Integration of the Regulated Deficit Irrigation Strategy in a Sustainable Orchard Management System

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Abstract

Irrigation in arid regions requires special attention to optimize the management of all components of the orchard system in order to increase water use efficiency and reduce environmental impacts (e.g. soil salinization, degradation of ground and surface waters). This six-year study reports the comparison of some orchard practices (soil and irrigation management, plant nutrition) routinely adopted by local farmers (conventional, *C*) with those interventions having the potential to save water and maximize water use efficiency in a peach orchard and therefore defined as sustainable (*S*). Due to the relative approach (*C* versus *S*) used in this study, classical statistical comparison of results could not be made. The *S* system included the application of regulated deficit irrigation (RDI) with specific crop coefficients to calculate the plant water requirement. The *S* system on average saved 1450 m^3 ha^{-1} of water per year without affecting yield or fruit quality. The concept of economic water productivity (E_{WP}) is discussed. We conclude that addressing some practices currently adopted by farmers could increase sustainability of irrigation and enhance E_{WP} in peach tree orchards.

INTRODUCTION

Irrigation is the largest consumer of global water resources. The irrigation sector is facing increasing water scarcity due to climate change and rising competition from non-agricultural water users. Arid regions in particular require irrigation practices that save water and minimise negative impacts on the environment (Xiloyannis et al., 2006a).

The regulated deficit irrigation (RDI) technique imposes water deficits during phenological stages when trees are less sensitive to water stress (non-critical periods). RDI therefore offers the potential to save water particularly to growers with a restricted water supply (Fereres and Soriano, 2007). However, more recently it has been pointed out that a prolonged and often severe water deficit imposed through RDI could decrease yield in fruit trees when deficits are applied over successive seasons (Pérez-Pastor et al., 2009). More information is needed to accurately and safely manage RDI in the field and for successive growing seasons. Additionally, irrigation and RDI in particular have not been sufficiently considered within a wider management system including other agronomic practices and land resources.

This paper reports results from a comparative study of conventional and sustainable orchard management practices. The conventional practices are representative of usual grower practice in the region while the sustainable practices aim to save water and maximize water productivity without impairing long-term yield.

MATERIALS AND METHODS

The six-year study was carried out in southern Italy in a peach orchard (‘Super Crimson’ grafted on GF677 at 5×4 m spacing). Conventional orchard management (*C*) (continuous soil tillage, mineral fertilizers, irrigation scheduling decisions exclusively based on grower experience) adopted by local farmers, was compared with sustainable orchard practices (*S*) (no tillage, cover crop, organic fertilizer, summer pruning and sustainable irrigation). Within the orchard, two adjacent plots of one hectare each were

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identified and differently managed according to *S* or *C* practices.

Trees were drip-irrigated (8 L h^{-1} with 2 drippers per plant) in both *S* and *C* treatments. Irrigation was scheduled in the *C* plot approximately every 10 days starting in April, while in the *S* plot, irrigation requirements (*I*) were calculated by the equation $I = ET_o \times K_c \times 0.9^{-1}$, assuming 90% distribution efficiency. Potential evapotranspiration (ET_o) was obtained from a weather station (Regional meteorological service, SAL-ALSIA) located within 5 km of the field site. In the *S* plot, crop coefficients (K_c) during the pre-harvest stage in April, May and June were 0.6, 0.8 and 1.2, respectively, based on previous local experiments (Dichio et al., 2007). During the postharvest stage, from July to September, RDI was applied by reducing the irrigation to approximately 50% of plant requirement (Dichio et al., 2007).

Summer pruning was performed in mid-June and at the end of July. The *S* plot received 15 t ha^{-1} y^{-1} of compost (24.8% moisture content) containing approximately 35% C on a dry matter basis. Fertilisation of the *S* plot was based on concentrations (% dry matter, DM) of various plant tissues, whole plant DM per plant and on availability in the soil of the various essential plant nutrients according to the methods in Xiloyannis et al. (2001, 2006b). In particular, the concentration of N (NO-3) was monitored and N distributed via fertigation each time the concentration in the top 40 cm of soil fell below 20 ppm. Fertilization of the *C* plot was based on grower practice of applying mineral fertilizer. Table 1 provides further details on the practices adopted.

The dry weight of pruning material (summer and winter), senescent leaf, cover crop and thinned fruit were determined by taking random samples under 20 trees in each plot. Carbon content was then determined as reported in Montanaro et al. (2009). Plant water status was monitored in the *S* plot on 5 trees per plot (× 5 leaves per tree) by measurement of midday stem water potential at weekly intervals following the procedure reported by Dichio et al. (2007). Each year yield was assessed on the whole plots.

RESULTS AND DISCUSSION

Large differences in seasonal irrigation volumes were seen for the two irrigation methods (Fig. 1). Average annual irrigation volume applied in the *S* plot was approximately 23% lower than in the *C* plot, a saving of 1450 m^3 ha^{-1} gained during the post-harvest stage. Despite the lower irrigation volume, cumulative yield was substantially higher (30%) in the *S* than in *C* plot (Fig. 2). The results agree with a view that yield does not increase beyond a threshold despite additional watering (Fereres and Soriano, 2007). Results also suggest that irrigation volume was not the only variable affecting yield.

RDI applied in the *S* plot may have reduced the formation and growth of watersprouts (30%) and lateral shoots (Fig. 3), while no differences were seen for fruiting shoots (data not presented). The total pruning weight (winter and summer) was approximately 32% lower for the *S* than the *C* plots (Fig. 3). The regulation of vigor due to moderate water stress possibly reduced the competition for assimilates between reserve tissues and the vegetative apexes resulting in better light interception and lower water use (Boland et al., 2000). In the *S* plot, summer pruning was performed twice a year reducing the leaf area in all by approximately 10 m^2 $plant^{-1}$. Considering a daily mean transpiration rate of 3 mmol m^{-2} s^{-1} (Dichio et al., 2007), the summer pruning in turn would have reduced the transpired water by about 800 m^3 ha^{-1} over approximately 40 days from August.

Based on the salt content of the irrigation water (not shown), cutback of irrigation volumes in turn reduced the amount of salt applied to the soil. This may have great significance in environments with low annual precipitation (≤500 mm) and high evapotranspirative demand (≥900 mm y^{-1}) (Xiloyannis et al., 2006).

Irrigation management in the present experiment integrated other sustainable practices concerned with soil rehabilitation like increasing the soil carbon level (Montanaro et al., 2009). On average, in the *S* plot, 21.1 t ha^{-1} y^{-1} carbon was returned to soil, compared to 6.1 t ha^{-2} y^{-1} in the *C* plot. Increased soil carbon is a prerequisite for soil fertility remediation, mineral element supply and better soil water holding capacity (Wilhelm et al., 1986). Therefore, higher carbon input in the *S* plot may have increased the retention of winter rainfall in the soil resulting in more available water compared to the *C* plot.

Harvest occurred on 2nd July, and thereafter RDI was applied in the *S* plot based on a previous study (Dichio et al., 2007). Midday stem water potential always remained within a range of -0.6 to -1.0 MPa during the pre-harvest stage in trees under *S* treatment. In the post-harvest stage, when RDI was applied, stem water potential was lower but never fell below -1.6 MPa. Application of deficit irrigation strategy through RDI can lead to lower yield and fruit weight and to a change in antioxidant and vitamin content of the fruit (Buendía et al., 2008; Pérez-Pastor et al., 2009).

Recently, emphasis has been placed on the concept of water productivity (WP), defined either as the yield or net income per unit of evapotranspiration (Fereres and Soriano, 2007). We evaluated the effect of orchard management practices on economic water productivity (E_{WP}), defined as the economic value of the marketable yield per unit of irrigation applied. Marketable yield value depends on fruit quality and in particular on fruit size distribution (Fig. 4), that in turn may affect E_{WP} as a result of applying sustainable orchard practices. E_{WP} index therefore seems to be an appropriate method of assessing the impact of irrigation technique on productivity. We believe that a water saving per-se does not necessarily result in increased yield, and that higher yield sometimes leads to reduced fruit size.

The present comparative study did not have a traditional experimental design and therefore statistical comparison of results was not possible. However, some information could be inferred. On a six-year average, based on the annual fruit price and marketable yield (not shown), the E_{WP} was 2.11 and 1.34 € m^{-3} for the *S* and *C* plots, respectively. This was evidently related to the increased yield and reduced irrigation in the *S* plot (Figs. 2 and 1). *S* did not strongly affect the fruit size distribution (Fig. 4). Based on the above mentioned beneficial effect of the carbon on soil water holding capacity, the high carbon input in *S* plot possibly contributed to increased E_{WP} via reducing the irrigation volumes.

CONCLUSIONS

Results demonstrated that integrating RDI into a wider sustainable fruit tree orchard management regime with increased soil carbon inputs, resulted in high and stable yields and a high E_{WP} over the medium term (six years).

This information should encourage water-management policy makers to promote strategies that promote industry wide adoption of RDI in order to reduce agricultural water use. For example, offering adequate extension service and, at the same time, introducing volumetric charges for irrigation water and economic penalties for excessive water consumption will almost certainly lead to a higher E_{WP}. However, using price policies to promote the economic productivity of water requires significant government intervention in order to ensure equity of access to public water. We believe E_{WP} should be a useful tool to evaluate the impact of alternative water management technologies on farm- and regional-scale economies.

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Tables

Table 1. Different practices adopted during the trial in the sustainable (*S*) and conventional (*C*) peach plots.

	S	*C*
Soil	not tilled, cover crop	tilled
Irrigation	based on ET_o, K_c and RDI	calculated empirically
Fertilization	based on plant demand and on soil N availability, compost (15 t ha^{-1} y^{-1})	calculated empirically, mineral
Pruning material	mulched in situ	removed and burnt

Figures

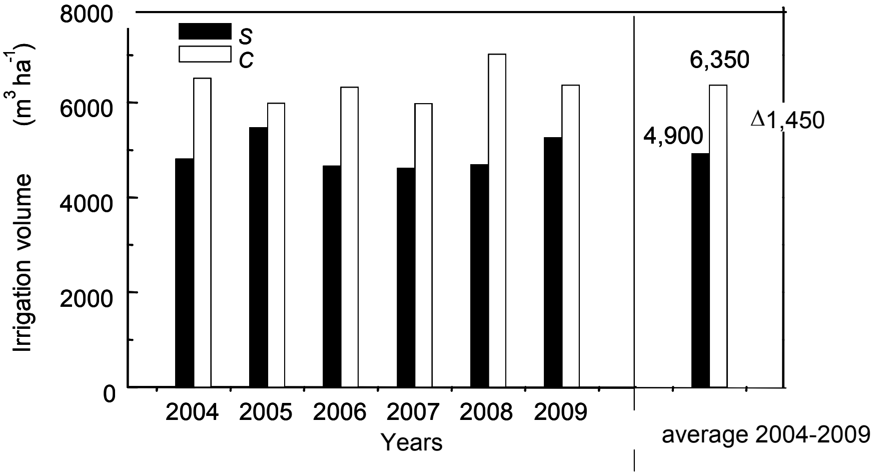

Fig. 1. Annual irrigation volumes (m^3 ha^{-1}) and 2004-2009 mean volume applied in the sustainable (*S*) and conventional (*C*) plots. Note, on average, 1450 m^3 ha^{-1} were saved on the *S* plot.

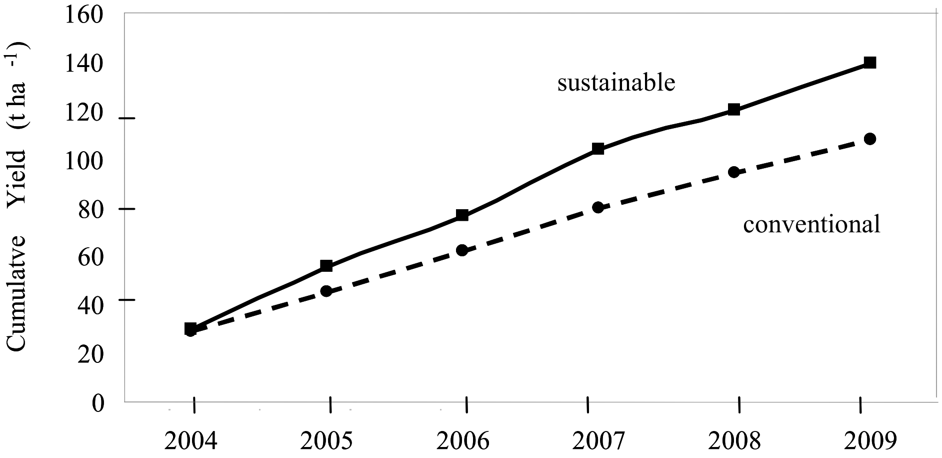

Fig. 2. Cumulative yield (t ha^{-1}) recorded during the 2004-2009 period in the sustainable (continuous line) and conventional (dotted) plots.

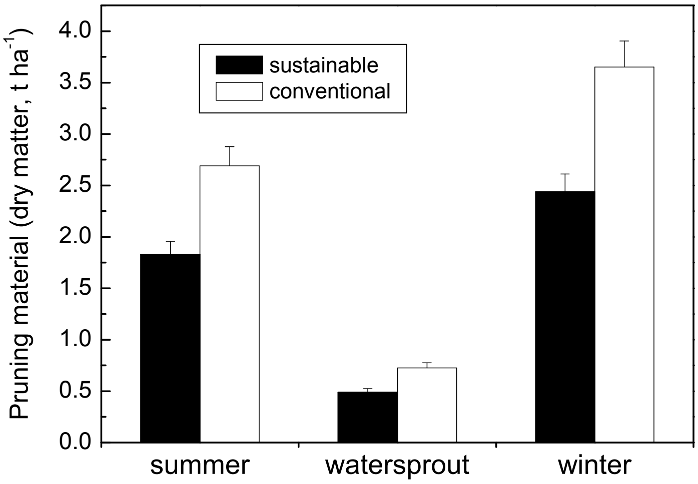

Fig. 3. Dry matter of summer and winter pruning measured in a conventional and sustainable orchard. Summer pruning weights include watersprout shoots. Data are means (±SE) of 10 data collected from 10 trees during the 2004-2009 period.

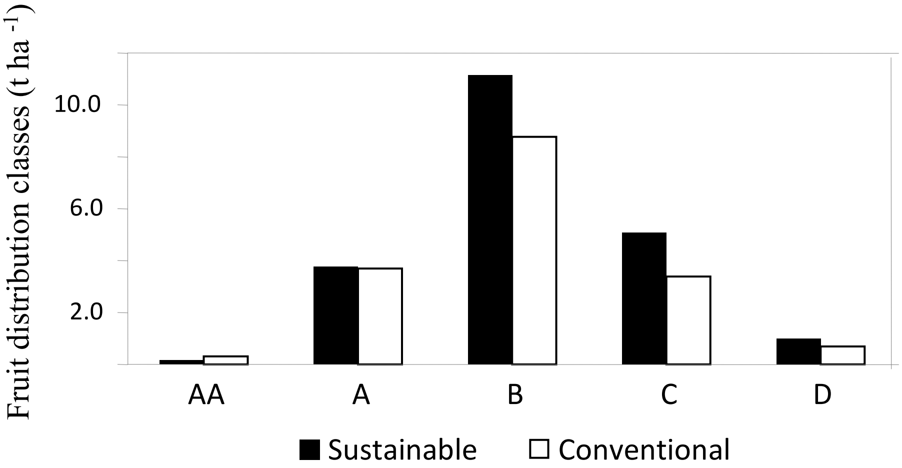

Fig. 4. Mean fruit size distribution classes of yield during the experiment (2004-2009).