierra.ucanr.edu/files/96234.pdf.

18. Prichard, T.L., Smith, R.J. and Verdegaal PS 2016. Regulated deficit irrigation management for wine grapes. http://www.vineyardteam.org/files/Regulated_Deficit_Irrigation_Mgmt.pdf

19. Roby, G., Harbertson, J.F., Adams, D.A. and Matthews, M.A. 2004. Berry size and vine water deficits as factors in wine grape composition:

anthocyanins and tannins. *Australian J. Grape Wine Res*. **10**: 100–07.

20. Santos, T., Lopes, C.M., Rodrigues, M.L., De Souza, C.R., Ricardo-Da-Silva, J.M., Maroco, J.P., Pareira, J.S. and Chaves, M.M. 2005. Effects of partial rootzone drying irrigation on cluster microclimate and fruit composition of Castelão field-grown grapevines. *Vitis*, **44**:117–25.

21. Schultz, H.R. 2003. Differences in hydraulic architecture account for near-isohydric and anisohydric behaviour of two field-grown *Vitis vinifera* L. cultivars during drought. *Plant Cell Environ*. **26**:1393–405.

22. Slinkard, K. and Singleton, V.L. 1977. Total phenol analyses: automation and comparison with manual methods. *American J. Enol. Vitic*. **28**: 49–55

23. Williams, L.E. and Matthews, M.A. 1990. *Grapevine*. In: Irrigation of Agricultural Crops. Series of Agronomy, pp. 1019–55. Madison, Wisconsin, USA.

Received : August, 2019; Revised : May, 2020; Accepted : May, 2020