Effect of using pruning waste as an organic mulching on a drip-irrigated vineyard evapotranspiration under a semi-arid climate

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ABSTRACT

In a drip-irrigated vineyard soil evaporation (E) can reach up to 30-40% of the seasonal grapevine crop evapotranspiration (ET_c). Vineyard soil management can be used as a technique to reduce soil E for improving crop water use efficiency. The aim of this experiment was to analyze the effect of using pruning waste as an organic mulching on vineyard ET_c. During three experimental seasons, several cycles of grapevines water use determinations were conducted using a large weighing lysimeter located in Albacete (southeast Spain) under drip irrigation. Measurements were carried out under different soil management practices: i) keeping the bare soil within the lysimeter during the first 2-3 days (bare soil), ii) covering the lysimeter soil surface with pruning waste as an organic mulching (about 5 cm thick) for the next 2-3 days (organic mulch), and iii) covering the lysimeter with a waterproof canvas (plastic mulch), similar in colour to the soil, for the last 2-3 days of each measurement cycle.

In 2017, the measurements period was initiated when midday stem water potential (Ψ_{stem}) values reached -1.3 MPa, in order to study the effect of the different soil management on grapevine ET_c when vines in the lysimeter were suffering from severe water stress. During the 3-year study, plant determinations (i.e., canopy cover and the phenological stage) showed that vines were at the same stage of development during each period of measurements. Under equal evaporative demand and fractional canopy cover, results showed a reduction in the vineyard ET_c between 16-18% with the organic mulching, and up to 24-30% with the plastic mulching. Even though plastic mulches significantly reduced water evaporation from soil surface, this reduction could have resulted in an increase in crop transpiration (T). However, results in this experiment show that both organic and inorganic mulching did not increase vine T compared to no mulching conditions, based on vine T values estimated during the three experimental periods of 2015. Therefore, using pruning waste as an organic mulch could be an environmental friendly alternative to reduce soil evaporation and increase crop water productivity in large areas where vineyards are drip-irrigated.

Keywords: weighing lysimeter, soil evaporation, vine transpiration, water use, organic mulch, plastic mulch

1. Introduction

Vineyards occupy large areas in the Mediterranean basin (mainly in Spain, France and Italy) and in other countries (USA, Australia, South Africa, Chile, etc.) under arid and semiarid weather conditions, in which vineyard crop evapotranspiration (ET_c) is an important component of the hydrological cycle (Trambouze and Voltz, 2001). The grapevine global planted area reached nearly 7 million ha in 2017, with a production of 74.3 million Mg. In Spain, the cultivated vineyard area was more than 900,000 ha in 2017, representing about 13.4% of the world harvested grapevine area. At the moment there are over 225,000 ha under irrigation in Spain, representing about 24% of the harvested vineyard area. The study area (La Mancha) has the world´s largest surface area devoted to grapevines with over 444,000 ha, of which 34% are currently irrigated (FAOSTAT, 2017; MAPA, 2017).

Although vineyards have been traditionally cultivated under rain-fed conditions, nowadays vineyard irrigation has increased considerably, driven by wine quality considerations and production stability aims. Furthermore, in environments characterized by high evaporative demand, and low and erratic rainfall during the growing season, irrigation is needed to keep vines alive and for the intensification of production, resulting in an economically viable activity. In areas with water resource shortages, vineyard irrigation is limited by the available water supply and the standard allocation is often well below the potential (i.e., maximum) water requirements (López-Urrea et al., 2012). Moreover, this water scarcity in many areas of the world seems to be worsening, mainly due to global warming and increasing competition with other water demand sectors (IPCC, 2018).

Even though grapevine is considered a drought tolerant specie able to perform well under a moderate degree of soil water deficit (Mirás-Avalos and Intrigliolo, 2017), the grapevine potential seasonal evapotranspiration (ET_c) under non-limiting soil water content might reach up 500 to 550 mm (López-Urrea et al. 2012) with crop coefficient as high as 1.0 for a ground cover of around 55% (Picón-Toro et al., 2012; Williams and Ayars, 2005). Vineyard crop evapotranspiration (ET_c) is due to both vine transpiration (T) and soil evaporation (E). While T is required to optimize vine productivity, soil evaporation is considered an unproductive component of the soil water balance, even if it affects the vineyard energy balance.

In discontinuous canopies and in plants with a large dormant period like grapevines, soil evaporation can be an important component of the water balance. In addition, nowadays vines are mostly trained with vertically shoot positioning under a trellis system leaving some part of the vineyard floor uncovered by the vine leaf area. On the other hand, drip irrigation is the irrigation system most commonly employed which wets a small part of the vineyard floor. Under these conditions (i.e., trellis system and drip-irrigated vineyard), previous studies have determined that E might represent up to 30% of the total vineyard water balance (Kool et al., 2014). More recently, Sánchez et al. (2017 and 2019) reported seasonal grapevine water requirements using a Simplified Two-Source Energy Balance (STSEB) approach, with the soil evaporation (E) resulting between 30% and 40% of the total vineyard ET_c. Two-source modeling allows to estimate accurate vineyard ET_c, as well as getting the partition in soil E and canopy T, using radiometric temperatures as a main input, together with meteorological and biophysical variables (Norman et al., 1995; Colaizzi et al., 2012; Sánchez et al., 2014 and 2015).

Vineyard floor management can be used as a technique to improve the whole vineyard water productivity (Medrano et al., 2015), reduce the competition between spontaneous vegetation and the cultivated grapevines and indeed influence vine performance and grape composition (Guerra and Steenwerth, 2012). In this sense, the use of mulching normally increases yield (Lanini et al., 1988) due to the higher retention of soil water content (Sales, 2015). On the other hand, the effects of mulching on grape composition are largely dependent on the type of material used for mulching and its final effects on soil nutrient concentration (Guerra and Steenwerth, 2012). For instance, when compost mulch manufactured from organic gardens was used, must potassium concentration and pH were increased (Chan et al., 2015). However, when natural mulches are used to cover the vineyard floor, clear effects on grape composition are not always found (Sauvage, 1995; Chan and Fahey, 2011).

Plastic mulching is often employed to null soil evaporation (Wittwer, 1993), and depending on the material used also to alter vine microclimate and particularly the radiation regime (Guerra and Steenwerth, 2012). For instance, when reflective material made from aluminium platelets is used, grape phenolic concentration can be increased (Osrečak et al., 2015). But it is important to search for more sustainable alternatives in line with the new European policies aimed at reducing plastic use. Moreover, although plastic mulches significantly reduce water evaporation from soil surface, this reduction might be associated with an increase in crop transpiration, due to transfer of both sensible and radiative heat from plastic mulching to adjacent crop (Allen et al., 2007). Under this context, the possibility of using pruning waste as an organic mulching might be explored. This use could also constitute an alternative to burning of vine pruning still often applied. Certainly, the amount of pruning residues might not be enough to cover their entire vineyard floor, but organic mulching using pruning waste could be still used in some parts of the vineyard. In any case, the focus of this study is to analyze the effect of using an organic mulching on vineyard ET_c, in order to reduce soil evaporation for improving crop water use efficiency. The study was conducted in a lysimeter facility located in La Mancha, Spain, where direct quantitative determinations of vine ET_c can be carried out.

2. Materials and methods

2.1. Experimental site description

The study was conducted during the period from 2015 to 2017 at the ITAP Research Facility located in Albacete (southeast Spain) (39º 03´N, 2º 05´W, at 695 m high). The climate is semiarid, temperate Mediterranean with dry and warm summers. The long-term average annual rainfall is 314 mm mostly concentrated during the spring and fall. Average mean, maximum and minimum temperatures are 13.7, 24.0 and 4.5 ºC, respectively. The soil in the lysimeter facility (i.e., in the lysimeter and surrounding field) is classified as Petrocalcic Calcixerepts (Soil Survey Staff, 2014). Average soil depth of the experimental plot is 40 cm, and is limited by the development of a more or less fragmented petrocalcic horizon. Texture is silty–clay–loam, with 13% sand, 49% silt and 38% clay, with a basic pH (8.1). The soil is low in organic matter (1.4%) and it has a normal content of nitrogen (0.13%) and a high content of active limestone (11.1%) and potassium (1.03 mmol 100 g^{-1}). Soil electrical conductivity (ECe) was 0.4 dS m^{-1} so there was no problem with salinity in the soil, and bulk density was 1.39-1.49 g cm^{-3}. Additional information about the soil characteristics in the lysimeter may be found in Soldevilla-Martinez et al. (2014).

A vineyard (*Vitis vinifera* L., cv. Tempranillo) was planted in 1999 grafted on 110 Richter rootstock on a one ha plot (100 m × 100 m). The spacing between vines and between rows was 1.5 and 3 m, respectively, giving 2222 vines ha^{-1}. During dormancy, grapevines were pruned to two, 10-node fruiting canes. The trellis, having four vertical wires, was composed of 1.7 m aluminum posts driven 0.4 m into the soil and separated by 6 m in the row. The lowest wire at 0.4 m above the soil supported the lateral irrigation pipe. The next wire, 0.8 m above the soil, supported the fruiting canes. Two more wires at 1.1 and 1.3 m above the soil supported the canopy. Vines were drip-irrigated with 3.5 L h^{-1} emitters spaced every 0.5 m. The plot was fertilized at the rate of 60-40-80 kg ha^{-1} of N, P and K, respectively, and it was managed according to cultural practices normally carried out in the area.

2.2. Lysimeter measurements and experiment design

Measurements of two grapevines water use were conducted with a monolithic large weighing lysimeter, with continuous electronic data recording (López-Urrea et al., 2012), installed in the center of the plot. 15-min ET_c values were calculated as the difference between lysimeter mass losses (from evaporation and/or transpiration) divided by the lysimeter area (9.0 m^2). Data collected during irrigation events, and when works were conducted for covering the soil surface of the lysimeter tank were not used in the final ET_c calculations. Neither drainage nor rainfall was recorded during the measurement periods.

The lysimeter container is 3 m × 3 m square and 1.7 m deep, with an approximate total weight of 18.5 Mg (see Fig. 1). The lysimeter soil-containing tank sits on a system of beams and a counterbalances that offsets the dead weight of the soil and the tank and reduces the load on the weigh beam by 1,000:1. A steel load cell (model SB2, Epelsa Ind., S.L., Spain) is connected to the weigh beam. The lysimeter mass resolution was 0.1 kg, and its accuracy was greater than 0.03 mm equivalent water depth. The sample frequency was 1 s, and a reading was registered by a datalogger (CR10X, Campbell Scientific Ltd., Logan, UT, USA) every 15 min. Two vines were planted in the lysimeter, each one occupying 4.5 m^2 and planted 1.5 m apart and 0.75 m from either end of the 3 m long lysimeter and 1.5 m from the sides of the lysimeter. Therefore, the lysimeter contains the soil, two plants and the structure of the two aluminum posts and the wires, which is independent of the rest of the plantation but with the same design (Montoro et al., 2020). The surface area of the lysimeter was thus identical to the area occupied by two plants outside it allowing for representative measurements of ET_c. Efforts were made to keep the vines inside the lysimeter growing at the same rate as the crop outside to minimize edge effects. Additional information about the technical features of the lysimeter is given in Montoro et al. (2008) and López-Urrea et al. (2012). The lysimeter weight data were checked daily to identify individual errors in the readings not explainable by natural processes of water input and loss.

Different periods of measurements were carried out during 2015-2017 growing seasons. Three periods were considered in 2015 (DOYs 193-198, 207-212 and 221-226), one period in 2016 (DOYs 192-197) and another one in 2017 (DOYs 227-252). For the

2015 and 2016 experiments, bare soil was kept within the lysimeter during the first two days. The soil surface was then covered with pruning waste as an organic mulching for the following two days. It was intended to maintain a homogeneous thickness of the pruning waste layer of about 5 cm. Finally, for the last two days the lysimeter soil surface was covered with a waterproof canvas (plastic mulch), similar in colour to the soil in order to prevent from any albedo modification effect.

Drip irrigation was applied every two days, at the beginning of each lysimeter soil surface management, commencing at 8:00 h (3 h applications, equivalent to 5 mm). In order to maintain non-limiting soil water content, irrigation was applied to replace the potential crop water requirements (i.e., ~100% ET_c). In 2017, the measurements period was initiated when midday stem water potential (Ψ_{stem}) values reached -1.3 MPa, then drip irrigation (5 h applications, equivalent to 7.5 mm) was applied at night commencing at 22:00 h. During this experimental period, the vines in the lysimeter were also irrigated to replace the potential crop evapotranspiration. Thus, the effect of different soil management (bare soil, organic and plastic mulch) on vineyard ET was studied when vines in the lysimeter were suffering from severe water stress. After irrigation, 15-min ET_c measurements using the lysimeter (bare soil) were carried out during the following three days. Likewise, this approach was followed for organic and plastic soil surface management in the lysimeter. Figure 2 shows an overview of the lysimeter facility and the different managements for the lysimeter soil surface during the experiment.

2.3. Weather station, soil and plant determinations

Meteorological variables during the experiment were measured with an automated weather station located over a reference grass surface less than 100 m from the grapevine lysimeter. All sensors were located between 1.5 and 2 m above the grass surface, and weather data were registered in 15 min, hourly and daily time steps. Variables measured were as follows: air temperature, relative humidity, wind speed, wind direction, shortwave and longwave radiation, and rainfall. All data were stored in two dataloggers (model CR10X, Campbell Scientific Instrument, Logan, UT, USA). For a more detailed description of the weather station, see López-Urrea et al. (2014). Reference evapotranspiration (ET_o) values were calculated with the daily time step FAO56 Penman–Monteith (FAO56 P-M) equation (Allen et al., 1998) using the recorded meteorological variables. Previous grass lysimeter studies at the same location showed good performance for this equation (López-Urrea et al., 2006; Trigo et al., 2018). The daily ET_o and ET_c or transpiration (T) values were used to calculate crop coefficients for the grapevines in the lysimeter.

Soil water content in the lysimeter was continuously monitored at 10, 40, 70 and 100 cm depths with capacitance sensors placed in one probe (EnviroSCAN, Sentek Pty Ltd., South Australia). The access tube was installed approximately 20 cm from the row line and from a dripper (See Fig. 2b).

Determinations of Ψ_{stem} were conducted with a pressure chamber (model 600, PMS Instrument Company, Albany, OR, USA) on the plants within the lysimeter and in two leaves per vine. The measurements were performed close to solar noon on mature leaves located in the upper third of the canopy that were covered with a foil-laminate bag for at least thirty minutes before being excised from the plant.

Determinations of the fractional vegetation cover (f_c) were performed for each soil management throughout the different periods of measurements. Values of f_c were determined based on the classic methodology for calculating green plant cover developed by Cihlar et al. (1987) using a supervised classification technique of digital photographic images with the maximum probability algorithm, in order to assign the current classes of green vegetation in the image (see Fig. 3). Digital photographs over the lysimeter area were taken at solar noon vertically from an approximate height of 4.5 m above ground. Supervised classification of these digital images was later carried out with the help of the ENVI® version 4.8 computer program (Exelis Visual Information Solutions, 2015). To apply this methodology, it is necessary to interpret each pixel of the visible panchromatic digital image and to decide which areas of the image make up the best training areas of green vegetation (with and without shade), and which are the areas of dry vegetation and those of bare soil (Calera et al. 2001). Moreover, crop height (h_c) was measured weekly and it remained constant around 1.5 m from mid-July (BBCH code of 75-77) to early September (BBCH code of 85).

Grapevines phenological stages were determined for each soil management and measurements period following the BBCH (Biologische Bundesanstalt, Bundessortenamt and CHemical industry) scale (Meier, 2001).

2.4. Infrared temperature measurements and STSEB model overview

Plant transpiration might increase because of the plastic mulching, due to the heat exchange from the mulching to adjacent vegetation. A set of five thermal-infrared radiometers (IRTs) were installed in 2015 to explore this effect and Fig. 4 shows the experimental set up of the IRTs over the lysimeter. A Simplified version of the Two-Source Energy Balance approach (STSEB) (Sánchez et al., 2008) was applied to estimate vineyard ET_c and separate soil E and canopy T using the radiometric temperatures as the main inputs, together with biophysical information and meteorological data. A detailed description of the STSEB approach is given in Sánchez et al. (2008). The feasibility of STSEB at a field scale has been already assessed in vineyard (Sánchez et al., 2019).

The IRTs (SI-121, Apogee Instruments, Inc., USA) were installed in a mast placed in the middle of the row, right next to the vineyard lysimeter. These instruments have a broad thermal band (8–14 μm) with an accuracy of ±0.2 °C, and 18° field of view. For an appropriate thermal characterization of the vines structure, two IRTs were assembled at a height of 1.3 m pointing to the plant canopy from a frontal view, measuring both sides of the vines. Two of the IRTs were mounted at a height of 0.4 m pointing to the soil and measuring also both sides of the inter-row. A fifth IRT pointed upward to measure the downwelling sky radiance, required for the atmospheric correction of both soil and canopy radiometric temperatures. Additional information about meteorological data and biophysical variables, needed for running the STSEB model, is given in Sánchez et al. (2019).

2.5. Statistical analysis

Statistical analysis was conducted with Microsoft Excel 2013 computer software (Liengme, 2015). A linear regression analysis was performed among midday stem water potential and soil water content to assess the degree of relationship based on the coefficient of determination (R^2) and error assessment (standard deviation).

3. Results

3.1. Meteorological conditions

Table 1 shows the meteorological conditions for each month during the three growing seasons. The three experimental seasons at the study site (Albacete, southeast Spain) were typical of the long-term average weather for this area, although in general terms, the three growing seasons were a little warmer and significantly drier than the 30-year means. Rainfall amounts during the growing seasons were 110 mm in 2015, 140 mm in 2016 and 64 mm in 2017, mainly concentrated during spring, being 30%, 11% and 60% lower than the historical mean, respectively. Average wind speed at 2 m elevation during the experimental seasons ranged from 2.5 m s^{-1} in 2015 to 3.1 m s^{-1} in 2016. Average solar radiation was similar during the three growing seasons ranging from 24.4 MJ m^{-2} day^{-1} in 2015 to 24.9 MJ m^{-2} day^{-1} in 2017.

Table 1. Summary of monthly average meteorological data during the vineyard growing seasons along the three consecutive years of the trial.

Season Month	T_{max} (ºC)	T_{mean} (ºC)	RH_{min} (%)	Solar radiation (MJ m^{-2} day^{-1})	Wind speed (m s^{-1})	Rainfall* (mm)
2015						
April	18.0	11.1	47.8	20.5	2.9	24.4
May	25.8	17.6	29.7	27.1	2.6	15.3
June	28.5	20.5	31.1	28.0	2.2	23.9
July	35.6	26.5	21.8	27.9	2.4	0.0
August	31.1	23.6	42.1	23.4	2.7	1.4
September	25.2	18.3	40.3	19.7	2.4	44.9
2016						
April	17.6	11.2	50.7	20.5	3.2	40.9
May	22.3	15.0	36.1	24.0	3.1	77.9
June	30.2	21.6	20.5	29.0	2.9	0.8
July	34.6	25.7	20.3	29.1	3.5	15.9
August	33.4	24.7	22.7	25.8	3.6	4.3
September	29.6	20.8	24.3	20.1	2.6	0.0
2017						
April	19.8	12.3	37.3	22.3	2.7	22.3
May	24.5	16.7	32.7	26.0	2.7	8.9
June	31.1	22.8	25.1	29.0	2.9	0.3
July	32.8	24.2	21.7	27.6	2.4	25.4
August	31.5	23.7	28.1	23.5	2.5	6.1
September	27.5	19.1	28.1	20.7	2.4	1.2

* Monthly totals

3.2. Soil and plant determinations

The variation of volumetric soil water content at 10, 40, 70 and 100 cm soil depths during the different periods of measurements is shown in Fig. 5. After each irrigation event, volumetric soil water content (SWC) showed slight variations at 70 cm and remained constant at 100 cm soil depth during the different periods of measurements. Table 2 shows daily average SWC values measured at 10 and 40 cm soil depth. These values indicate that the SWC available to the vines was similar for each soil management during the different experimental periods. In 2015 and 2016, the values of midday stem water potential indicate that the vines did not suffer considerable water stress under any of the three soil management conditions. Although, there is a slight trend to higher (less negative) vine water status in the days when the lysimeter was covered with a plastic mulching, probably due to the lower ET_c values (Table 2) and therefore, a little more soil water availability. Moreover, stem water potential measurements suggest that both pruning waste (organic) and plastic mulching did not affect significantly the microclimate of the vines, since the vine water status was not negatively affected by the application of these techniques of soil management. In 2017, both soil and plant water status measurements show that the vines in the lysimeter were subjected to significant water stress and there was a significant linear relationship between Ψ_{stem} and SWC (Fig. 6). The fraction of ground covered by the canopy and the phenological stage were the same for each of the measurements period, showing that vines were at the same stage of development.

Table 2. Soil and plant water status, fractional vegetation cover, BBCH-identification codes and vineyard growth stages during 2015-2017 experimental periods.

Season **Soil management**	**Date**	**SWC** (m^3 m^{-3})	**Ψ_{stem}** (MPa)	**f_c**	**BBCH Code**	**Description of Phenological Stage**
			2015			
Bare soil	Jul. 13	0.22	-1.0	0.32	77	Berries beginning to touch
Organic mulch	Jul. 15	0.24	-1.0	0.32	77	Berries beginning to touch
Plastic mulch	Jul. 17	0.25	-0.9	0.32	77	Berries beginning

						to touch
Bare soil	Jul. 27	0.23	-0.9	0.32	83	Berries developing colour
Organic mulch	Jul. 29	0.25	-1.0	0.32	83	Berries developing colour
Plastic mulch	Jul. 31	0.25	-0.9	0.32	83	Berries developing colour
Bare soil	Aug. 10	0.26	-1.0	0.32	85	Softening of berries
Organic mulch	Aug. 12	0.27	-0.8	0.32	85	Softening of berries
Plastic mulch	Aug. 14	0.27	-0.8	0.32	85	Softening of berries
			2016			
Bare soil	Jul. 11	0.33	-0.7	0.24	75	Berries pea-size, bunches hang
Organic mulch	Jul. 13	0.35	-0.6	0.24	75	Berries pea-size, bunches hang
Plastic mulch	Jul. 15	0.39	-0.5	0.24	75	Berries pea-size, bunches hang
			2017			
Bare soil	Aug. 16	0.19	-1.3	0.27	85	Softening of berries
Organic mulch	Aug. 22	0.23	-1.3	0.27	85	Softening of berries
Plastic mulch	Sept. 5	0.24	-1.3	0.27	85	Softening of berries

SWC: soil water content, mean of the daily value measured at 10 and 40 cm depth; Ψ_{stem}: midday stem water potential; f_c: the fraction of ground covered by the canopy.

3.3. Reference and vineyard evapotranspiration, and crop coefficients

Fig. 7a shows an example of the hourly evolution of vineyard ET_c, after an irrigation event of 5 mm, for DOYs 221 (bare soil), 223 (organic mulch) and 211 (plastic mulch) in 2015. For the different soil management techniques, both the fractional canopy cover (f_c = 0.32) and the evaporative demand (ET_o ~5 mm day^{-1}) were similar. Figure 7b shows accumulated vineyard ET_c for the different soil management conditions during the experimental periods in 2015. Both figures show significant higher values of vineyard ET_c under bare soil conditions than when the lysimeter soil was covered with either; pruning waste or plastic. Likewise, vineyard ET_c values when the lysimeter was covered with pruning waste (organic) were higher than under plastic mulching conditions, showing that still exists evaporation from the soil surface when the 5 cm thick organic mulch layer is used.

Table 3 presents daily and accumulated ET_c and ET_o values for each soil management conditions during the experimental periods of 2015, 2016 and 2017 growing seasons. The results show that for the same evaporative demand and fractional canopy cover (Table 2), the organic mulching reduced vineyard ET_c between 16 and 18%, whereas the plastic mulching reduced it between 24 and 30%.

Table 3. Crop evapotranspiration (ET_c), reference evapotranspiration (ET_o) and crop coefficient ($K_c = ET_c/ET_o$) for a vineyard under different soil management conditions during 2015-2017 experimental periods.

Season	**ET_c** (mm)		**ET_o** (mm)		**Crop**
Soil management	Daily	Accumulated	Daily	Accumulated	**coefficient**
2015					
Bare soil	3.1	18.6	6.1	36.5	0.51
Organic mulch	2.7	16.2	6.5	38.7	0.42 (18%)*
Plastic mulch	2.1	12.6	5.6	33.7	0.37 (27%)
2016					
Bare soil	2.8	5.6	7.5	15.0	0.37
Organic mulch	2.2	4.4	6.9	13.8	0.32 (16%)
Plastic mulch	1.7	3.4	6.1	12.2	0.28 (24%)
2017					
Bare soil	2.6	7.8	5.9	17.7	0.44
Organic mulch	2.1	6.3	5.9	17.7	0.36 (18%)
Plastic mulch	1.4	4.2	4.5	13.5	0.31 (30%)

*In brackets the percentage of ET_c reduction with respect the soil management without mulching (bare soil)

3.4. Effect of organic and plastic mulching on estimated vine transpiration

As mentioned above, the STSEB approach allows to estimate vineyard ET_c and its partitioning on soil evaporation and canopy transpiration. Table 4 presents vine transpiration (T) values estimated using the STSEB model for the different management conditions in the lysimeter soil during the three experimental periods of 2015. Both pruning waste (organic) and plastic mulching did not increase vine T during the 6-day period analyzed for each soil management condition.

Table 4. Vineyard transpiration (T), reference evapotranspiration (ET_o) and basal crop coefficient (K_{cb}) for a vineyard under different soil management conditions in 2015 experimental periods.

Soil	**Transpiration** (mm)		**ET_o** (mm)		**K_{cb}**
management	Daily	Accumulated	Daily	Accumulated	
Bare soil	2.1	12.6	6.1	36.5	0.35
Organic mulch	2.1	12.4	6.5	38.7	0.32
Plastic mulch	2.0	11.9	5.6	33.7	0.35

4. Discussion

Strategies to optimize vineyard water use efficiency (WUE) are required and have been subject of extensive research (Medrano et al., 2015). For instance, precision irrigation practices, aimed at adjusting irrigation scheduling to the actual water needs, allow optimizing on-farm WUE by increasing the efficiency in water application (Fernández, 2014). However, it is important to search for field practices able to reduce the consumptive water use for achieving net water savings at the water basin level. In this sense, deficit irrigation has been extensively tested in grapevines (Mirás-Avalos and Intrigliolo, 2017). Nevertheless, this practice can reduce yield, and requires the continuous monitoring of soil and plant water status, to prevent from the appearance of severe stress that could even decrease WUE (Fereres and Soriano, 2007). Under this context, the present research has shown that a vineyard soil management, either using plastic or organic mulch, can reduce water use and then lead to net water savings, because of the linked reduction in the whole vineyard ET_c.

Extensive research has been conducted determining the effects of soil mulching on several aspects of the vineyard performance, management and grape and wine composition (see review by Guerra and Steenwerth, 2012). These works focus mainly on yield and plant water relations, grape composition or weed management, with less quantitative information reported on the effects of organic mulch on vineyard water use. Most often, when water productivity was determined, this was an indirect measurement obtained from the vine performance results and the irrigation+rainfall water applied (Chan et al., 2010; Fourie, 2011). For instance, Gil et al. (2018) found similar yield levels for a vineyard managed with plastic mulch and with water application at half of a standard control under bare soils. Earlier on, Zhang et al., (2014) determined the additional effects of mulching on vineyard ET under a subsurface irrigation strategy. A reduction of 17% in water use was obtained by these authors. More recently, Fraga and Santos (2018) conducted a simulation analysis using the STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) process-based crop model. They concluded that for the Alentejo region of Portugal, mulching can mitigate the negative impacts of climate change scenarios on yield by 10 to 25%. The results obtained in this work indicate an overall ET_c reduction ranging 24-30% and 16-18% for plastic and organic mulching, respectively, in line with previous research carried out (Montoro et al., 2016). Previous work by Yunusa et al. (2004) quantified that soil evaporation could be up to 40% of the total ET and Lascano et al. (1992) and Heilman et al. (1994) estimated up to 44 to 77% of soil evaporation contribution to the entire vineyard ET.

A previous research carried out in maize, compared several mulching treatments effects on the entire growing season ET but found very slight differences in the cumulative ET when compared to a control without mulching (Li et al., 2018). Previously, also in maize, Bu et al. (2013) tested gravel and a plastic film mulching and found that both treatments increased the water productivity when compared with an un-mulched control treatment; with plastic mulching resulting in an additional increase in water productivity compared to gravel mulch by 15 to 80% depending on the experimental season. To the best of our knowledge, in grapevines, a direct comparison between plastic and organic mulching vineyard ET had not been previously carried out. The reduction in water use by organic mulching here reported was 37% lower than using plastic mulch. This means that organic mulching did not completely null soil evaporation, as expected. This might not optimize water productivity, but it could generate in the long-term improvements in soil porosity (Oliveira and Merwin 2001), which might bring some benefits on soil biological status (de Vetter et al., 2015), which is beyond the scope of this research.

The results shown in this study were obtained under general low rainfall rates and during periods of the season when irrigation was the only water input. Under these conditions, soil evaporation occurs principally in the soil areas wetted by the irrigation system. As a consequence, under conditions of higher rainfall, where the entire vineyard floor might be more humid, soil evaporation could be higher and then the beneficial effects of soil mulching on the total vineyard ET_c reduction could be more important than what reported in the present research. In addition, note our experiments were carried out in the middle of the season, when the vine canopy growth had stopped, in order to compare soil management practices during days with similar vine growth and development. We expected soil evaporation to be larger at beginning and end of the growing cycle, when rainfall can be substantial, as reported by Sánchez et al. (2019) in an earlier research conducted at our location. Therefore, the benefits brought by organic mulching could be, on a seasonal basis, more significant than those obtained here.

The influence of the irrigation regime in the decrease in vineyard ET_c due to plastic mulching has been also studied. Very similar reduction in the relative evapotranspiration (i.e., the crop coefficient) was observed for all three seasons. Only under plastic mulching, in 2017, when plants were under water deficit, the reduction in evapotranspiration was higher. Under certain degrees of water stress, it is expected that the contribution of the soil evaporation to the total ET_c could be higher because plant water stress reduces transpiration. However, in the present experiment, because of the irrigation management in the lysimeter that probably also reduced soil evaporation, no clear impacts of plant water status in the relative reduction in water use due to organic mulching were obtained. The final effect of the watering regime (dose and frequency of irrigation) on the contribution of soil evaporation to the whole vineyard ET might be very dependent on the soil physical characteristics and still warrants further research. In this sense, a previous field trial concluded that, in clay soil, high irrigation frequency could result in a decrease in irrigation efficiency (Sebastian et al., 2015). In addition, Montoro et al. (2016), comparing soil evaporation rates under different irrigation frequencies, reported that when irrigation dose is increased to lower watering frequency, soil evaporation rates can be reduced in comparisons with a more frequent irrigation regime.

Under a theoretical framework, a reduction in soil evaporation could increase the energy available to latent heat or plant transpiration. This could be more relevant during the periods of high evaporative demand or when vine ground cover has still not reached the maximum values. These aspects have not been fully investigated in discontinuous canopies like vineyards but several studies in field crops such as rice, cotton and wheat demonstrated that when soil evaporation is reduced, plant transpiration can increase (Balwinder-Singh et al., 2011; Lascano et al., 1994; Li et al., 2008). However, extrapolating results obtained in field crops with continuous canopies to vineyards is not straightforward since grapevine transpiration is also affected by canopy conductance while field crops transpiration is more dependent on the net radiation available for latent heat transfer (Jiao et al., 2018). It is, therefore, important to properly quantify the effects on plant transpiration of practices minimizing or nulling soil evaporation in vineyards and orchards. For instance, it is now widely accepted the use of subsurface irrigation with considerable benefits in term of the total water balance (Martínez-Gimeno et al., 2018; Valentín et al., 2020). Our results did not allow to infer that there could be an increase in plant transpiration in response to a reduction in soil evaporation. This could be due to: i) under the no soil water limitations, plants were already transpiring at the maximum potential and vine transpiration could not increase more above a threshold level, ii) because of the experimental approach, the microclimate within the two vines planted within the lysimeter was not modified since the surrounding vines were not mulched, and iii) the color chosen for the plastic mulch did not affect significantly soil albedo and also the possible effects on soil temperature might not have been considered because of the short-term effects evaluated. In the future, a larger experimental design, with the better fetch conditions should be carried out.

In the present research, the type of mulch material used (brown waterproof canvas) and the pruning waste were selected in order not to affect the albedo. In fact, previous research has demonstrated that vine microclimate can be modified depending on the color of the material used for mulching (Tarara, 2000). For instance, white or aluminum color material is often employed in cool climate viticulture areas in order to increase the radiation in the cluster zone and enhance grape ripeness (Coventry et al., 2005). In this sense, grape composition has been demonstrated to be affected not only by the total PAR intercepted by clusters but also by the red to and far-red radiation regime (Guerra and Steenwerth, 2012) that can be specifically altered choosing different plastic colors.

Vine water relations might be affected by the application of mulching (Guerra and Steenwerth, 2012) and in the present study we only determine Ψ_{stem} as an integrator of the effects of soil water content and vine transpiration rates on vine water status. Considering most of the Ψ_{stem} determinations carried out, there were not clear differences in this physiological indicator among the orchard floor management practices (Table 3). Only in two determinations, coinciding with the highest value of soil water content, Ψ_{stem} was improved (less negative) by mulching. In Mediterranean conditions, it was previously reported that most of the differences in yield and grape composition in responses to several irrigation and leaf area to fruit ratio regimes were explained by differences in Ψ_{stem} (Mirás-Avalos et al., 2017), suggesting that vine water status is a major determinant for vine yield. In any case, to complement the present research, further works need to determine the agronomic effects of using soil mulching on the agronomic performance and grape composition. In fact, this will depend on the specific agronomic (varieties and irrigations regimes), soil and environmental conditions.

In order to finally generalize the application of the mulching operations, it should be considered that the pruning waste from a vineyard is not enough to cover the entire vineyard floor. However, in arid areas, it could be sufficient to mulch only the soil portions wetted by the drip irrigation systems. Another possibility is to cover only a certain surface of the entire vineyard with the pruning waste. It is also needed to explore for how long the pruning waste mulch laid on the vineyard floor can last, since it is possible to keep accumulating pruning waste season after season resulting in the long-term in a larger area of the vineyard floor covered with the pruning waste. In this sense, more attention should be paid on the possible effects of the organic mulching on soil chemical and physical characteristics. The present study was carried out with the intention to determine the short-term effects of mulching on vineyard evapotranspiration, but previous research has demonstrated that, in the long-term, mulching can increase soil organic matter (Thomson and Hoffman, 2007), soil fertility (Ferrara et al., 2012), decrease soil compaction and protect soil from erosion (Mirás-Avalos et al., 2020); all aspects indeed positively influencing soil water holding capacity (Oliveira and Merwin, 2011). Finally, the potential effects of pruning waste as an inoculum for trunk fungal disease will also need to be determined.

5. Conclusions

The results of this study show that for the same evaporative demand and fractional canopy cover, vineyard ET_c might be reduced between 16 and 18% using an organic mulching, whereas a plastic mulching can reduce it between 24 and 30%. Thus, the reduction in vineyard consumptive water use by pruning (organic) mulch results 37% less than what obtained with plastic mulch. As expected, organic mulching does not completely null soil evaporation. A simplified version of the Two-Source Energy Balance (STSEB) is used to estimate vine transpiration for the different management conditions in the lysimeter soil. Results show no increase in vine transpiration for organic nor plastic mulching during the period analyzed and for our experimental design. Further research is required at this point. In the Mediterranean basin and other semi-arid environments with scarce water resources, where vineyards occupy large areas and drip-irrigation system is dominant, the vineyard floor management using pruning waste could be an attractive alternative to reduce vineyard evapotranspiration and the consumptive water use and increasing crop water productivity.

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List of figures

Fig. 1. Different pictures of the monolithic large weighing lysimeter used to measure grapevines (cv. Tempranillo grafted on 110 Richter) water use: a) the cross section of the vineyard lysimeter, b) the lysimeter container in the construction phase during 1998, and c) the two vines planted in the lysimeter on July 11, 2016 ($f_c = 0.24$ and $h_c = 1.5$ m).

Fig. 2. a) Overview of the lysimeter facility and the area surrounding it, and different pictures of the soil management practices within the lysimeter during the experiment: b) no mulching (bare soil) on July 13, 2015, c) pruning waste (organic mulch) on July 15, 2015, d) waterproof canvas (plastic mulch) on July 17, 2015.

Fig. 3. a) Digital photograph taken over the lysimeter at solar noon vertically from an approximate height of 4.5 m above ground (July 29, 2015), b) picture cut out (adjusted) to the lysimeter surface, c) supervised classification of the digital images conducted with the help of the ENVI computer program showing areas of green vegetation and

bare soil, d) result of the classification obtaining a fractional vegetation cover (f_c) of 0.32.

Fig. 4. a) Scheme of the experimental deployment of the thermal-infrared radiometers (IRTs) over the lysimeter spot: 2 sensors pointing to the plant canopy from a frontal view at a height of 1.3 m measuring both sides of the vines, and 2 pointing to the soil from a height of 0.4 m measuring both sides of the inter-row. A fifth IRT pointed upward to measure the downwelling sky radiance, b) detail picture of the IRT pointing upward, c) detail picture of IRTs pointing to the soil and the canopy.

Fig. 5. Variation in the lysimeter of volumetric soil water content (SWC) at different soil depths in the experimental periods during 2015-2017 growing seasons. SWC values were continuously monitored with four capacitance sensors placed in one probe. Irrigation events are also indicated as black points. In all graphs, the SWC values correspond to the different managements for the lysimeter soil surface as follows: the first 2-3 days bare soil, the following 2-3 days organic mulch and the last 2-3 days plastic mulch.

Fig. 6. Relationship of midday stem water potential (Ψ_{stem}) and volumetric soil water content (SWC) during 2015-2017 experimental periods. Values reported are SWC means ± standard deviation of 48 measurements and Ψ_{stem} means ± standard deviation of 4 determinations. *Significant at $P < 0.05$.

Fig. 7. Hourly evolution (a) and accumulated (b) vineyard ET_c for the different soil management conditions in 2015.

Figure

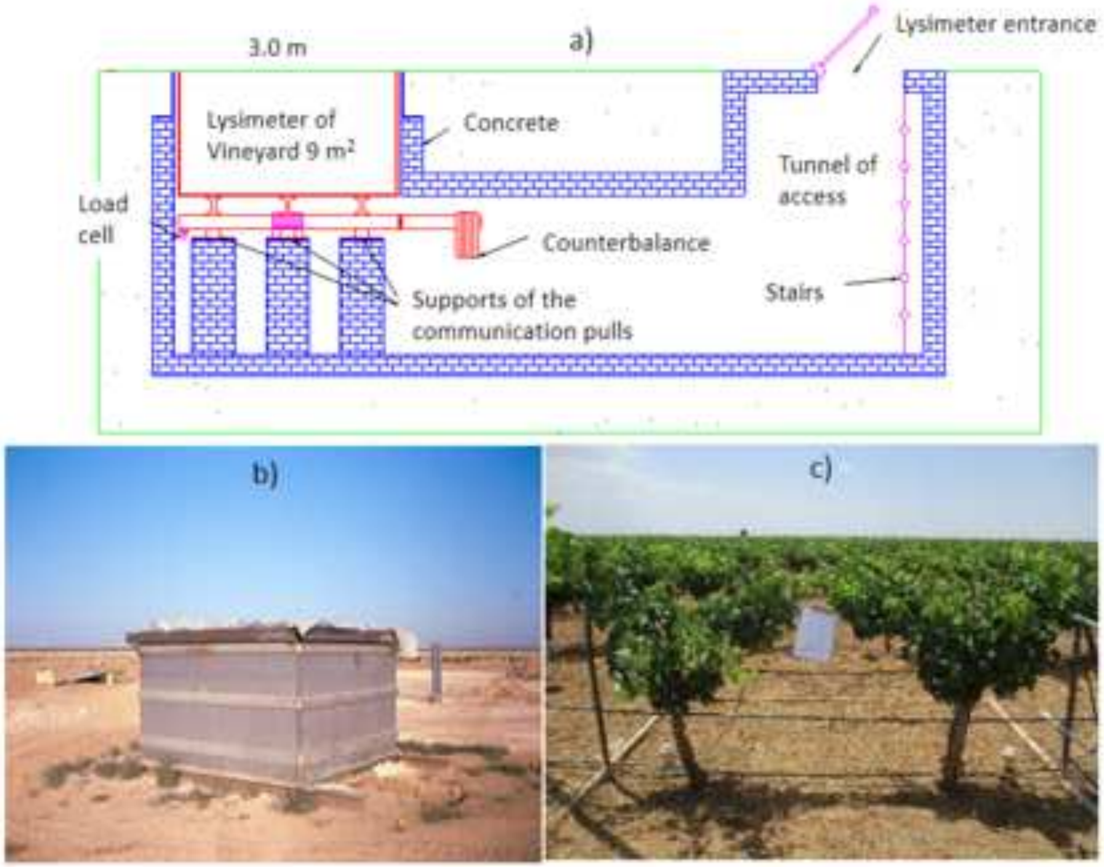

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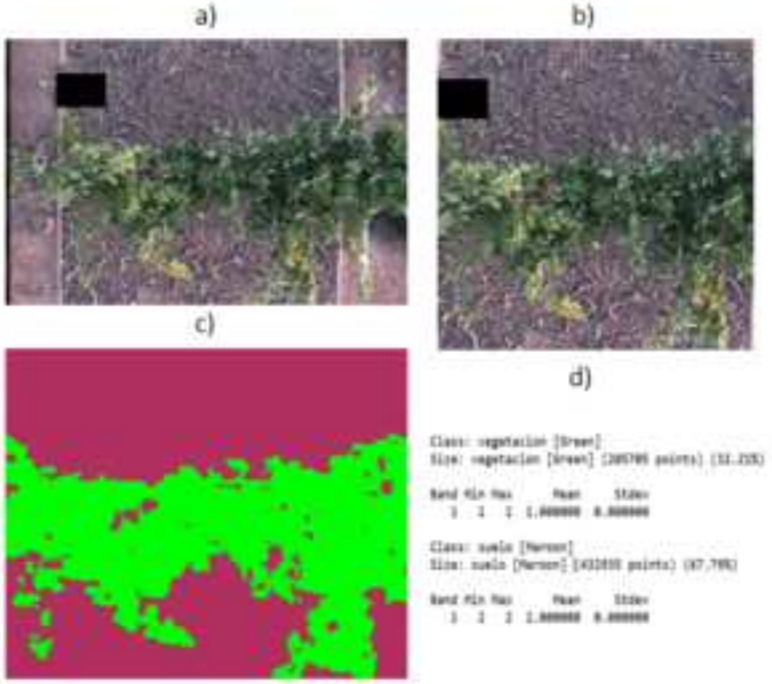
Fig. 2.TIF

Fig. 3.TIF



```
Class: vegetacion [Green]
Size: vegetacion [Green] (205705 points) (32.21%)

Band Min Max      Mean     Stdev
   1   1   1  1.000000  0.000000

Class: suelo [Maroon]
Size: suelo [Maroon] (432850 points) (67.79%)

Band Min Max      Mean     Stdev
   1   2   2  2.000000  0.000000
```

Figure

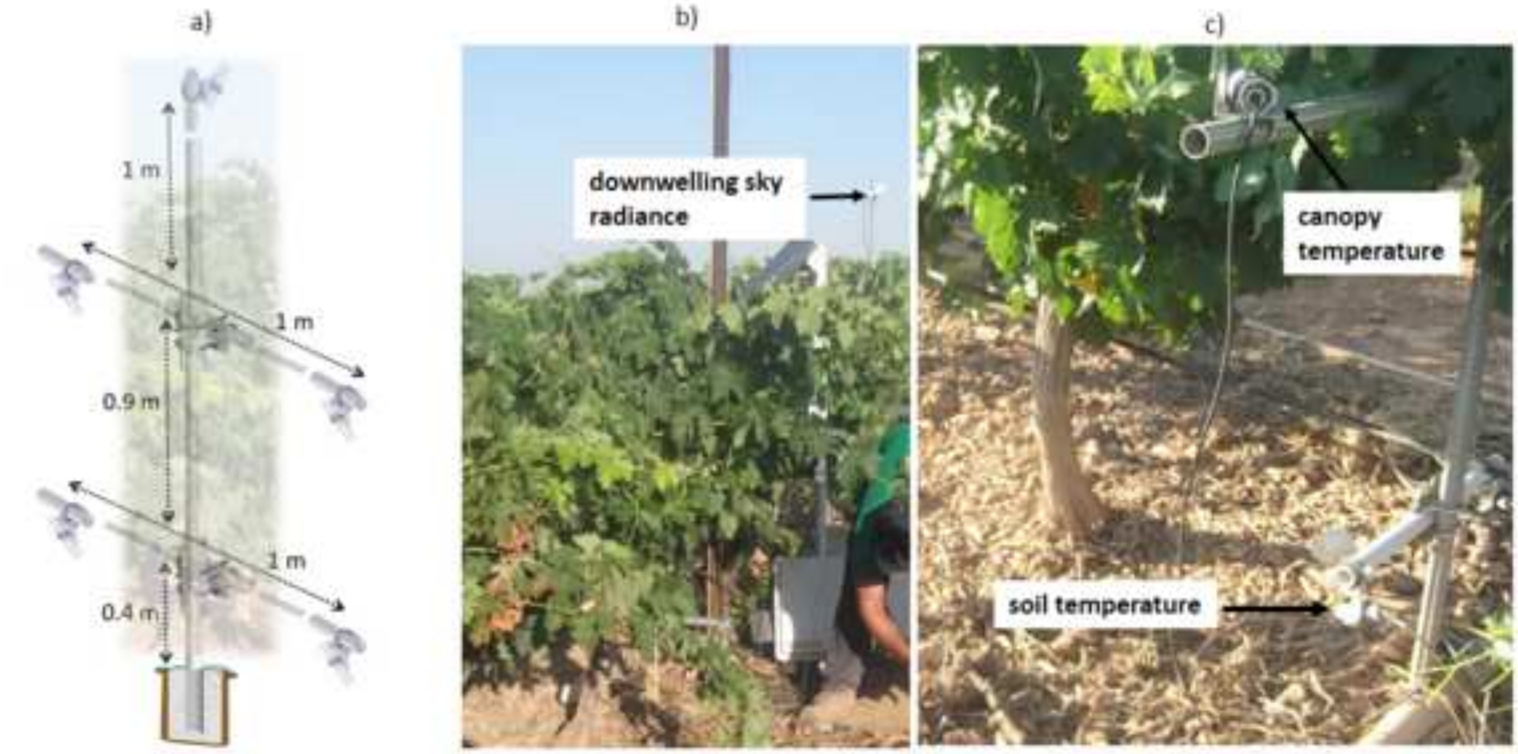


Fig. 4.TIF

Figure

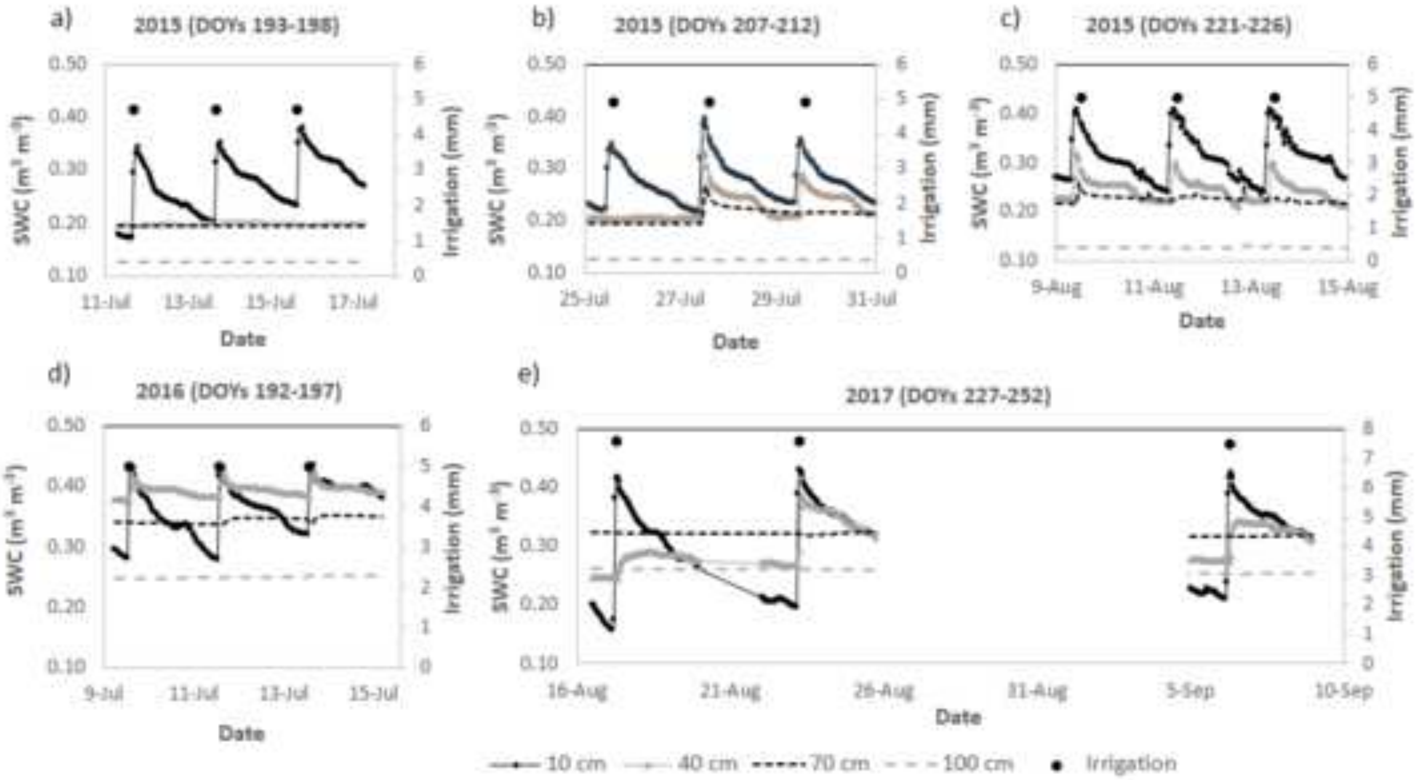
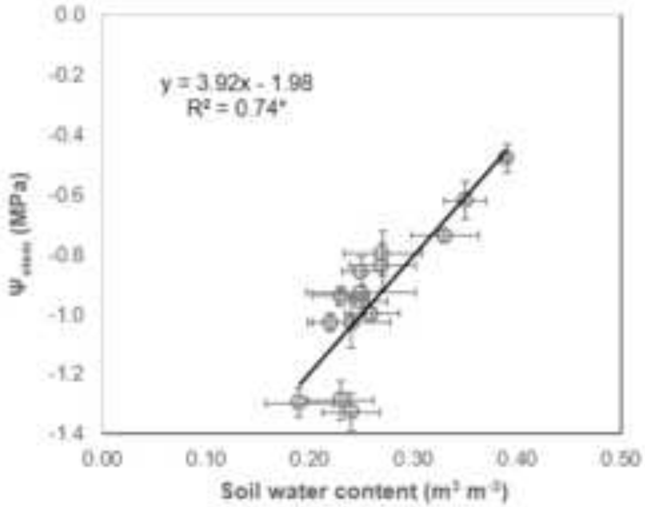


Fig. 5.TIF

Figure

Fig. 6.TIF



Figure

Fig. 7.TIF