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Crimson Seedless table grape grown under plastic film: ecophysiological parameters and grape characteristics as affected by the irrigation volume.

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Abstract

Plastic films used to cover vineyard change microclimate conditions aiming to advance or delay grape maturity according to the table grape marked demand. The capacity of the covering materials to modify the greenhouse microclimate strongly depends on their radiometric properties. The aim of this paper is to study the effect of three watering regimes and of the radiometric characteristics of plastic film used to delay harvest of Crimson seedless table grape grown in the Apulia region (Southern Italy). Crimson Seedless vines trained to "tendone" trellis system were irrigated with different water regimes, from berry set to one week before harvesting, corresponding to about 50% (WR1), 100% (WR2) and 80% (WR3) of water lost by evapotranspiration. After veraison, Crimson Seedless vines were covered with plastic film until grape harvest. Laboratory tests were carried out on the new film in order to evaluate the radiometric properties. Vine water status and leaf gas exchange were assessed. At harvest, the yield components and the grape characteristics were analyzed. Vine water status measured under midday conditions showed a moderate improvement for WR3 and WR2 treatments, but leaf temperature decreased and leaf gas exchange increased in WR3 vines. Water availability significantly affected berry growth, inducing the lowest cluster weight in the treatment WR1 that received the lowest watering volumes; also berry diameters were significantly affected by the irrigation treatments. Crop water productivity (grape production per unit of applied water) decreased from WR1 to WR2 and WR3. The greatest water deficit reduced significantly the total pruning weight per vine, that is an indicator of the vegetative vigor.

Keywords: radiometric properties, water deficit, leaf gas exchange, crop water productivity, pruning weight

1 Introduction

Covering the vineyard with plastic film is a technique largely adopted in Southern Italy in order to advance or delay the ripening of table grapes according to marked demand. Grape yield, precocity or delay, and quality depend on the variety, the cover management and the radiometric properties of the plastic film used to protect the vineyard (Novello et al., 2000).

The capacity of the covering materials to modify the greenhouse microclimate strongly depends on their radiometric properties. For agronomical purposes a covering film must have a high transmission of the photosynthetically active radiation (PAR) and a low transmission of long wave infrared radiation (LWIR). Plastic covering films are also used to protect vineyard against rain, hail, spring frost, and wind, in order to enhance berry growth and to obtain a more uniform skin color.

Table grape growing needs irrigation water supply in order to get a satisfying grape yield and bunch quality. Today there is a renewed interest about deficit-irrigating table grape vines (Ezzahouani and Williams, 2007, Du et al., 2008, El-Ansary et al., 2005) stimulated in large part by the attention to climate change and their impact on agriculture (Schultz, 2000).

Crimson Seedless is a late-season red seedless table grape variety developed by David Ramming and Ron Tarailo of the USDA Fruit Genetics and Breeding Research Unit, Fresno, (Dokoozlian et al., 2000). This grape has superior eating characteristics, firm and crisp berry texture and excellent flavour. The cluster is conical with a shoulder, medium in size, with average length and weight of about 0.5 kg and 20 cm, respectively. The natural berry has cylindrical to oval shape, medium size, and the following average carpometric traits: length 20.8 mm, width 16.6 mm, weight 4.0 g. The vine is vigorous and leafy, as it often occurs with seedless grapevine varieties.

In the Apulia region, Crimson Seedless vineyards are trained to “tendone system” and moreover, starting from the stage of berry veraison, they are covered with plastic films in order to delay the harvesting up to the Christmas period. Thanks to this technique Crimson Seedless contributes to extend the availability of fresh table grapes from October up to the winter season (de Palma et al., 2005; Tarricone et al., 2005).

The aim of this paper is to study the radiometric characteristics of a plastic film used to delay the grape harvesting, as well as the effects of three irrigation regimes on the vine ecophysiological performance and on the grape yield and quality, in cv. Crimson Seedless grown in Southern Italy.

2 Materials and methods

2.1 The field test

The field test was carried out at a commercial vineyard located in the Apulia region, Southern Italy (Castellaneta Marina, Taranto, latitude 40° 37’ N, longitude 16° 56’ E, 45 m a.s.l.) during the 2011 season. *Vitis vinifera* cv. Crimson Seedless was grafted onto 140 Ruggeri rootstock and trained to “tendone overhead trellis”, with a plant density of 1379 vines ha^{-1} (2.50 m x 2.90 m apart). The soil is sandy-clay and has a natural low fertility. The area is characterized by Mediterranean sub-arid climate with average maximum temperature of 33°C in August and average minimum temperature of 3°C in January. The average rainfall is 500 mm per year, mostly concentrated from September to April.

The Crimson Seedless vineyard was covered at veraison (first week of August) with a polyethylene film, coded as “Yellow”; the film was provided by Serroplast (Rutigliano, Bari, Italy) with a thickness of 200 µm. Only the roof of each vine row was covered with the plastic film, while the vineyard lateral perimeter was surrounded by a plastic net.

The microclimatic variables, such as air temperature, air relative humidity and photosynthetically active radiation (PAR), were continuously measured under the plastic film, at 15 min frequency, and recorded during grape ripening. Sensors and data loggers were provided by Decagon Devices Inc (Pullman, Washington, USA). The PAR sensors were situated over the canopy (2.06 m height); the sensors of air temperature and relative humidity were situated both over the canopy (2.00 m) and under the canopy (1.70 m).

Three watering volumes, corresponding respectively to 50% (WR1), 100% (WR2) and 80% (WR3) of daily crop evapotranspiration (ETc), were compared. Treatments were arranged in a randomized block design with 3 replications. Irrigation was scheduled using the water balance method (Allen et al., 1998) providing the restitution of the amount of water lost by evapo transpiration, after effective rainfall, whenever the readily available water (RAW) in the wetted soil volume was depleted.

Daily crop evapotranspiration (ETc) was calculated by means of the Penman-Monteith method (ETo) using weather data from an automatic agrometeorological station localized near the experimental vineyard; FAO crop coefficients defined for table grape in Mediterranean region were adopted (Allen et al.,1998). Irrigation took place after berry set (end of May) up to one week before harvest (II week of October). The total volumes of water supplied during the season were respectively 1094, 2190 and 1751 m^3 ha^{-1} for WR1, WR2 and WR3 treatments. Irrigation was provided trough drip system with a single irrigation line per row and pressure-compensated emitters, with a discharge rate of 8, 16 and 12 L h^{-1} respectively for WR1, WR2 and WR3 treatments. Each row drip line had its own valve which allowed switching off the irrigation individually for each treatment, basing on the calculated water needs.
In order to assess the vine water status and monitor the effect of the irrigation schedule, midday stem water potential (Ψmds) was measured on 12 leaves of similar maturity per treatment, with a pressure chamber (Soilmoisture Equipment Corp., Santa Barbara CA, USA).
In a hot summer day of early August (after vineyard covering), the main parameters of physiological leaf functioning were measured, between 09:00 and 12:00 solar time, on sun-exposed mature main leaves of the middle shoot portion: blade temperature (Lafayette TRI-88 infrared thermometer), stomatal conductance (CD), net photopynthesis (Pn) and leaf transpiration (TR) at ~1000 µmol m^{-2} s^{-1} of PPF (Infrared Gas Analyzer LC pro plus, ADC, Hoddeston, UK). Leaf water use efficiency was calculated as Pn:TR ratio. Moreover, Ψmds was also measured the same day . All parameters were taken on 4 leaves per replicate.
At harvest, on 15 bunches per replicate, the following parameters were assessed: bunch and berry weight, berries per cluster, berry diameters. On the berry juice, total soluble solids (T.S.S.) by digital refractometer (Atago Co. LTD, Japan), pH, and titratable acidity expressed as tartaric acid (T.A., neutralization with NaOH 0,1 N) were assessed and T.S.S./T.A. ratio was calculated.
Leaf area per vine was estimated by applying the weight-to-area method; moreover, the leaf area/grape yield ratio was calculated as an index of vegetative-reproductive efficiency. Vine vegetative growth was also estimated by measuring cane mass at winter pruning. Crop water productivity (CWP, fresh fruit per unit of water applied) were also computed.
Collected data were statistically processed applying ANOVA and Duncan test ($p \leq 0.05$).

2.2 Radiometric laboratory tests

The radiometric tests on the plastic film were carried out at the “Laboratory for the Measurement of the Radiometric Properties of Materials” of the University of Bari. Spectral direct transmissivity of the film in the solar range was measured by a double beam UV-VIS-NIR spectrophotometer (Lambda 950, Perkin Elmer Instruments, Norwalk, CT, USA). Measurements were carried out in the wavelength band from 200 to 2500 nm in steps of 10 nm using radiation with a direct perpendicular incidence. Spectral total transmissivity was measured by means of an integrating sphere (diameter 60 mm) used as receiver of the Lambda 950 spectrophotometer, with a double beam comparative method (Wendlandt and Hecht, 1966). Spectral diffuse transmissivity was calculated by subtracting the direct transmissivity from the total transmissivity. The radiometric coefficients in the solar range were calculated as the weighted average value of the spectral transmissivity using the spectral distribution of the solar radiation at ground level as weighting function.
The spectral transmissivity in the long wave infrared radiation (LWIR) range, between 2500 and 25000 nm, were measured by a FT-IR spectrophotometer (1760 X, Perkin Elmer Instruments, Norwalk, CT, USA) in steps of 4 cm^{-1}. Spectral transmissivity was measured using radiation with a direct perpendicular incidence. The transmissivity coefficients in the LWIR range were calculated as average values of the spectral transmissivity in the wavelength range from 7500 to 12500 nm (Vox and Schettini, 2007).
The transmissivity were performed on five rectangular samples (50x70 mm) both in the solar and in the LWIR measurements.

3 Results and discussion

Figure 1 shows the spectral total and direct transmissivity of the Yellow film measured in the solar wavelength range, between 200 and 2500 nm. The spectral transmissivity of the Yellow film measured in the LWIR wavelength range, between 2500 and 25000 nm, is shown in Figure 2. The transmissivity coefficients of the Yellow plastic film were equal to 86.3 % in the Solar wavelength range (300-2500 nm), equal to 86.0 % in the PAR wavelength range (400-700 nm), equal to 90.0% in the Solar IR wavelength range (700-2500 nm), equal to 17.2% in the UVA wavelength range (320-380 nm) and equal to 33.9% in the LWIR wavelength range (7500-12500 nm). The Yellow film was characterised by a high total transmissivity in the PAR wavelength range, a high solar IR transmissivity coefficient and a low LWIR transmissivity coefficient. The Yellow film allowed to pass through the film a low fraction of UVA radiation.

The effect of the irrigation regime on the vine water status was well evident after the pea-size stage, although at a moderate extent, as it is shown by midday stem water potential (Ψmds). During berry growth, up to veraison, average Ψmds values were statistically different and the lowest value was shown by WR1 treatment (-1.42 MPa), as expected. In WR2, Ψmds ranged from -0.79 to -0.88 MPa; in WR3, it reached -1.0 MPa at veraison (Table 1). The ability of midday stem water potential in highlighting differences in water status of table grape vines agrees with other studies on grapevine (Choné et al., 2001; Naor and Wample, 1994; Novello and de Palma 1997).

The effect of the irrigation regime on the leaf functioning of cv. Crimson Seedless covered to delay grape harvest was assessed under extreme environmental conditions: the maximum air temperature and the minimum air relative humidity of the area were 34 °C and 10%, respectively, but, under the plastic film, the air temperature reached 49 °C and air humidity was 22% generating a very high air VPD, that is, 9 kPa. The Ψmds resulted -1,27 MPa either in WR2 or WR3, and -1.363 MPa in WR1 (-8%), without any significant difference. It is known that, with high VPD, the root uptake of available soil water is not able to match the evapotranspirative demand and, in our experience, the differences of water status in soils with different water supplies may be flattened.

In the present experimental conditions, stomatal conductance, net photosynthesis and leaf transpiration had low rates (Figure 3), as expected; however, WR3 showed significant higher values. It seemed that WR3 vines were able to maintain a higher stomatal aperture, photosynthetic activity and transpiration per unit of leaf area, inducing the best leaf water use efficiency. The trend of leaf temperature, that, generally speaking, is negatively correlated with transpiration, agreed with the best ecophysiologically functioning of WR3 leaves. In order to explain why the leaf functioning was better in WR3 than in WR2 it is hypnotizable that vines irrigated at the maximum regime had developed a larger ‘total size’ and that this habit increased the total root-to-leaf water flow hydraulic resistance which, in turn, under extreme environmental conditions, exerted a considerable limitation on stomatal conductance and related parameters.

Water availability significantly affected berry growth, inducing the lowest bunch and berry weight in the treatment WR1 that received the lowest watering volume. Bunch weight decreased respectively by 24% in WR1 (severe stressed vines) and 10% in WR3 treatment (moderately stressed vines) respect to WR1 (well-irrigated vines). Also, berry weight and berry diameters were significantly affected by the irrigation treatments (Table 2).

As a consequence of the water deficit occurred during the crop cycle, fruit yield was significantly affected by the different water regimes. Compared to WR2 treatment, a yield decline of 18% and 26% was observed for WR3 and WR1 respectively, due to both a reduction in bunch size and berry weight considering that the same clusters number per vine retained.

In this trial, the total soluble solid concentration and titratable acidity of juice were influenced by the watering volumes (Table 3). Indeed, the lowest value of TSS was observed for the well irrigated vines.

The application of different irrigation volumes induced significant differences in total leaf area per vine. Leaf area of WR2 and WR3 treatments were quantitatively higher than that of the other treatment (Table 4) and were able to support the growth and maturation of bunches, if we accept that optimum grape evolution needs about 10 cm^2 of leaves per gram of fruit. Maximum berry weight was obtained in WR2 and WR3 treatments which showed a leaf area (m^2)

per fresh yield (kg) ratio ranging between 1.21 to 1.39; similar results were shown also by others authors (Kliewer and Dokoozlian, 2005).
Crop water productivity (production per unit of water applied) increased moderately from WR2 (17.4 kg m^{-3}) to WR1 (23.5 kg m^{-3}) and to WR3 (17.7 kg m^{-3}). Intense water stress (50% of ETc) reduced significantly the vegetative growth as shown by the pruning weight, in comparison to WR1 (100% of ETc) and WR3 (80% of Etc) (Table 4).

4 CONCLUSIONS

According to the preliminary results of this study, the application of a higher irrigation volume (WR2) on Crimson Seedless improved, at a moderate extent, the average vine water status, and, moreover, it favored the canopy development and induced an increase in the vegetative and productive growth. These 'well irrigated' vines took more advantage from the highest water supply, in such a way that their higher metabolic activity determined a higher vegetative and productive development. Irrigation at 50% ETc (WR1) appeared to be insufficient to achieve a complete table grape vineyard development under the environmental condition of the Apulia region. By comparing WR1 (severe stressed vines), WR2 (well irrigated vines) and WR3 (moderately stressed vines), the best balance among vegetative growth, grape yield, berry quality and water use in table grape production, was obtained in WR3 vines. These latter, moreover, in the year of trial, proved to maintain the best ecophysiological leaf functioning and give the best leaf water use efficiency when extreme environmental conditions occurred, in a hot summer period, under the plastic film used to delay the grape harvest.
In addition, from this study it is confirmed the utility of midday stem water potential as interesting and simple tool for evaluation of deficit irrigation and normal irrigation on table grape vines.

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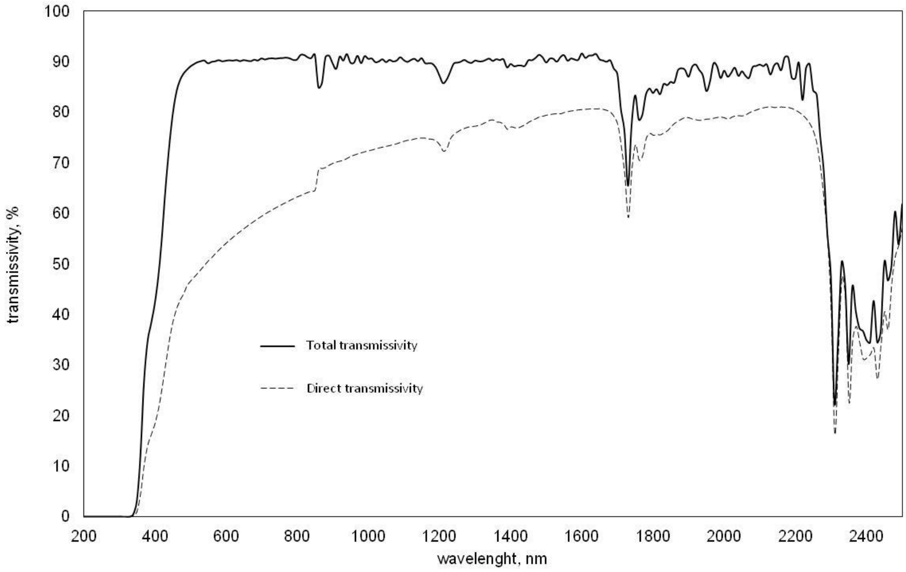

Figure 1: Total and direct transmissivity as a function of the wavelength of the Yellow film in the solar wavelength range (200–2500 nm).

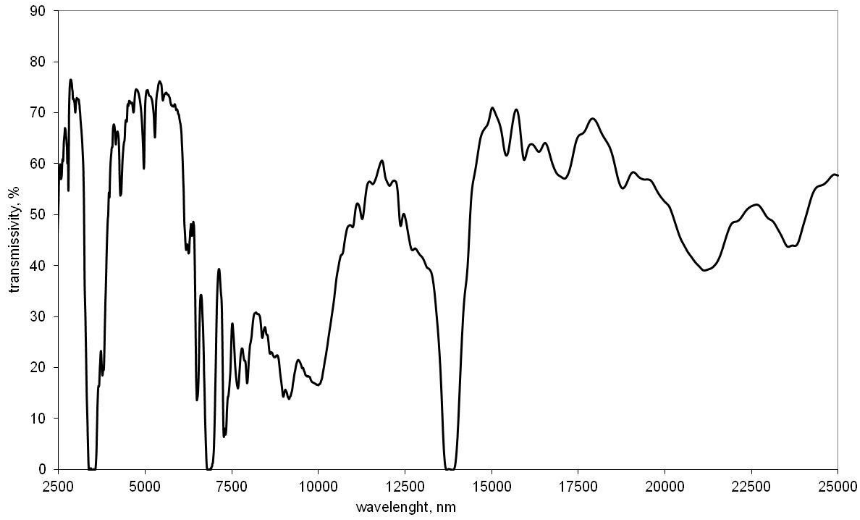

Figure 2: Long wave infrared (LWIR) spectral transmissivity of the Yellow film in the wavelength range 2500-25000 nm.

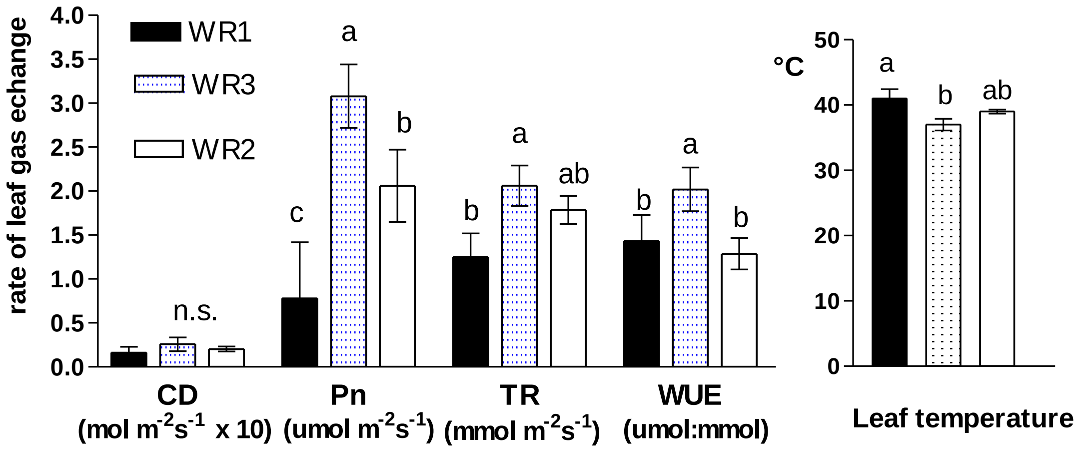

Figure 3: Effect of the irrigation regime on ecophysiological leaf functioning of Crimson Seedless in a hot summer day; from veraison, the vineyard was covered with plastic film to delay grape harvest. Measurements were taken under plastic cover (the bar represents the standard error; different letters indicate significant differences at P < 0,05 using Duncan test)

Table 1: Effects of the irrigation regime on midday stem water potential (Ψmds, MPa), of Crimson Seedless at different phenological stage; from veraison, the vineyard was covered with plastic film to delay grape harvest.

Treatment	Fruit set (MPa)	Pea-size (MPa)	Berry growth (MPa)	Veraison (MPa)	Harvest (MPa)
WR1	-1.36^{a}	-1.10^{a}	-1.42^{a}	-1.12^{a}	-1.36^{a}
WR2	-1.27^{a}	-0.99^{a}	-0.88^{b}	-0.79^{b}	-1.27^{a}
WR3	-1.26^{a}	-1.02^{a}	-1.19^{b}	-1.00^{ab}	-1.26^{a}

In column, means followed by different letters were significantly different at P≤0.05 using SNK test.

Table 2: Effects of the irrigation regime on yield components of Crimson Seedless; from veraison, the vineyard was covered with plastic film to delay grape harvest.

Treatment	Yield per vine (kg)	Bunch weight (g)	Berry weight (g)	*Berry size (mm)*	
				lenght	*width*
WR1	*18.65[c]*	549[b]	5.19[b]	24.86[b]	17.12[b]
WR2	*25.09[a]*	723 [a]	5.35[a]	27.26[a]	19.29[a]
WR3	*20.38[b]*	647[a]	5.21[a]	25.21[b]	17.43[b]

In column, means followed by different letters were significantly different at P=0.05 using SNK test.

Table 3: Effects of the irrigation regime on berry juice composition of Crimson Seedless; from veraison, the vineyard was covered with plastic film to delay grape harvest.

Treatment	T.S.S. (°Brix)	T.A. ($g\ L^{-1}$)	pH
WR1	19.53[a]	4.53[ab]	3.66[a]
WR2	18.23[c]	4.42[b]	3.62[a]
WR3	19.10[b]	4.65[a]	3.68[a]

In column, means followed by different letters were significantly different at P=0.05 using SNK test.

Table 4: Influence of the water regime on vegetative parameters and on indices of crop efficiency of Crimson Seedless; from veraison, the vineyard was covered with plastic film to delay grape harvest.

Treatment	Pruning weight per vine (g)	Total leaf area per vine (m^2)	Crop water productivity ($kg\ m^{-3}$)	Leaf area/ grape yield ($m^2\ kg^{-1}$)
WR1	2750 [b]	20.80[b]	23.50[a]	1.11[b]
WR2	4170[a]	30.39[a]	17.39[b]	1.21[a]
WR3	3880[a]	28.45[a]	17.66[b]	1.39[a]

In column, means followed by different letters were significantly different at P=0.05 using SNK test.