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Grape production assessment using surface and subsurface drip irrigation methods

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Abstract

The study involved experimental work implemented from April 2014 until March 2017. Its purpose was to observe grape production quality parameters, such as yield, water productivity, berry size and bio-mass. Different irrigation methods, such as drip irrigation (DI), drip irrigation with plastic mulching (DIPM), drip irrigation with organic mulching (DIOM), subsurface irrigation with stone column (SISC), subsurface irrigation with mud pot (SIMP), and subsurface irrigation with plastic bottles (SIPB) have been used during the experimental work. The crop has been irrigated following the CROPWAT-8.0 model developed by the FAO. Climate parameters are obtained from the automatic weather station located near the experimental field. Based on experimental results and analyses, it has been observed that the drip irrigation with the plastic mulching method is the best for irrigation in terms of the grape yield comparing with all other methods due to its highest productivity of 35–40%. Subsurface irrigation with the plastic bottle method is found to be suitable as it gives 20% higher yield than the traditional drip irrigation method. The SIPB method shows the cost-benefit ratio of 112.3, whereas the DIPM method had the ratio of 36.6. Based on the cost-benefit analysis, it is concluded that the SIPB method is economically more viable as compared with all other methods. Hence, based on the findings, it is recommended to use drip irrigation with a plastic mulching and drip irrigation with a plastic bottle as the best options to achieve grape productivity while using minimum water.

Key words: *crop water requirement, irrigation with plastic bottles, organic mulch, plastic mulch, stone column, sustainable irrigation, water productivity*

INTRODUCTION

Grape production involves a regular provision of water throughout the year. Therefore, at the water-scarce areas, sustainable production of grape is difficult. In arid areas, with continuous demand for the irrigation, water supply is needed to ensure supplemental irrigation [AYARS *et al*. 1999; WILLIAMS *et al*. 1988]. The volatility of rainfall and temperature regimes affect the physiology and productivity of grapevines, and thus it requires irrigation in drought--prone areas [SAVI *et al*. 2018]. The average actual crop coefficient (K_{cact}) value estimated by HYDRUS-2D and simulated for grape grop is 0.27 [PHOGAT *et al*. 2017]. Subsurface drip irrigation was the treatment of the highest hydric comfort and greater weight per cluster and yield/vine [INTRIGLIOLO *et al*. 2016; PÉREZ *et al*. 2016]. Water productivity indices related to pruning weight and grape yield have shown that vegetative growth in a temperate climate has an important influence on water use in vineyards [CANCELA *et al*. 2016; STEVENS *et al*. 2008; TEHRANI *et al*. 2016]. Most of the previous studies concluded that supplemental irrigation systems show significant improvements in the crop production in many regions of the world [FERERES, EVANS 2006; NGIGI *et al*. 2005; SHAHBAZ *et al*. 2006]. Maximizing production and enhancing water use efficiency are more feasible objectives using on-farm water management in arid regions [THEIB, AHMED 2006]. Some options of farm scale water management are rotations of crop, better use of rainfall, and creation of farm ponds to retain excess rainfall water for irrigation. On-farm water storage facilities can be used to satisfy the variable diurnal water demand during a required period and simultaneously prevent water wastage [MEHTA, AKIRA 1992]. The efficient use of water has to become a global concern due to enhancing food production requirements with limited water availability [IPCC 2007; PÉREZ-ESCAMILLA 2017]. Poverty and hunger are the major challenges that arise globally. India has set the goal for sustainable agriculture to be achieved through the use of advanced technology [CHATURVEDI *et al*. 2019]. There are critical issues related to irrigation, i.e. crop water demand and timely water application. Due to scarcity of water, it is difficult to maintain consistent crop yield [GARUDKAR *et al*. 2011]. Hence, it is advisable to use of advanced irrigation methods for the optimum use of water.

In the present study, different irrigation methods have been designed separately for surface and subsurface irrigation. These include drip irrigation (DI) as a control method, drip irrigation with a plastic mulching (DIPM), drip irrigation with an organic mulching (DIOM), subsurface irrigation with a stone column (SISC), subsurface irrigation with a mud pot (SIMP) and subsurface irrigation with plastic bottles (SIPB), as described in detail by KADBHANE and MANEKAR [2016]. Laterals and emitters are common in all above-mentioned irrigation methods. In the surface irrigation methods concerned, water is released into the atmosphere from the emitters. In the subsurface irrigation methods, water is directly applied to the root zone of the plant. A comparative study between the different irrigation treatments has been executed through the field experiments carried out during three growing seasons (from April 2014 to March 2017) based on yield, water productivity, berry size, and bio-mass in the grape orchard.

MATERIALS AND METHODS

STUDY AREA

In this study, experimentation work was carried out in April 2014 – March 2017. It focused on the 'Thomson' grape (*Vitis vinifera*) orchard located at the Nashik district in the West Agro-Climatic Zone of India (WACZI) at 20°04'19" N, 73°54'05" E, and altitude is 585 m above sea level. The study area is a flat terrain, with semiarid climatic conditions, mean annual rainfall of 550 mm and maximum dry period in April to June. High surface temperature and low rainfall are the prominent characteristics of a semi-arid region. The study area has moderate rainfall and moderate temperature, hence it can be classified as a semi-arid region [SRINIAS *et al*. 2012]. Climatological monthly average data have been collected from the India Meteorological Department (IMD) and Nashik Meteorological station for the period of 1981–2013 (Fig. 1 a, b, c). The average monthly climatic data from the Nashik metrological station (1981–2013) has shown that the annual total precipitation is 350 to 550 mm during the monsoon (rainy) season i.e. July to October. Maximum temperature has been recorded in the summer season, i.e. April to June, and minimum temperature in the winter season, i.e. November to February. Other parameters, such as wind speed, sunshine hours, and evapotranspiration (ET_o) vary between seasons [KADBHANE, MANEKAR 2017].

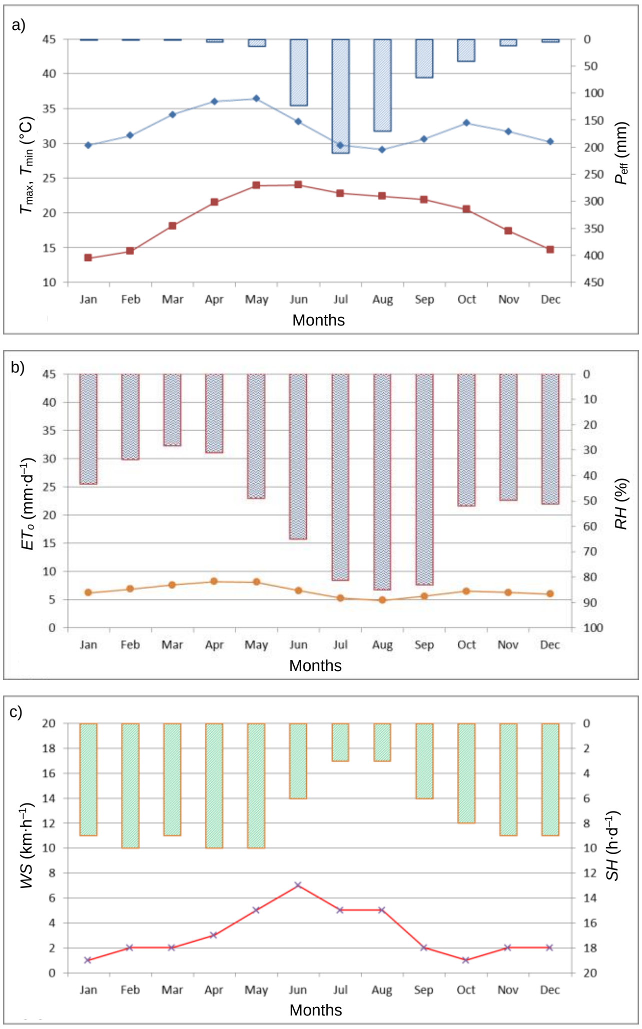

Fig. 1. Monthly averaged climatological data (1981–2013); a) maximum, minimum temperature (T_{max}, T_{min}) and precipitation (P_{eff}); b) evapotranspiration (ET_o) and relative humidity (*RH*); c) wind speed (*WS*) and sunshine hours (*SH*); source: own elaboration

EXPERIMENTAL DESIGN

Initially, six different irrigation systems are designed, and installed in the field. The schematic view of six irrigation systems such as DI, DIPM, DIOM, SISC, SIMP and SIPB [KADBHANE, MANEKAR 2016] are shown in Fig. 2. In the grape orchard under the study, plant rows are placed in the North-South direction with 10 plants in a row with a one-meter spacing between them. Each row has been allotted for a different irrigation method. Between two irrigation methods, one row is compulsory blank to maintain distance and avoid mixing of root zones. The distance between two rows is 2.1 m for convenience of labour and machines.

ANALYSIS OF THE CROP WATER DEMAND USING THE CROPWAT-8.0 MODEL

A farm pond is used for irrigation water supply. Grape plants are irrigated every 3–4-day for 4–6 hours as per the results of Equation (1). Planning of irrigation is based on

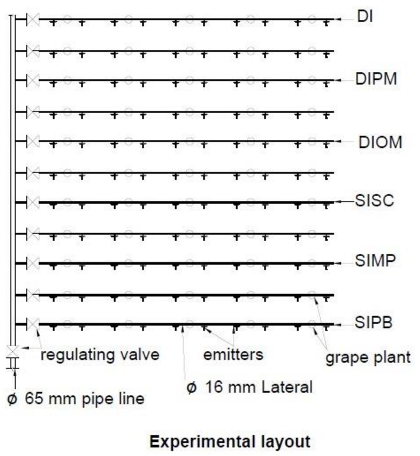

Fig. 2. Overview of six irrigation methods; DI = drip irrigation, DIPM = drip irrigation with plastic mulching, DIOM = drip irrigation with organic mulching, SISC = subsurface irrigation with stone column, SIMP = subsurface irrigation with mud pot, SIPB = subsurface irrigation with plastic bottles; source: own elaboration

a simple relationship, i.e. duration of drip irrigation and the use equation (1):

$$DI = \frac{RI \cdot PI \cdot NIR \cdot 1000}{EC \cdot N} \quad (1)$$

where: DI = duration of irrigation (h), RI = the row distance (m), PI = plant distance (m), NIR = the net irrigation requirement (m), EC = irrigation capacity (dm^3·h^{-1}), N = the number of emitters per plant.

Properties of soil and cropping technique are the same as per KADBHANE and MANEKAR [2016].

The CROPWAT-8.0 model developed by the FAO [1998] is used to calculate the water requirement of grapevine. The main purpose of CROPWAT is to calculate irrigation schedule and crop water demand on the basis of input of data provided by the user in the prescribed format [GHAMARNIA *et al*. 2011]. CROPWAT calculation procedures are based on FAO guidelines [ALLEN *et al*. 1998]. The reference evapotranspiration (ET_o) is a climatic parameter and can be computed from weather data. The FAO Penman–Monteith theory is used to calculate the reference evapotranspiration (ET_o). The crop evapotranspiration (ET_c) can be calculated as:

$$ET_c = ET_o \cdot K_c \quad (2)$$

where: K_c = crop coefficient.

The Penman–Monteith equation gives consistent performance and fairly accurate results in arid as well as humid climates. The FAO Penman–Monteith equation [ALLEN *et al*. 1998] mention as Equation (3):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (3)$$

where: ET_o = the reference evapotranspiration (mm day^{-1}), Δ = the inclination of the vapor pressure curve (kPa·°C^{-1}), R_n = the net radiation at the crop surface (MJ m^{-2} day^{-1}), G = the heat flux density of soil (MJ m^{-2} day^{-1}), T = the mean of air temperature at 2 m height daily (°C), u_2 = the wind speed at 2 m height (m s^{-1}), e_a = the actual vapor pressure (kPa), γ = psychrometric constant (kPa °C^{-1}), e_s = the saturation vapor pressure (kPa), $e_s - e_a$ = the deficit saturation vapor pressure (kPa).

GRAPE CROP MANAGEMENT

The phenological cycle of the grape plant in tropical and subtropical regions includes phases of dormancy, active vegetation, reproductive development, and growth. The grape plant has mainly six phenological stages i.e. bud breaking, vegetation growth, flowering, berry set, berry growth and ripening, and harvest [BAGGIOLINI 1952]. In the study area, grape plant generally has two pruning cycles, such as foundation pruning (from April to September) and fruit pruning (from October to March). Nearly about 90% of grape orchards are following this schedule except red varieties and grape yards located in the Northern region of the Nashik district. In particular climatic conditions, plant stages have played a vital role in the grape production [ADSULE *et al*. 2013].

In the study area, there is a practice involving two pruning stages in a year. The first pruning takes place in April, known as foundation pruning. The first is germination, so there is no fruit for harvesting. The second coincides with the second week of October, and it is known as fruit pruning. Seasonal K_c changes are affected by the climate (temperate vs. tropical) and crop age [BAGGIOLINI 1952]. The seasonal crop coefficients are different in two phases. K_c increases during active growth to the peak canopy size and decreases during leaf senescence. The relationship of K_c and the leaf area index cannot be unique due to large variation in a canopy structure with pruning and training systems i.e. the link is different for decreasing or increasing of K_c [NETZER *et al*. 2009]. Hence, according to theory, above- mentioned K_c has taken values 0.7, 0.65, 0.75 in summer, rainy and winter season simultaneously.

COST-BENEFIT ANALYSIS

In the study area irrigation water is provided from different sources like a well, pond with the conveying system like pipeline, laterals, and emitters. The DI method is commonly used as an irrigation method and considered as the default irrigation method for the study area. This default method already consist of the conveying system. Hence, there is no extra cost for the remaining irrigation methods. Therefore, whatever extra material and labor are required for other five methods, these are considered as a material cost in the analysis.

Being the default method, DI is eliminated from the cost-benefit analysis. The material and labor cost is considered in the analysis based on the prevailing market rates. Materials required and procured for different methods are as follows: (i) for the DIPM method – one meter wide and 100-micron thick plastic paper is chosen to cover the field; (ii) for the DIOM method – organic material purchased from agencies the organic material and the organic bio-mass after pruning is also used as the organic mulching material. The basalt aggregate of 2.5–3.0 cm is purchased from a nearby quarry, mud pots of 10 cm diameter purchased from the local manufacturer for the SIMP method. Plastic bottles are purchased from scrap material shop for the SIPB method. Plastic bottles are perforated 5 mm size pore at the outer surface and then placed in the excavated pit.

STATISTICAL ANALYSIS

To evaluate the impact of six irrigation methods on grape yield, and quality of fruit, an experimental study has been carried out and data collected for three years 1 April 2014 (pruning) to 25 March 2017 (harvesting). A statistical analysis has been carried out using Statistical Analysis ToolPak available with Microsoft Excel 2010. The statistical analysis, including mean values, standard deviation and coefficient of variance, is carried out for the processing of experimental results. Mean values are determined for observed parameters, standard deviation (*SD*) expresses how much members of a group differ from the mean value for the group, and coefficient of variance (*CV*) is the average of the squared differences from the mean [GUPTA 2018]. If the coefficient of variance value is lower, then result shows better performance. Observations of grape quality parameters have applied to ten grape plants in a single row per each of the six irrigation methods. The experimental observations are expressed in the form of parameters such as grape yield, water productivity, berry size and bio-mass. Water productivity ($kg \cdot m^{-3}$) is defined as ratio of grape yield ($kg \cdot m^{-2}$) and irrigation amount ($m^3 \cdot m^{-2}$) [THEIB, AHMED 2006]. Grape pruning is the primary source of bio-mass (kg per plant) resulting from the management practice for both wine and table grapes [PERALBO-MOLINA, CASTRO 2013].

RESULTS AND DISCUSSION

CROP WATER REQUIREMENTS AND IRRIGATION SCHEDULING

The evapotranspiration and effective rainfall was calculated with the CROPWAT-8.0 model, as shown in Fig. 3. In the Figure 3, the data-wise net irrigation requirements (*NIR*, mm), irrigation water provided (*IWP*, mm), crop evapotranspiration (ET_c, mm) and effective precipitation (P_{ef}, mm) are shown for the crop in 2014–2015, 2015–2016, and 2016–2017. Irrigation water provided is calculated as per Equation (1).

The ET_c was steady in all the three study years. Grape irrigation based upon evapotranspiration was found most suitable [INTRIGLIOLO *et al*. 2012]. The net irrigation requirement for growing seasons was the lowest in 2014–2015 when compared with other two study years. The difference is due to higher effective precipitation. Crop water demand was satisfied at the appropriate time using the all six irrigation methods.

IRRIGATION METHODS IMPACT ON GRAPE PRODUCTION

Statistical analysis of experimental results. Table 1 shows recorded data of grape yield, water productivity ($kg \cdot m^{-3}$), berry size (mm), and bio-mass (kg per plant) with reference to six irrigation methods. Observations have covered 10 plants allotted to each irrigation method.

According to experimental results in Table 1, the drip irrigation with a plastic mulching (DIPM) method shows low coefficient of variance, which means higher performance on yield, water productivity and bio-mass, whereas, the subsurface irrigation with plastic bottles (SIPB) method shows good performance on water productivity and yield. Hence, based on the performance, it is recommended that in the case of surface irrigation the DIPM method should be used, and in the case of subsurface irrigation the SIPB method is more suitable in the study area for enhancing the grape quality parameters.

Performance of the irrigation methods based on yield per plant. The box plot between grape yield (kg per plant) and the irrigation methods for the three study years of 2015-2017 is shown in Fig. 4.

From the performance plot in Figure 4, it is observed that among six irrigation methods the DIPM method shows the highest yield as compared with all other methods and 35–40% more grape yield as compared to the drip irrigation (DI) method, a method which is commonly used in the study area. The SIPB method shows 25–35% more grape yield as compared with the DI method during the period under the study (2015–2017). The DIOM method shows 2–5% more grape yield as compared with the DI method during the study years. Subsurface irrigation with a stone column (SISC) and subsurface irrigation with a mud pot (SIMP) methods show 5–10% less grape yield as compared with the DI method.

In the cases of SISC and SIPM subsurface irrigation methods, the grape yield reduction is due to the labor and animal activity, the surface of the stone column get disturbed, and this results in lesser yields. As expected, higher or lower water availability due to irrigation and soil tillage management during berry development induced an increase or decrease in berry fresh weight, which is more evident in larger than smaller berries [BARROSO *et al*. 2017].

In the case of the SIPM, first water is dropped in a mud pot and then it percolates into the soil. Hence, most of the time, due to falling of surface material, there are chances of choking the mud pot and there are very high chances of breaking of the mud pot due to labor and animal activity. Hence, with these disadvantages, the grape yield observed is lower as compared with the drip irrigation method. Another cause of a reduced grape yield is a permanent defect in biochemical properties of soil. Even though biochemical properties of soil in this particular location have been checked before planting, soil properties vary from place to place [MANGALA 2006].

It is observed that DIPM and SIPB methods enhance grape yield and are recommended to be used in the study area. It has been concluded that the application of the appropriate amount of water is essential for plant performance and berry development. Indeed, moderate irrigation can maintain or even improve the fruit quality [MARTÍNEZ, RECA 2014; SIVILOTTI *et al*. 2005].

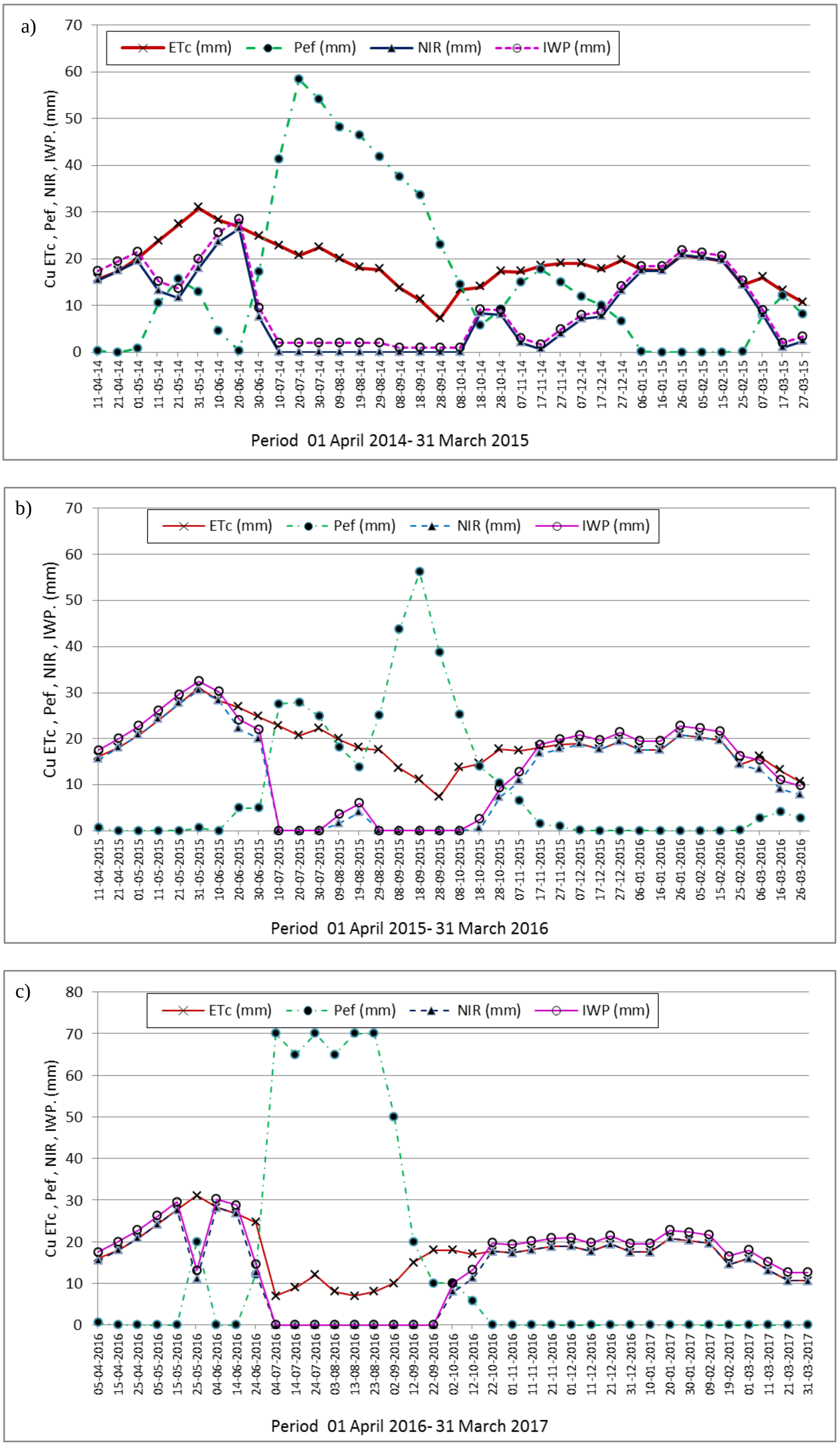

Fig. 3. Cumulative net irrigation requirements (*NIR*), irrigation water provided (*IWP*), crop evapotranspiration (ET_c) and effective precipitation (P_{ef}): a) 2014–2015; b) 2015–2016; c) 2016–2017; source: own study

Table 1. Experimental data for yield, water productivity (*WP*), berry size and bio-mass per six irrigation methods (2015–2017)

Type of irrigation	Parameter	Value in year								
		2015			2016			2017		
		mean	*SD*	*CV* (%)	mean	*SD*	*CV* (%)	mean	*SD*	*CV* (%)
DI	yield (kg·plant^{-1})	5.9	1.0	17.4	6.5	1.8	27.9	6.2	1.3	20.8
	WP (kg·m^{-3})	9.6	1.7	17.4	10.1	2.3	23.0	10.0	2.1	20.8
	berry size (mm)	18.3	1.0	5.5	19.4	0.8	4.1	17.3	0.8	4.7
	bio-mass (kg·plant^{-1})	5.6	0.6	11.6	6.1	0.7	12.1	5.6	0.7	13.0
DIPM	yield (kg·plant^{-1})	9.5	1.3	13.5	10.4	1.4	13.1	10.0	1.3	13.3
	WP (kg·m^{-3})	15.4	2.1	13.5	16.8	2.1	12.5	16.0	2.0	12.5
	berry size (mm)	19.0	1.3	6.7	20.0	1.3	6.3	20.2	0.9	4.4
	bio-mass (kg·plant^{-1})	7.7	0.7	9.2	8.1	0.6	7.8	7.8	0.8	10.4
DIOM	yield (kg·plant^{-1})	6.4	1.3	19.9	7.0	1.2	17.0	6.7	1.2	17.9
	WP (kg·m^{-3})	10.3	2.0	19.9	11.3	1.9	17.0	10.8	1.9	17.9
	berry size (mm)	17.6	1.2	6.8	20.0	1.8	8.9	18.6	1.3	6.9
	bio-mass (kg·plant^{-1})	6.9	0.7	10.6	7.3	0.7	10.1	6.8	0.7	10.9
SISC	yield (kg·plant^{-1})	4.7	0.8	16.6	5.6	1.4	25.4	5.2	1.0	19.8
	WP (kg·m^{-3})	7.6	1.3	16.6	9.0	2.3	25.4	8.3	1.7	19.8
	berry size (mm)	17.1	0.9	5.5	18.0	1.3	7.0	17.8	1.2	6.6
	bio-mass (kg·plant^{-1})	6.5	0.7	10.3	6.8	0.6	8.7	6.3	0.6	9.6
SIMP	yield (kg·plant^{-1})	5.3	1.2	22.3	5.2	1.0	20.0	5.3	0.7	13.5
	WP (kg·m^{-3})	8.6	1.9	22.3	8.5	1.7	20.0	8.5	1.1	13.5
	berry size (mm)	17.7	1.0	5.7	19.2	1.0	5.1	18.5	0.9	5.1
	bio-mass (kg·plant^{-1})	7.2	0.6	7.8	7.0	0.5	7.6	7.1	0.6	8.8
SIPB	yield (kg·plant^{-1})	9.0	1.8	20.2	9.2	1.8	19.7	9.2	1.1	12.3
	WP (kg·m^{-3})	13.9	2.0	14.1	15.4	2.3	14.9	14.8	1.6	11.1
	berry size (mm)	17.8	0.9	4.9	19.6	2.2	11.5	19.0	1.1	5.6
	bio-mass (kg·plant^{-1})	7.0	0.9	13.5	7.3	0.8	11.5	6.9	0.9	13.6

Explanations: *SD* = standard deviation, *CV* = coefficient of variance, DI = drip irrigation, DIPM = drip irrigation with plastic mulching, DIOM = drip irrigation with organic mulching, SISC = subsurface irrigation with stone column, SIMP = subsurface irrigation with mud pot, SIPB = subsurface irrigation with plastic bottles.
Source: own study.

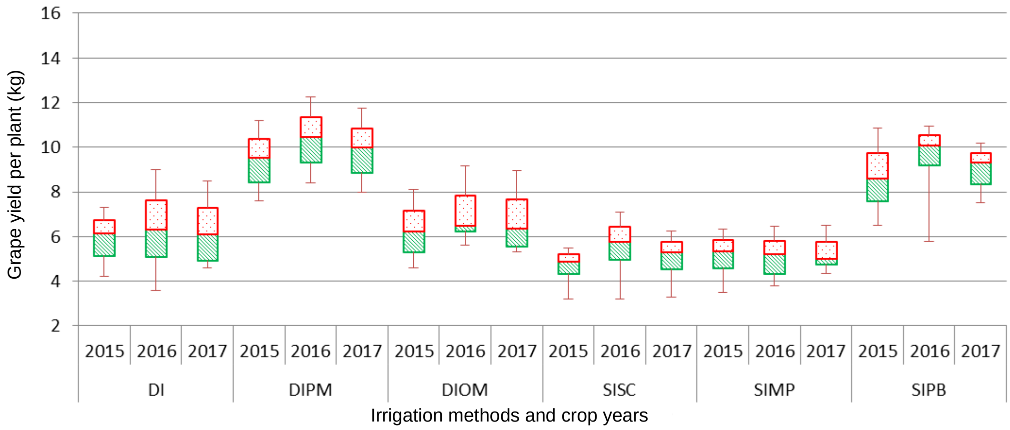

Fig. 4. Box plot of tested irrigation methods based on grape yield (2015–2017); DI, DIPM, DIOM, SISC, SIMP, SIBP as in Fig. 1; source: own study

PERFORMANCE OF THE IRRIGATION METHODS BASED ON THE WATER PRODUCTIVITY

The box plot between water productivity (kg·m^{-3}) and the irrigation methods during 2015–2017) is shown in Fig. 5.

It is observed from Figure 5 that the DIPM method shows 35–40% more water productivity as compared with the DI method, a method which is commonly used in the study area during the period under the study (2015–2017). The SIPB method also shows 20–25% more water productivity as compared with the DI method. The drip irrigation with organic mulching (DIOM) method also shows 10–13% more water productivity as compared with the DI method during the three study years. But SISC and SIMP methods show 8–12% less water productivity as compared with the DI method. Hence, it is concluded that DIPM and SIPB methods enhance water productivity and are recommended in the study area. Surface and subsurface irrigation methods show varying results for water productivity. Mulching and subsurface irrigation treatments supposed to save 40% of water without compromising total yield and its components. It should also increase water use efficiency by about 40% [CONESA *et al*. 2015; SIVILOTTI *et al*. 2005].

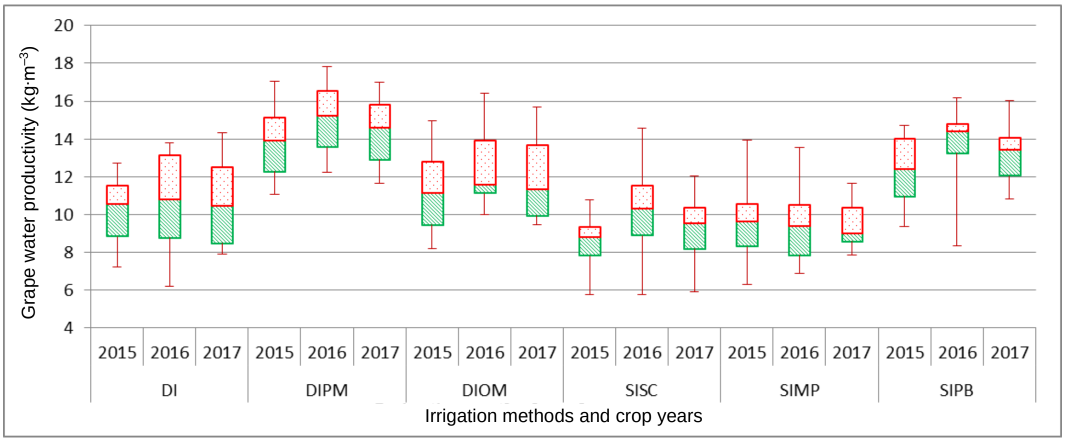

Fig. 5. Box plot of tested irrigation methods based on water productivity (2015–2017); DI, DIPM, DIOM, SISC, SIMP, SIBP as in Fig. 1; source: own study

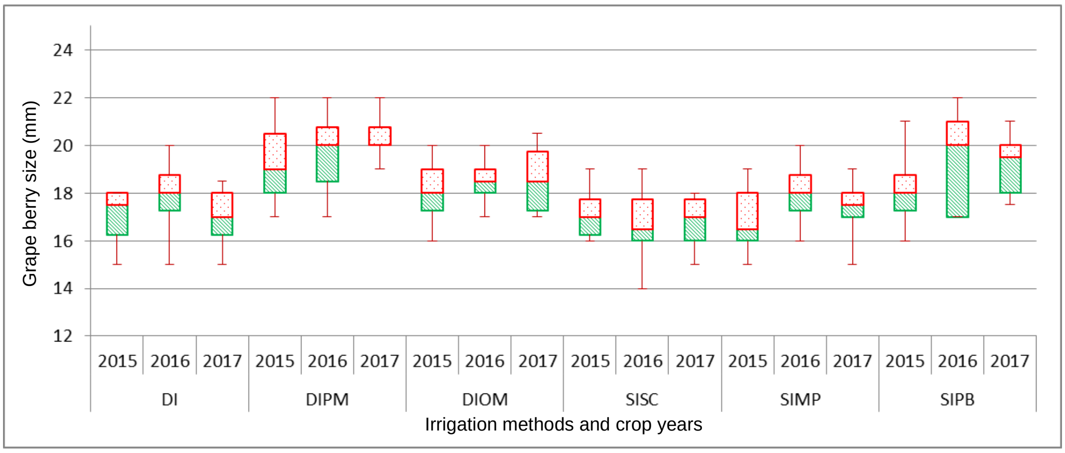

Fig. 6. Box plot of tested irrigation methods based on berry size (2015–2017); DI, DIPM, DIOM, SISC, SIMP, SIBP as in Fig. 1; source: own study

Performance of the irrigation methods based on the berry size. The box plot between berry size (mm) and the irrigation methods for the three study years (from 2015 to 2017) is shown in Fig. 6. According to the quality of table grape, big size grapes (more the 17 mm) are best for export.

According to Figure 6, the DIPM method shows 10–18% more berry size as compared with the DI method during the study period (2015–2017). The DIOM method also shows 5–8% more berry size as compared with the DI method. The SIPB method also shows 5–12% more berry size as compared with the DI method. But SISC and SIMP methods show 5–8% smaller berry size as compared with the DI method. Hence, the DIPM and the SIPB methods are more beneficial to increase the berry size. Surface and subsurface irrigation methods show different results regarding the berry size. The lower supply of water and carbohydrates during the berry growth period could possibly have induced reduced berry expansion [CHAVES *et al*. 2010].

THE PERFORMANCE OF THE IRRIGATION METHODS BASED ON THE BIO-MASS

The box plot between bio-mass and the irrigation methods during the study years (from 2015 to 2017) is shown in Fig. 7.

According to Figure 7, the DIPM method shows 11–18% more bio-mass as compared with the DI method during the study period (2015–2017). The DIOM and SIPB methods show 2–3% and 1–3%, respectively, more bio-mass as compared with the DI method. SISC and SIMP methods show 4–7% less bio-mass as compared with the DI method. Hence, the DIPM and SIPB methods are recommended to be used in study area to increase the bio-mass. Timely water provision to the grape plant resulted in good growth of leaf and branches. It is suggested that bio-mass growth processes are very sensitive to water stress. However, it also depends on the variety [MATHEWS, ANDERSON 1989; ROBY, MATTHEWS 2004].

Based on the study, it is recommended that DIPM and SIPB methods should be used to enhance the measured grape parameters. However, it is necessary to validate the recommended methods against the cost-benefit analysis.

COST-BENEFIT ANALYSIS OF IRRIGATION METHODS

To estimate benefits the average grape yield and quality (berry size) of fruit using each irrigation method have been taken into considerations. The yield and offered market rates are always found higher for grapes grown using DIPM, DIOM, and SIPB irrigation methods. This is due to the fact

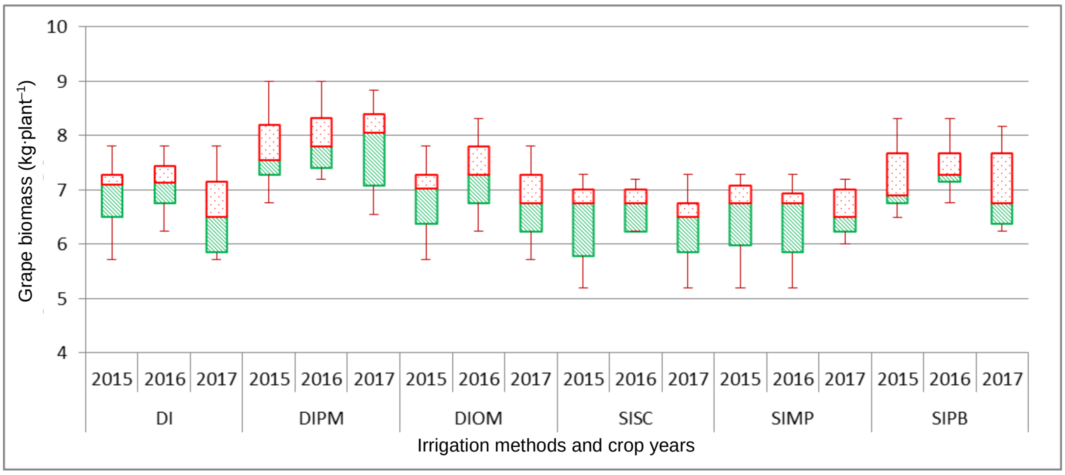

Fig. 7. Box plot of tested irrigation methods based on bio-mass (2015–2017); DI, DIPM, DIOM, SISC, SIMP, SIBP as in Fig. 1; source: own study

that timely provision of water resulted in the production of the best quality grapes. Results of the cost-benefit analysis for the irrigation methods are shown in Table 2.

Table 2. Results of benefit-cost analysis of experimented irrigation methods

Cost and benefit per plant	DIPM	DIOM	SISC	SIMP	SIPB
A – the gross cost of material (USD)	0.04	0.08	0.14	0.27	0.05
B – labour charges (USD)	0.04	0.07	0.27	0.09	0.16
C – sum of material and labour (A + B) (USD)	0.08	0.15	0.41	0.36	0.22
D – life of materials (years)	1	1	6	5	10
E – the total cost per year (C/D) (USD)	0.08	0.15	0.07	0.07	0.02
F – three years average yearly yield (kg) of designed method minus three years average yearly yield (kg) of DI method	0.05	0.01	–0.01	–0.01	0.04
G – average market rate (USD·kg^{-1})	0.81	0.81	0.41	0.41	0.81
H – net benefit per year per plant (K = (F·G) – E) (USD)	2.97	0.23	–0.49	–0.45	2.43
I **– benefit cost ratio (I = H/E)**	**36.6**	**1.6**	**–7.3**	**–6.2**	**112.3**

Explanations: DIPM, DIOM, SISC, SIMP, SIPB as in Tab. 1.
Source: own study.

According to Table 2, the SIPB method shows the highest cost-benefit ratio of 112.3, whereas the DIPM method shows 36.6, i.e. these two methods are economically more viable as compared with other methods. According to the results shown in Table 2, the DIPM irrigation method shows a higher average yearly yield of 3.76 kg per plant than the DI method, whereas the SIPB shows a yield of 3.02 kg per plant more than the DI method. It is also experimentally verified that in the case of DIPM, DIOM and SIPB, high-quality grapes are grown as well. In the market, these are recognized as export quality grapes. Market rates offered for this quality grape is almost double as compared with low-quality grapes. Based on the cost-benefit analysis, it is concluded that the SIPB method is economically more viable as compared with the DIPM method. It is because in this method waste plastic bottles are recycled.

CONCLUSIONS

According to the experimental study in 2014–2017, experimental grape yield, water productivity, berry size and bio-mass show different results for different irrigation methods. It is observed that in case of grape yield, water productivity, berry size, and bio-mass, the DIPM and SIPB show the best performance, whereas the SISC and SIPM methods show poor performance as compared with the DI irrigation method. Hence, the DIPM method is recommended in case of surface irrigation and the SIPB method in case of subsurface irrigation for better quality and quantity of grape production in the study area. The DIPM method shows cost-benefit ratio of 36.6, whereas for the SIPB it is 112.3. Based on the cost-benefit analysis, it is concluded that the SIPB method is economically more viable as compared with all other irrigation methods because waste plastic bottles are recycled and the cost is negligible. According to experimental results and cost-benefit analysis, the SIPB is the best irrigation method in crop and climate conditions similar to the study area. Hence, the SIPB irrigation method is strongly recommended to grape farmers in study area.

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