

Title USE OF PYRANOMETERS FOR CONTINUOUS ESTIMATION OF GROUND COVER FRACTION IN ORCHARDS

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Abstract: Ground cover fraction (GCF) is defined as the fraction of ground beneath the canopy covered or shaded by a crop near solar noon as observed from directly overhead. GCF is a useful variable that can be determined in a variety of experimental procedures performed at a field plot scale. GCF is usually measured in experimental field plots using ceptometers or digital imagery. The use of these techniques in the field requires the presence in situ of qualified workers and do not permit the continuous recording of GCF. Thus, only a small number of measured values of GCF are available along the season. A network of pyranometers located at the ground level and above canopy can be connected to a datalogger so a continuous series of global radiation values can be recorded for long periods of time without the presence of any staff. Continuous values of daily GCF can be worked out from those readings. This approach could be particularly useful at remote, unattended sites. Nevertheless, the feasibility of such measures must be evaluated as the main constraint is that the pyranometers must be placed nearby the plant rows to avoid possible damage by the machinery used in the farm. This work presents the daily GCF estimates from pyranometer readings ('pyranometer-driven' method, GCF_{pyr}) at two experiments: a) Experiment I, at a table grape grown under a net, from February 2007 to November 2009; b) Experiment II, at a late peach orchard, from May to September 2011. In the Experiment II measurements were taken for one full irrigated, 'control' tree and for one 'deficit irrigation' tree. The daily GCF_{pyr} values were compared to measured values ('reference' method, GCF_{ref}) using either photographic techniques (table grape) or ceptometers (late peach). For computation of GCF_{pyr} , solar radiation below and above the canopy was averaged for two time periods: a) two hours around solar noon; b) daytime period (8:00 to 18:00 Universal Time Coordinated, UTC). For both experiments, the results obtained with the 'pyranometer-driven' method improved when the solar radiation was averaged for daytime periods. For the table grape vineyard (daytime averaging period), the 'pyranometer-driven' method showed a good agreement with the GCF_{ref} values as shown by a mean estimation error (MEE) of 0.000, a root mean square error (RMSE) of 0.113, and an index of agreement (IA) of 0.967. For the peach orchard (daytime averaging period), the agreement of the 'pyranometer-driven' method with the GCF_{ref} values was worse, particularly with the 'deficit irrigation' tree. MEE was 0.046 to 0.210, RMSE was 0.064 to 0.217, and IA was 0.863 to 0.232. The highest GCF attained, the larger measurement range for GCF (which involves a larger variability of sun angle above the horizon) and the presence of the net above the table grape, were the likely reasons for the better performance of GCF_{pyr} in this crop. Further research is required to develop more appropriate calibration equations of GCF_{pyr} taking into account the whole range of GCF variability.

Key words: Ground cover fraction, Woody crops, Global solar radiation, Estimation methods.

1. INTRODUCTION

Ground cover fraction (GCF) is defined as the fraction of ground beneath the canopy covered or shaded by a crop near solar noon as observed from directly overhead (Allen et al., 1998; Williams and Ayars, 2005; Allen and Pereira, 2009). GCF is directly related to several plant characteristics such as the canopy size and the proportion of solar radiation captured by plants for potential conversion into evapotranspiration (Allen et al., 1998; Williams and Ayars, 2005). For row crops, GCF has been used as an auxiliary variable in the estimation of water use (Goldhamer and Synder, 1989; Allen and Pereira, 2009) or development of crop coefficient (K_c) curves as a function of GCF as the main variable (Williams and Ayars, 2005; López-Urrea et al., 2012). Therefore GCF turns up as a useful variable to be determined in a variety of experimental research works performed at a field plot scale.

Several procedures have been used to determine GCF at that scale such as a grid inscribed on a wooden board beneath the crop canopy (Williams and Ayars, 2005), digital photography and digital image processing software (Williams and Ayars, 2005; López-Urrea et al., 2009; Bojaca et al. 2011) and solarimeter bars such as ceptometers due to the strong relationship between GCF and fraction of light interception by crop canopies (Ayars et al., 2003; Moratiel and Martínez-Cob, 2012, 2013). All of these methods are quite accurate and reliable. However they are relatively time consuming, require the work of a qualified technician and, in the case of digital photography, may require an intensive maintenance work. Thus they can be difficult to be applied when the measurements must be performed at remote field sites. In these situations, an automatic relatively cheap and low maintenance instrumentation could be more suitable. A set of pyranometers connected to a datalogger could be adequate at those remote sites. When those sites are located at commercial farms that set should include a limited number of sensors and should be placed as close to the rows as possible to avoid any damage by the farm machinery.

The objective of this paper is to evaluate the feasibility of using a set of few pyranometers for continuous estimation of ground cover along the crop season for two types of fruit orchards, table grape vineyard and peach orchards. The GCF values obtained were compared to those derived from 'reference' methods, digital photography (vineyard) or ceptometers (peach), in order to check the feasibility of the proposed 'pyranometer-driven' method and to eventually calibrate it. Still, it is assumed that the 'reference' methods provide more accurate estimations of GCF and the 'pyranometer-driven' method is only foreseen as an alternative approach when measurements must be taken at remote, relatively unattended sites located at extension or commercial farms.

2. MATERIAL AND METHODS

This work was performed at two different orchards at Caspe (Zaragoza), northeast Spain: a) Experiment 1, at a table grape (*Vitis vinifera* L.) vineyard; b) Experiment 2, at a peach (*Prunus persica*) orchard. Following the weather network SIAR (MAGRAMA, 2013), the annual average meteorological conditions (2004-2013) in the area are: annual precipitation, 319 mm; mean air temperature, 15.2 °C; mean global solar radiation, 199 W m⁻²; and annual reference evapotranspiration, 1,456 mm.

2.1. Experiment 1

Experiment 1 was conducted on a commercial table grape vineyard (2.0 ha) at the farm Santa Bárbara from 2007 to 2009. The geographical coordinates of the farm were 41°16'N latitude, 0°02'W longitude, and 147 m elevation above the sea level. The 4-year old (in 2007) cultivar 'Crimson' was grown in the vineyard; this cultivar was grafted on 'Richter 110' rootstock (*V. berlandieri* x *V. rupestris*). Row direction was approximately northwest to southeast (about 113° azimuth). Row and vine spacing were 3.5 and 2.5 m, respectively. The vineyard was trained on an overhead trellis system such that the canopy was about 2.0 m above ground and had about 1.0 m height at the maximum development stage. Thus total vine height was about 3.0 m. A net made of a thread warp of high-density white polyethylene (Criado and López, Almería, Spain) covered the vineyard to protect it from hail, birds, and insects. This netting was translucent with individual pores of 12 mm² (2.2 mm x 5.4 mm). It was placed at a height of 3.0 m above ground level just above the canopy level (Fig. 1A). The vineyard was irrigated with a drip irrigation system which included one lateral in each row of vines with integrated self-compensating emitters of a discharge of 2.2 L h⁻¹, spaced 0.5 m. Daily drip irrigation from May to September, herbicide and fertilizer were applied following the farm manager's criteria. Vines were winter pruned. An additional summer pruning of the shoots in a strip 0.5 m wide between vine rows was performed in 2009 around veraison, to allow a better penetration of light in the canopy thus enhancing berry quality and colour uniformity. Suvočarev et al. (2013) provides further details of the vineyard.

Two methods for obtaining GCF were applied. The first one, considered the 'reference' method, used digital imagery and post processing (Blanco et al., 2010). Pictures were taken at six different sites with a digital camera (Olympus, model μ 810, China) that was placed on the ground and focused upwards to a quarter of the whole spacing of a vine (1.25 m x 1.75 m). The images were processed with the GIMP program (available at www.gimp.org), by selecting exactly the quarter of the vine area. The program

transformed the picture into black (leaves and branches) and white (clear screen) pixels (Fig. 1B). The histogram of the black and white pixels was calculated, giving a value of the fraction of the black pixels which represents the GCF at this site. The digital photography as used here does not require taking the images at a specific time of the day. For each measurement date, the six GCF values at the sites were averaged to get the 'reference' GCF value (GCF_{ref}) for that date. The total number of available GCF_{ref} values was 22 in 2007, 13 in 2008, and 28 in 2009. The images were taken every 7 to 14 days, from 15 February to 26 September in 2007, 26 March to 15 October in 2008, and 23 March to 9 November in 2009.

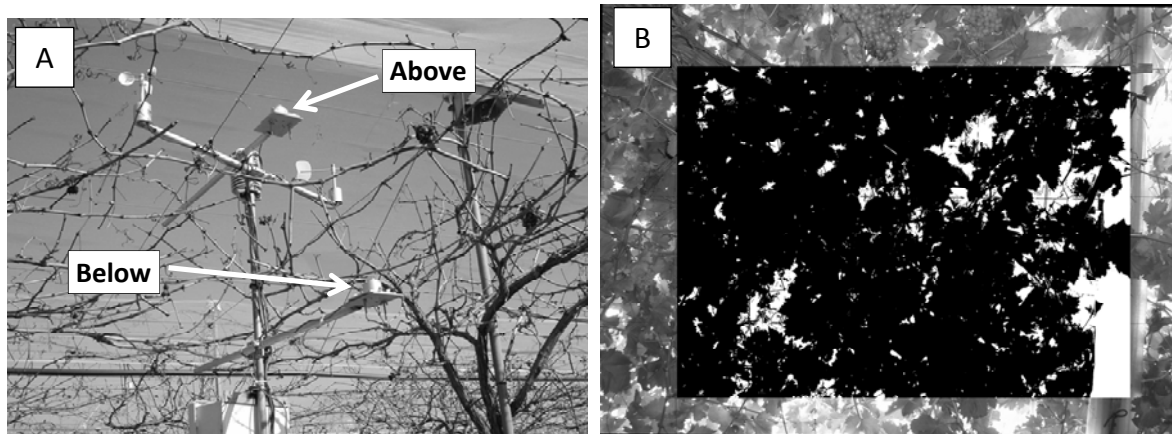


Fig. 1. A. View of the trellis system of the table grape vineyard before budbreak and location of the two pyranometers. B. Image taken with digital photography on 28 July 2009 after post processing.

The second method consisted of only two pyranometers (Kipp & Zonen, model CM3, The Netherlands): one above the canopy just below the net, at about 2.8 m above the ground; the second one completely below the canopy, at about 2.0 m above the ground, and at about 0.5 m horizontal distance from the vine row (Fig. 1A). Both pyranometers, oriented toward southwest (about 223° azimuth) consisted of a thermocouple sensor, housing, and a protective dome. A black absorbant layer coated the thermopile, absorbed the radiation and converted it to heat and subsequently energy flow. Due to the housing the sensor measured the solar energy received from the whole hemisphere (180° field of view). The spectral sensitivity of the sensor was 300 to 3000 nm. Both sensors were connected to a datalogger (Campbell, model CR10, UK) that monitored them and continuously recorded hourly averages of global solar radiation above (Rs_u) and below (Rs_d) the vine canopy from 15 February 2007 to 20 November 2009. Maintenance included clipping out leaves growing too close to the sensors. Due to this problem some periods were removed before further analysis: 26 May to 5 June in 2007, 15 June to 2 October in 2008, and 28 June to 7 July and 13 to 25 August in 2009. The average values of Rs_u and Rs_d from 11:00 to 13:00 UTC and from 8:00 to 18:00 UTC for each day were used to get the 'pyranometer-driven' GCF at this site (GCF_{pyr}): $GCF_{pyr} = 1 - Rs_d / Rs_u$. A total of 865 GCF_{pyr} values were available for each averaging time period. While the GCF_{ref} values do not depend on time period within a given day, the GCF_{pyr} values do. As shading changes along the day, it was hypothesized that the GCF_{pyr} values derived from average midday solar radiation (11:00 to 13:00 Universal Time Coordinated, UTC) could be biased as only one sensor at a fixed spot was used below the canopy, and thus may only represent shade at just a reduced portion of the total area corresponding to each vine. Thus the GCF_{pyr} values derived from average daytime solar radiation (8:00 to 18:00 UTC) could represent better the true GCF; that averaging daytime period could be seen as if the pyranometer below canopy has been moved around the vine during the midday readings because of the change of the angle of the solar radiation during that period.

2.2. Experiment 2

Experiment 2 was conducted at the extension farm AFRUCCAS. The geographical coordinates were 41°19'N latitude, 0°05'E longitude, and 140 m above the mean sea level. The farm included several fruit tree species and cultivars. A group of 105 peach trees (35 trees for each of three rows) was selected for this work. Tree and row spacing were 2 and 6 m, respectively. Row direction was northwest to southeast (about

135° azimuth). The late season peach 'Calrico', grafted on 'GF-677' rootstock (*P. persica* x *P. amygdalus*), was trained to an open-center round canopy. Total tree height was about 3.5 m (the lowest 0.5 m corresponded to the main trunk). Canopy width was about 2 m. Drip irrigation was applied daily using two polyethylene irrigation laterals for each tree row, one lateral at each side and at 0.5 m of the tree row. Emitters were extruded in the laterals at 1 m intervals. This work located at a deficit irrigation experiment, so the emitter discharge was 4 L h⁻¹ for half of the trees ('control' trees) and 2.5 L h⁻¹ for the remaining half ('deficit irrigation' trees). Nevertheless, the effect of irrigation dose in GCF, if any, was not the purpose of this work, and thus was not analyzed. Pruning and fruit thinning were performed seasonally. Herbicides were applied to avoid weeds in the tree rows and minimize the growth of weeds between the tree rows.

Two methods for obtaining GCF were analyzed. The first method determined 'reference' GCF (GCF_{ref}) as: $GCF_{ref} = 1 - PAR_d / PAR_u$, where PAR_d was the average photosynthetically active radiation (PAR) recorded at the soil surface, and PAR_u , the average PAR recorded above crop canopy. PAR_d was measured every 1–2 weeks within 1-2 h before solar noon using a ceptometer or SunScan Canopy Analysis System (Delta-T Devices, UK) which consisted of a 1 m length probe containing 64 photodiodes equally spaced along its length, and a handle containing batteries and electronics for converting the photodiode outputs into digital PAR readings collected by a Data Collection Terminal (Psion, model Workabout, UK) via the RS232 link. The PAR_d readings were taken at 18 points within the surface area assigned to a single tree (2 m x 6 m = 12 m²) with the ceptometer pointing towards southwest, i.e. perpendicular to the rows (Fig. 2A). One 'control' tree and one 'deficit irrigation' tree were monitored. PAR_u was also obtained using the ceptometer, set outside the orchard at a spot not shaded by trees. Two readings were taken, one just before and one just after the PAR_d readings. Later, the 18 PAR_d readings and the two PAR_u readings were averaged to apply the above mentioned equation to get GCF_{ref} for each tree and measurement data. A total of 11 measurement dates of GCF_{ref} were available from 11 May 2011 until 13 September 2011.

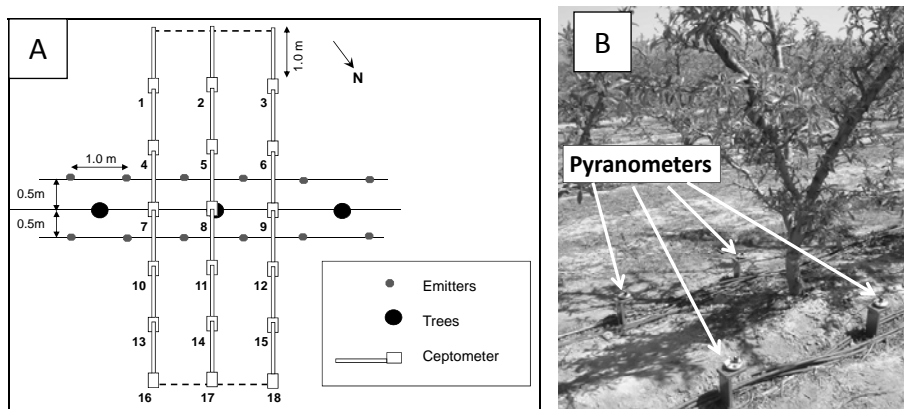


Fig. 2. A. Scheme of PAR_d readings recorded at ground level at the peach orchard within the area assigned to a tree. Numbers represent readings along the different positions. B. Location of the pyranometers below the canopy.

The second method for determining GCF used a set of four silicon pyranometers (SP110, Apogee, Utah, USA) below the canopy at each of two trees close to those where PAR_d readings were taken. A ninth pyranometer was placed above the canopy. At each tree, the four pyranometers below the canopy were placed at about 0.2 m above the ground and about 0.5 m from the row and at both sides of the trees; two pyranometers were next to the tree and the other two were half-way between two consecutive trees in the same row (Fig. 2B). These silicon-cell pyranometers feature a fully potted, domed-shaped head (anodized aluminium with cast acrylic lens) making the sensor fully weatherproof, self-cleaning, and impervious to thermal based accuracy fluctuations. The spectral sensitivity of the sensor was 300 to 1100 nm. All sensors were connected to two dataloggers (Campbell, model CR10, UK), one for each tree; these dataloggers monitored them and continuously recorded 30-min averages of global solar radiation above (Rs_u) and below (four sets of Rs_d values) the tree canopy from 11 May 2011 until 13 September 2011. The average values of Rs_u and Rs_d from 10:00 to 12:00 UTC and from 8:00 to 18:00 UTC for each day were used to get the 'pyranometer-driven' GCF at this site (GCF_{pyr}): $GCF_{pyr} = 1 - Rs_d / Rs_u$. A total of 126 GCF_{pyr} values were available for each averaging time period and each tree. In experiment 2, averages from 10:00 to 12:00 UTC

were used instead of averages from 11:00 to 13:00 UTC (experiment 1) as ceptometer readings were taken within that time period frame.

2.3. Data analyses

Values of GCF_{pyr} were compared to those of GCF_{ref} computing several statistics following Willmott (1982): mean estimation error (MEE), root mean square error (RMSE), index of agreement (IA), and systematic (MSE_s) and random mean square error (MSE_u). Regression analyses and curve fitting for eventual calibration of the ‘pyranometer-driven’ method were also performed using the application SigmaPlot v. 11.2 (Systat Software, California, USA).

3. RESULTS AND DISCUSSION

Table 1 lists the phenology of the crops studied at each experiment. These values show the differences in development between the two studied crops. For the table grape case, values in Table 1 also reflect in some extent the different average meteorological conditions for the different years.

In Experiment 1, there were 54 available dates with both GCF_{ref} and GCF_{pyr} values. Fig. 3 shows the evolution in time of GCF_{ref} and GCF_{pyr} for the two averaging time periods, 11:00 to 13:00 (GCF_{pyr_M}) and 8:00 to 18:00 (GCF_{pyr_D}) at the table grape vineyard. At first glance, a general good agreement was observed for the two averaging time periods both among them and against the GCF_{ref} values. Nevertheless, GCF_{pyr_M} showed a worse performance than GCF_{pyr_D} particularly at the end of May 2007, October 2008 and June 2009. No clear reason can be provided for this behavior in these particular dates. There was a clear disagreement between GCF_{ref} and GCF_{pyr} values (regardless of averaging time periods) from August to November 2009. These was due to the summer pruning of the shoots in a strip 0.5 m wide between vine rows performed in 2009 around veraison as discussed in the Material and Methods section. This strip only represented 14 % of the total row spacing (Fig. 4). Please compare Fig. 1B and Fig. 4 where it can be seen the limited size of the pruning performed at that date. The disagreement observed between GCF_{ref} and GCF_{pyr} values from August to November 2009, as compared to the general good agreement observed for the remaining measurement dates, was likely due to the fact that the clearing was systematic, completely at one end of the whole image. In other words, when the open spaces (i.e. those not occupied by leaves) in the images were less systematic, only due to the free crop development, the pyranometer below the canopy was able to reasonably record ground cover fraction (Fig. 3).

Table 1. Phenology of the crops studied at each experiment. Values between parenthesis are days after budbreak.

Table grape					
Year	Budbreak	Flowering	Veraison	Harvest	
2007	13 Mar (0)	23 May(71)	30 Jul (139)	1 Oct (202)	
2008	5 Mar (0)	20 May (76)	7 Aug (155)	20 Oct (229)	
2009	23 Mar (0)	20 May (58)	22 Jul (121)	5 Oct (196)	
Late peach (2011)					
Budbreak	Flowering	Pit hardening		Veraison	Harvest
		Begins	Ends		
1 Mar (0)	31 Mar (30)	11 May (71)	9 Jun (100)	24 Aug (176)	2 a 12 Sep (185 a 195)

Fig. 5 and Table 2 present the regression and error analyses of the comparison between GCF_{ref} and GCF_{pyr} for both averaging time periods in Experiment 1. These analyses were in accordance with the results displayed in Fig. 3. The agreement between GCF_{ref} and GCF_{pyr} was relatively high as shown by a coefficient of determination (R^2) above 0.84, regression intercepts and slopes no significantly different than 0 and 1, respectively ($\alpha = 0.05$), the low values of MEE and RMSE, and the high values of IA. All mean square error was random (Table 2) meaning that the uncertainty in the ‘pyranometer-driven’ GCF values was completely random. When the solar radiation values recorded by the pyranometers were averaged for the whole daytime period (8:00 to 18:00 UTC), there was an improvement in the performance of the ‘pyranometer-driven’ GCF method as compared to the averaging time period from 11:00 to 13:00 UTC. Naturally, using

only one pyranometer below the canopy did not completely warrant an accurate measurement of the shade below the table grape canopy. But the averaging of values for the whole daytime period likely compensated in part this problem. This daytime averaging could be seen as if the pyranometer was being moved around the shaded area and thus representing better the GCF.

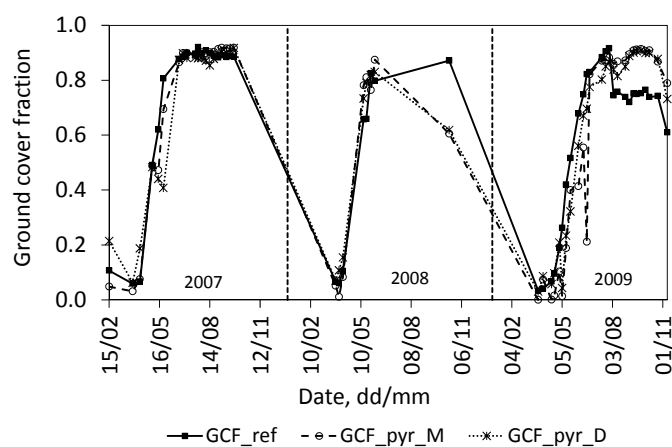


Fig. 3. Evolution in time of ‘reference’ (GCF_{ref}) and ‘pyranometer-driven’ ground cover fraction for both averaging time periods, 10:00 to 12:00 (GCF_{pyr_M}) and 8:00 to 18:00 (GCF_{pyr_D}), at the table grape vineyard.

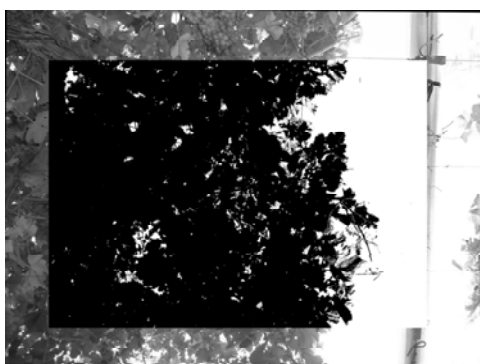


Fig. 4. Image taken at the table grape vineyard with digital photography on 5 August 2009 after post processing.

Table 2. Error analyses of the comparison between ‘reference’ (GCF_{ref}) and ‘pyranometer-driven’ (GCF_{pyr}) ground cover fraction for both averaging time periods, 10:00 to 12:00 and 8:00 to 18:00, at Experiment 1 and Experiment 2. N, sample size; MEE, mean estimation error; RMSE, root mean square error; MSE_u and MSE_s, random and systematic mean square error, respectively; IA, index of agreement

Experiment	Crop	Averaging time	N	MEE fraction	RMSE fraction	MSE _u (fraction) ²	MSE _s (fraction) ²	IA unitless
1	Table grape	11:00-13:00	54	-0.012	0.139	0.019	0.000	0.955
		8:00-18:00	54	0.000	0.113	0.013	0.000	0.967
2	‘Control’ peach tree	11:00-13:00	11	0.228	0.240	0.005	0.053	0.247
		8:00-18:00	11	0.046	0.064	0.002	0.002	0.863
	‘Deficit irrigation’ peach tree	11:00-13:00	11	0.320	0.323	0.002	0.102	0.000
		8:00-18:00	11	0.210	0.217	0.003	0.044	0.232

As it will be discussed later, these results for the table grape were better than those obtained in the Experiment 2 despite more pyranometers below the canopy were used. It seems that the reliability of the ‘pyranometer-driven’ GCF method improved as the true GCF increased. It must be also pointed out that the table grape vineyard was under a net which reduced the solar radiation above the canopy by around 15 %

(Moratiel and Martínez-Cob, 2012). The shading effect of the net, that was uniform for the whole orchard, could also explain in part the good agreement observed between GCF_{ref} and GCF_{pyr} for the table grape vineyard even for early crop development stages which GCF was still low for.

As the regression parameters are computed minimizing errors in respect to the dependent variable, it is not possible to derive a calibration equation from that depicted in Fig. 5. Thus a simple regression of GCF_{pyr} (time averaging 8:00 to 18:00 UTC) as independent variable versus GCF_{ref} as dependent variable was performed in order to get a calibration equation for the 'pyranometer-driven' method at the table grape vineyard. The obtained calibration equation was: $GCF_{ref} = 0.062 + 0.903 GCF_{pyr}$. Thus this equation should be applied to 'correct' the 865 GCF_{pyr} values obtained in this work to get a reliable continuous curve of GCF for the table grape along the season.

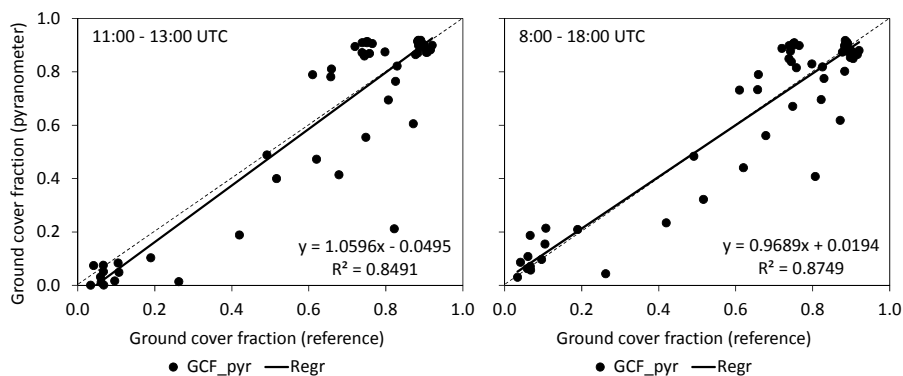


Fig. 5. Simple linear regression between 'reference' (GCF_{ref}) and 'pyranometer-driven' (GCF_{pyr}) ground cover fraction for both averaging time periods, 10:00 to 12:00 and 8:00 to 18:00, at the table grape vineyard.

Fig. 6 displays the evolution in time of 'reference' (GCF_{ref}) and 'pyranometer-driven' ground cover fraction for both averaging time periods, 10:00 to 12:00 (GCF_{pyr_M}) and 8:00 to 18:00 (GCF_{pyr_D}), at the two studied trees in the peach orchard. In general terms, the behavior of GCF_{ref} and GCF_{pyr} values was relatively similar along the season. Note the small decrease in GCF around mid-July for the 'control' tree due to a slight summer pruning in this tree. Both the 'reference' method and the 'pyranometer-driven' method were able to detect that summer pruning. However, the agreement between the GCF_{ref} and GCF_{pyr} values was clearly worse than that observed in Experiment 1 (Table 2). Also, the 8:00 to 18:00 UTC time averaging period showed a better performance than the 10:00 to 12:00 UTC averaging period likely for the same reasons discussed previously for Experiment 1. Measurements in Experiment 2 were performed for a much lower range of GCF compared to those in Experiment 1. This limited variability in GCF explains the poor results of the simple linear regression analyses (Fig. 7). In Experiment 2, most of the mean square error was systematic (Table 2) meaning that the results were clearly biased in contrast with Experiment 1. In accordance with the results observed in Experiment 1, the performance of the 'pyranometer-driven' method improved for higher true GCF values. The performance of the 'pyranometer-driven' method was better for the 'control' tree than for the 'deficit irrigation' tree (Table 2). This latter showed a lower GCF than that the former likely due to water stress leading to leaves with much lower turgidity.

The simple linear regression of GCF_{pyr} as independent variable versus the GCF_{ref} was used to get a calibration curve for the 'pyranometer-driven' method for the daytime averaging period (8:00 to 18:00 UTC) and both the 'control' and the 'deficit irrigation' trees. These calibration curves were $GCF_{ref} = 0.231 + 0.463 GCF_{pyr}$ for the 'control' tree, and $GCF_{ref} = 0.212 + 0.284 GCF_{pyr}$ for the 'deficit irrigation' tree. As discussed previously, the limited variability range analyzed for GCF in the Experiment 2 did not allow for a better regression analysis. Thus these calibration equations should be taken with caution.

The use of a short number of pyranometers placed near the rows was necessary to avoid the sensors being damaged by the machinery in these remote, relatively unattended locations. Of course, this short number of pyranometers highly reduces the possibilities for recording accurate values of GCF. The 'pyranometer-driven' method is biased towards overestimation of GCF. The performance of this method increased when the true GCF was higher and thus the shade was larger. The good performance of the 'pyranometer-driven' method in the table grape vineyard even for development stages with low GCF

indicates that this method can also provide good results for periods when the sun angle above the horizon is low (i.e. during winter, early spring and late fall). This behavior was not observed in Experiment 2 because all measurements were taken in summer and late spring.

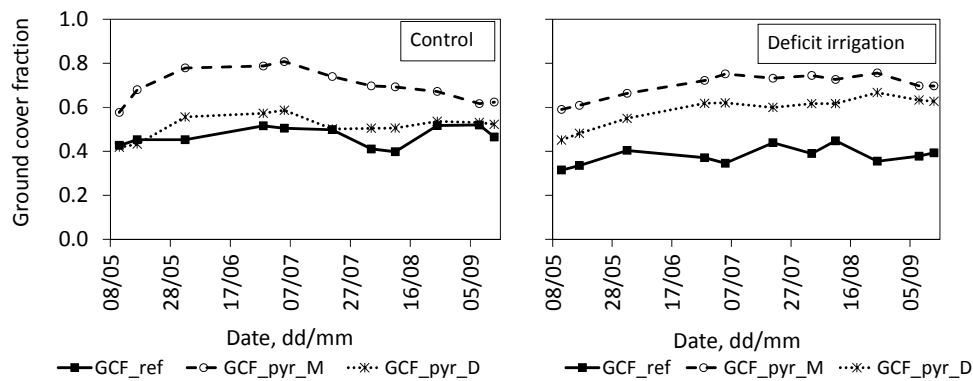


Fig. 6. Evolution in time of 'reference' (GCF_{ref}) and 'pyranometer-driven' ground cover fraction for both averaging time periods, 10:00 to 12:00 (GCF_{pyr_M}) and 8:00 to 18:00 (GCF_{pyr_D}), at the two studied trees in the peach orchard.

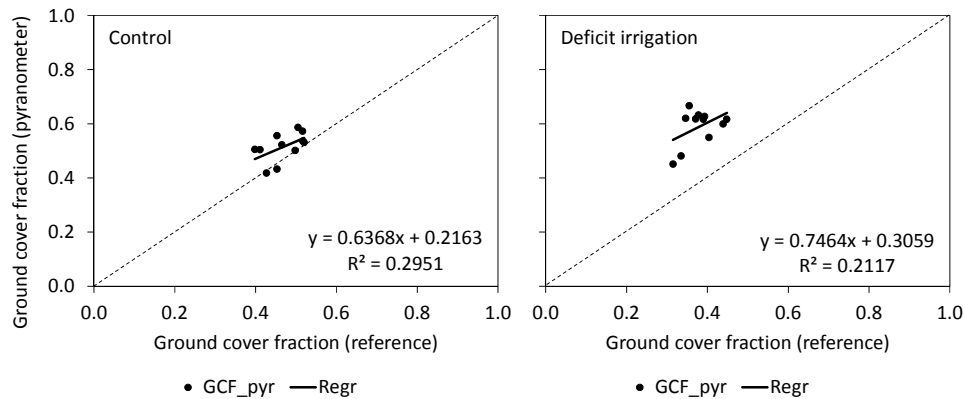


Fig. 7. Simple linear regression between 'reference' (GCF_{ref}) and 'pyranometer-driven' (GCF_{pyr}) ground cover fraction for the averaging time period 8:00 to 18:00, at the two studied trees in the peach orchard.

Further research is required. Because this work was a first attempt to evaluate the feasibility of the 'pyranometer-driven' method, a short number of measurements were taken. Measurements should be taken along all the season and the number of replications for both GCF_{ref} and GCF_{pyr} should be increased. Better calibration equations should be developed taking into account the whole range of variability of GCF.

4. CONCLUSIONS

For both experiments, the results obtained with the 'pyranometer-driven' method improved when the solar radiation was averaged for daytime periods (8:00 to 18:00 UTC) as compared to averaging only for a couple of hours around solar noon. For the table grape vineyard (daytime averaging period), the 'pyranometer-driven' method showed a good agreement with the GCF_{ref} values as shown by $MEE = 0.000$, $RMSE = 0.113$, $IA = 0.967$ and regression parameters no significantly different than 0 (intercept) and 1 (slope) ($\alpha = 0.05$). This agreement was likely due to several factors: a) the use of a net above the vineyard; b) the almost complete GCF attained; c) the measurements be taken along the whole season, i.e. along a whole range of values of sun angle above the horizon.

For the peach orchard (daytime averaging period), the agreement of the 'pyranometer-driven' method with the GCF_{ref} values was worse, particularly with the 'deficit irrigation' tree. MEE was 0.046 to 0.210, RMSE was 0.064 to 0.217, and IA was 0.863 to 0.232. Regression analyses were poor. The short range of GCF values analysed caused these poor regression results. The lower GCF attained at the peach orchard and the short range of values of sun angle above the horizon also reduced the performance of the 'pyranometer-driven' method.

Further research is required. Measurements should be taken along all the season and the number of replications for both GCF_{ref} and GCF_{pyr} should be increased. Better calibration equations should be developed.

ACKNOWLEDGMENTS

Work funded by the Ministry of Science and Innovation, Spain (project Consolider CSD2006 – 00067). Kindly thanks to the owners and managers of the farms 'Santa Bárbara' and AFRUCCAS, and J. Negueroles, J.L. Espada, M. Izquierdo, J. Gaudó, J.M. Acín, C. Merino and Antonio ('Toño') for technical and field assistance.

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