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Soil Profile Water Content in Pepper Crop Production as Affected by Different Weed Infestation

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Abstract: Experiments were conducted to evaluate the soil water status and pepper water use efficiency under irrigated and rainfed conditions as affected by different weed infestation in a semiarid environment. The experiment was carried out in 2008 and 2009 in Southern Italy. Two water regimes were imposed to compare water competitive effects under irrigated and rainfed conditions. Weeds were studied within a naturally occurring weed population in a pepper field, where a rainfed treatment was compared to a full irrigated one corresponding to the restoration of 100% of the maximum crop evapotranspiration. Leaf water potential, soil water content, water use efficiency, maximum Leaf Area Index, dry matter and pepper yield were measured. Results revealed that all parameters differed significantly due to irrigated and rainfed treatments. Weed infestation reduced the pepper yield and interaction between irrigation regime with weed interference was highly significant. In 2008 weed-free pepper yield of irrigated treatment was equal to 36.5 t ha^{-1}, while it was 43.4 t ha^{-1} in 2009. Lower yield was obtained in rainfed weedy treatment in both years, 0.2 and 0.5 t ha^{-1}, respectively. In semiarid environment, different weed population had a great impact on pepper growth and yield, both in rainfed and irrigated conditions. Results showed that a weed-free agrosystem, especially in a drought condition, is necessary to maximize production and water use efficiency.

Key words: Water competition, weed-crop competition, water use efficiency, soil water content, leaf water potential

INTRODUCTION

In many parts of the world weed control remains one of the greatest costs for farmers (NASS, 2006). The main problem related to the presence of the weeds on a cultivated field is the competition for resources with the crop (Radosevich *et al*., 2007; Zimdahl, 1999).

Since world population is increasing it is crucial to meet future food needs and improve water use efficiency to limit conflicts with non agricultural uses of water (Berger *et al*., 2010). Moreover the effects of CO_2 increase in the atmosphere and the subsequent rise of temperatures must be taken into account for their effects on crop-weed interference. In the Mediterranean region, reduction of water availability and situations of severe drought will be more frequent as a result of climate change (Lovelli *et al*., 2010). In a frame of climate change since rainfall pattern becomes more unpredictable, plants will be subjected to increasing fluctuations in soil moisture availability (Davies and Gowing, 1999).

An effective control of weeds is considered a key management practice to mitigate the effects of water stress on crop yields (Radosevich *et al*., 2007; Berger *et al*., 2010), especially in Mediterranean areas. Water stress can have a different impact on crops and weed growth, changing in this way the competitive balance between species. It is believed that weeds compete with crops for water but the mechanisms through which this kind of competition is realized and the ways in which weeds interfere with the processes of crop growth are not sufficiently known (Berger *et al*., 2010). The understanding of how drought may affect weed induced crop losses is essential to manage weeds in a more appropriate way (Valerio *et al*., 2013).

Plant responses to low water availability and water stress vary widely among species of weeds and crops and has an impact on the process of weed/crop competition. Of course water uptake by crops inevitably reduces the availability of water to the weeds present in the field. The result of weed/crop competition for this resource is in relation to abilities of weed and crop to uptake water and to stand drought (Patterson, 1995).

There have been numerous efforts to quantify crop weed competition that have considered leaf canopy

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dynamics and above-ground competition for light but less studies on water competition (Kropff and van Laar, 1993). There are few papers on water uptake dynamics from respective soil profile layers over time during crop-weed competition: More data of this type is needed to understand the variability in weed-crop competition outcomes (Sadeghi *et al*., 2007).

Currently, no data exist on the effect of irrigation and weed interference on pepper yield in Mediterranean area and its implications on weed management. Moreover a more detailed analysis of water interference could provide very useful information to process water simulation models in the context of the crop-weed interaction (Massinga *et al*., 2003).

Therefore, a two years irrigation experiment was carried out in South Italy to evaluate how weed presence affects soil water status and pepper water use efficiency. The experiment started in 2009 on pepper crop irrigated with full restoration of water use and in rainfed conditions, both in presence and absence of weeds.

MATERIALS AND METHODS

Field experiments were conducted in 2008 and 2009 in Southern Italy (40°00' N; 16°00' E; 397 m a.s.l.) on a loam soil with a moderate chemical fertility. Soil moisture content was 24.2% at field capacity and 17.2% at the theoretical wilting point (determined in lab at -0.03 and -1.5 Mpa, respectively). Previous crop was durum wheat in both years. Experiments were located in different contiguous fields in each year. Soil tillage consisted in moldboard ploughing, disking and land levelling previous to crop planting. Bell pepper (*Capsicum annuum* L.) (cv. peppone) was transplanted on May 19 in 2008 and on May 7 in 2009, 1×0.4 m spaced and gradually harvested until August 26 and August 30 in 2008 and 2009, respectively. An overall amount of 150 kg ha^{-1} N, and P_2O_5 and 180 kg ha^{-1} of K_2O was applied before sowing and during pepper crop cycle by fertirrigation.

The experiment design was a split-plot with three replications. The main plot factor was irrigation, which consisted of rainfed (V0) and fully irrigated treatment (V100). In the irrigated treatement (V100) 100% of total crop water evapotranspiration (ETc) was restored when 40% of total available water was depleted according to the evapotraspirometric method of Doorenbos and Pruitt (1977). For irrigation scheduling ETc was calculated as ETc = ETo×Kc where ETo (reference evapotraspiration) was calculated according to Hargreaves and Samani (1985) and Kc was the crop coefficient of bell pepper as reported by Allen *et al.* (1998), corrected for the specific environmental conditions, yielding Kc initial = 0.5; Kc midpoint = 1.15; Kc end = 0.8. The experimental site was irrigated weekly both in 2008 and 2009. Drip irrigation was used, with dripping wings placed on each row and "on line" drippers, spacing 20 cm, with a 3 L h^{-1} delivery. Main plots consisted of six 30 m rows, spaced 1 m apart. Subplot treatments consisted of presence (weedy) or absence (weed-free) of weed interference, such that weed presence was a random effect over time. Subplots measured 15 m in length by 3 rows wide (3 m). In weed-free plots all emerging weeds were removed by hoe or hand.

Max and min T, air humidity, wind speed were acquired every 10 min on a weather station placed in a meadow next to the plots, averaged and recorded every 30 min by a datalogger. Data were processed to obtain the daily means.

Soil water content: During 2008 and 2009 soil water content was measured once (68 days after pepper transplantation) during pepper growth cycle by gravimetric methods (at 0.30 and 0.60 m soil depth) and only in 2009, weekly during the whole pepper cycle by means of gypsum blocks. They were located at 0.30 and 0.60 m soil depth, on row line under the emitter and between rows at a distance of 25 cm in three replicates of each treatment. Near each gypsum block were collected soil samples on which soil water content was assessed either by gravimetric method and gypsum block reading to obtain a calibration curve for this site. At the end of the trial all readings by gypum blocks were converted to soil water content by a calibration curve previously obtained.

Plant water content: Leaf water potential (Ψ) was measured on pepper 68 days after transplantation on the youngest uppermost fully-expanded leaf of four representative plants per treatment at midday using the pressure chamber technique (Scholander pressure probe; Scholander *et al*., 1965).

Growth parameters: Above ground dry matter production of weed-free pepper and weedy pepper was determined in both treatments (three replicates) at pepper harvesting. Samples were dried in a ventilated oven at 75°C until constant weight was reached.

Water use efficiency (WUE, kg m^{-3}) was calculated as the ratio between total yield and total water use measured at harvesting by calculation of water balance.

Statistical analyses: Statistical analyses of all data were performed using statistical package SPSS 11 for Windows. Bartlett's test was applied to establish homogeneity of variance, following which the data were subjected to

Analysis of Variance (ANOVA). It was used to test the effect of irrigation regime on soil water content, plant water content, pepper dry matter, yield, LAI and water use efficiency. About soil water data (percent values) ANOVA was applied on data converted according to Bliss (1938). They are reported on the conversion and original scales both in Table 1 and result section, respectively. Least Significant Difference (LSD) Test was used for multiple comparison of means for the different treatments.

RESULTS AND DISCUSSION

The first year (2008) was less rainy in June, July and August than the second one (2009) and monthly average daily air temperature was warmer in 2008 than 2009 during the same months (Fig. 1). In irrigated plots (V100) seasonal irrigation volume ranged from 398 to 403 mm, in 2008 and 2009, respectively. Weed species, common to the Mediterranean area began emerging 10 days after pepper transplantation. Total weed densities in weedy plots ranged from 33 to 63 and from 20 to 45 plants m^{-2}, in V0 and V100 and in 2008 and 2009, respectively (Fig. 2). During 2008 in the irrigated treatment the most present weeds at pepper harvesting were pigweed and bindweed. Other weeds also observed on the pepper field were purslane (*Portulaca oleracea* L., POROL) and lambsquarters (*Chenopodium album* L. CHEAL). In irrigated treatment pigweed prevailed, while in drought conditions purslane prevailed, 30 and 22 plants m^{-2}, respectively (Fig. 2). During 2009 weeds present in the field were the same observed during the first year, except for thistle (*Cirsium arvense* (L.) Scop, CIRAR) that was absent in 2008 (Fig. 2). There were more thistle plants in irrigated treatment than in rainfed treatment, 28 and 7 plants m^{-2}, respectively.

Plant water status: Leaf water potential was more negative next to lower soil water content value (Table 1). More negative values (-2.8 Mpa) were reached in weedy pepper in drought plots, while in weed-free pepper plants it was -2.0 Mpa.

Others authors did not observed significant differences in stomatal conductance. Young *et al*. (1983) and Berger *et al*. (2010) showing that weeds had no impact and did not intensify crop moisture stress during dry periods. The results were in disagreement with these but these trial measurements were made in a drier environment.

Soil water content varied in agreement to the different rainfall and temperature trends observed in the two years (Table 1 and Fig. 1). Only irrigation regime significantly affected this parameter, either at 0-30 and 30-60 cm. Soil humidity was higher in the second year and in the irrigated treatment and higher values reached about 24% at two considered depths also because 2009 was more rainy than 2008.

As regard to the overall weekly soil moisture pattern measured during the 2009 for each water application at the different depths, it was evident that the greatest differences occurred between irrigated and rainfed treatment (Fig. 3 and 4). In irrigated plots water content varied greatly as a function of the distance from irrigation emitters (Fig. 3 and 4). At 30 cm depth there were significant differences of soil water content between weed-free and weedy plots in the irrigated treatment (V100) only in the second part of the crop cycle starting from 60 days after transplantation. Such differences were greater in the inter row than on the row (Fig. 3). At the end of crop cycle in the not weedy plot on the row, soil moisture was equal to 23%, little below field capacity, while in weedy plot it was significantly lower (20%), corresponding to about 50% available water. In the inter

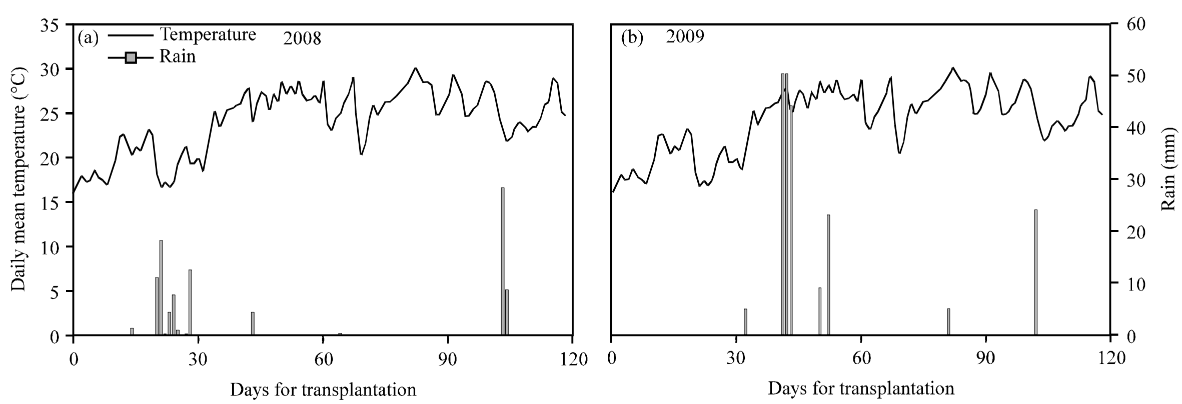

Fig. 1(a-b): Daily temperature-rainfall pattern measured during pepper growing cycle trends during 2008 and 2009

Table 1: Leaf water potential and soil water content of weed-free and weedy pepper, in irrigated (V100) and rainfed (V0) treatments, measured at 68 days from transplantation in 2008 and 2009

	Leaf water potential (Mpa)		Soil water content 0-30 cm (converted data from % dry weight)		Soil water content 30-60 cm (converted data from % dry weight)	
Parameters	V0	V100	V0	V100	V0	V100
2008						
Weed-free papper	-2.00	-1.27	20.1	25.4	19.6	25.0
Weedy papper	-2.78	-1.25	18.8	25.1	19.5	24.5
2009						
Weed-free pepper	-1.65	-1.38	25.9	29.4	26.0	29.9
Weedy pepper	-2.00	-1.45	26.0	29.0	25.9	29.1
LSD						
Year	*	0.2 ($p<0.05$)	**	3.0 ($p<0.05$)	**	2.2 ($p<0.01$)
Irrigation	**	0.5 ($p<0.01$)	**		**	
Weed interference	**		ns		ns	
Year×irrigation	**		ns		ns	
Year×weed Interference	ns		ns		ns	
Irrigation×weed Interference	**		ns		ns	
Year×irrigation×weed Interference	ns		ns		ns	

LSD: Represents the least significant difference between means, **Highly significant ($p<0.01$), *Significant ($p<0.05$), ns: Not significani

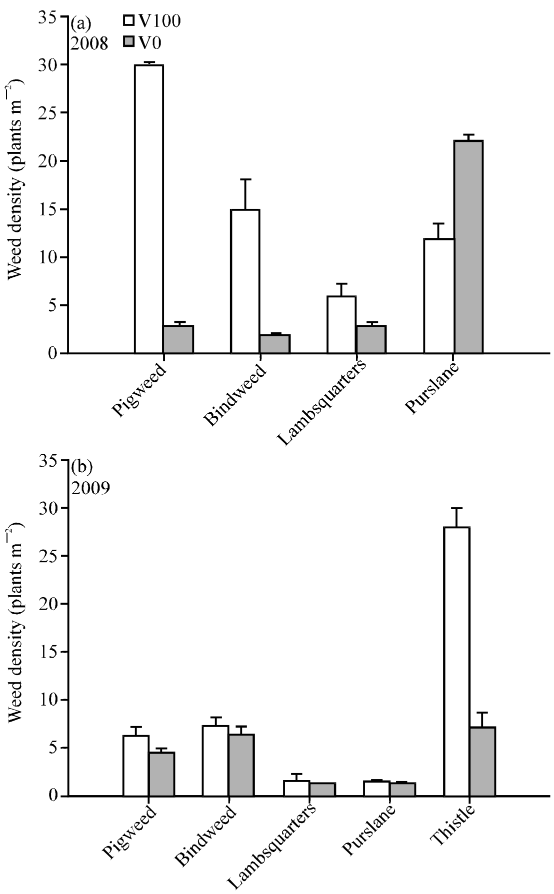

Fig. 2(a-b): Densities of weeds observed on field at pepper harvesting in 2008 and 2009. Common names of weeds are reported under each vertical bar. Vertical bars represent standard error of the mean

rows although soil water was lower in weedy plots in the second part of crop cycle, at the end of the crop cycle soil water content was equal both in weedy-free plots and weedy plots between rows, 19% dry weight (Fig. 3).

At 30 cm depth in the rainfed treatment about 30 days after transplantation soil water content reached 50% of available water in both weed-free and weedy treatments. Successively soil moisture increased due to rainfall and then decreased below wilting point till the end of crop cycle. Soil water content was similar both in weed-free and weedy treatments both on rows and between rows. In rainfed plots, starting from 60 days after pepper transplantation, soil water content measured by gypsum blocks was equal in weedy and weed free plots because the water uptake by plants caused sensor malfunctioning. At 60 cm depth in rainfed treatment about 30 days after transplantation soil water content reached 50% of available water only in weedy treatments, while in weed free treatments it was near to field capacity. No difference was observed at 60 cm depth in inter row between weed-free and weedy treatments.

These results showed that water availability under weedy conditions was limited only in irrigated conditions in the second part of the pepper cycle. Some authors underlined that measurements of water content in the soil profile under weedy and weed-free conditions did not show differences in soil water content (Young *et al*., 1984; Tollenaar *et al*., 1997), while other authors measured significant reduction in soil water content due to weed presence (Dalley *et al*., 2006; Green *et al*., 1998; Sadeghi *et al*., 2007; Berger *et al*., 2010). Evidently our knowledge of the interaction of pepper and weeds for water is limited. In some cases field trial on crop-weed

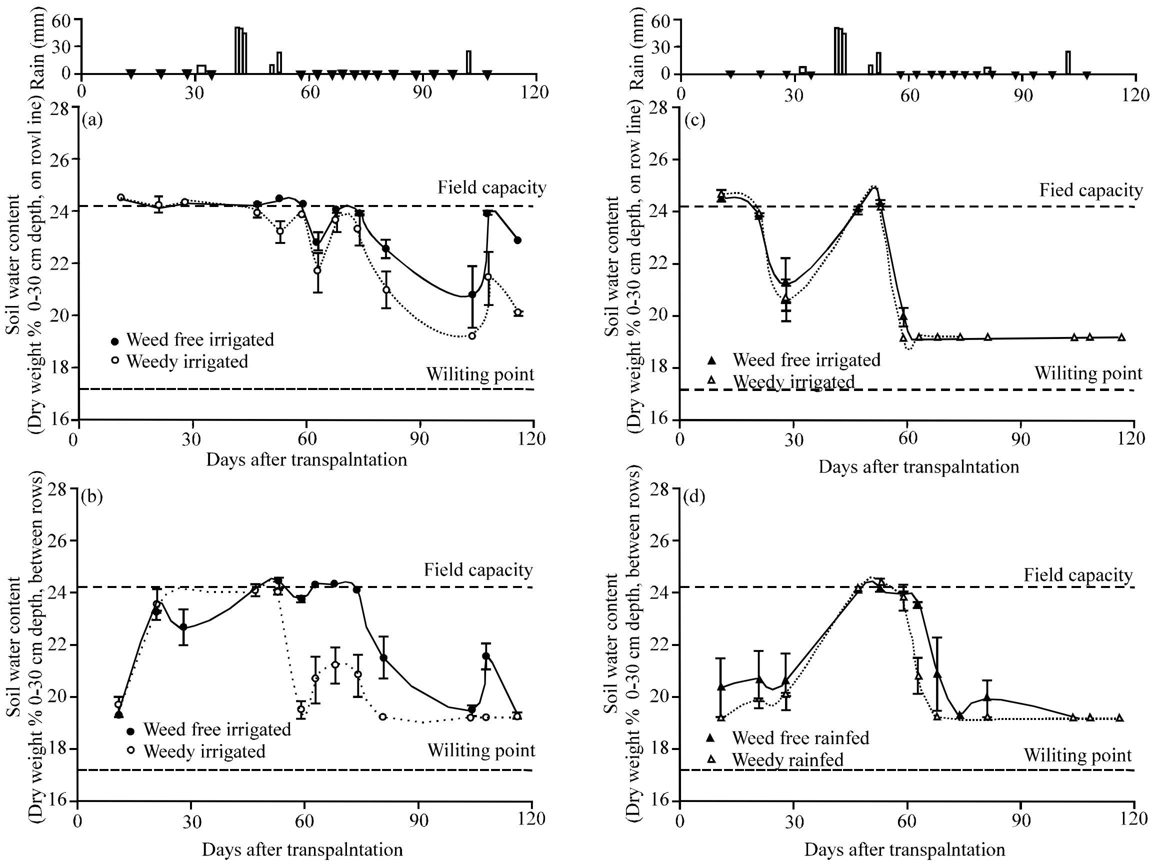

Fig. 3(a-d): Time course of soil water content at 0-30 cm depth measured weekly (weedy plots open symbols, weed-free plots closed symbols), irrigated (a, b) and rainfed treatments (c, d) in 2009. Vertical bars represent standard error of the mean

competition for water have considered only one parameter (i.e., leaf water potential), measured only once during the growing period (Rajcan and Swanton, 2001). Competition for water should be considered as an outcome of the interaction between two dynamic system: The soil-plant-atmosphere system and the crop-weed system, rather than exclusively a reduction of available water (Rajcan and Swanton, 2001). Some authors (Massinga *et al.*, 2003; Berger *et al.*, 2010) put in relation soil water reduction to canopy radiation interception in weedy systems. In this experiment it was also measured reduction of radiation interception by 73% in weedy irrigated plots (data not showed).

There were other papers showed how weedy systems take up more water and deeper in the soil profile compared to weed-free systems but these researches did not report data for canopy development (Dalley *et al.*, 2006; Green *et al.*, 1998).

Table 2: Maximum leaf area index and above-ground dry matter weight measured at pepper harvest in 2008 and 2009

	LAI		DM (g m^{-2})	
Parameters	V0	V100	V0	V100
2008				
Weed-free pepper	0.35	0.73	75.0	325.0
Weedy pepper	0.10	0.39	13.4	42.1
2009				
Weed-free pepper	0.58	1.10	127.0	211.0
Weedy pepper	0.18	0.60	32.3	136.0
LSD				
Year	**	0.2 ($p<0.01$)	ns	
Irrigation	**	0.05 ($p<0.05$)	**	55 ($p<0.01$)
Weed interference	*		**	19 ($p<0.05$)
Year×irrigation	**		*	
Year×weed Interference	**		**	
Irrigation×weed Interference	ns		**	
Year×irrigation×weed Interference	ns		**	

LSD: Represents the least significant difference between means, **Highly significant ($p<0.01$), *Significant ($p<0.05$), ns: Not significani

Growth parameters: Maximum Leaf Area Index was different between the irrigated and rainfed treatments and between weed-free pepper and weedy pepper (Table 2). Leaf expansion was higher in irrigated and weed-free

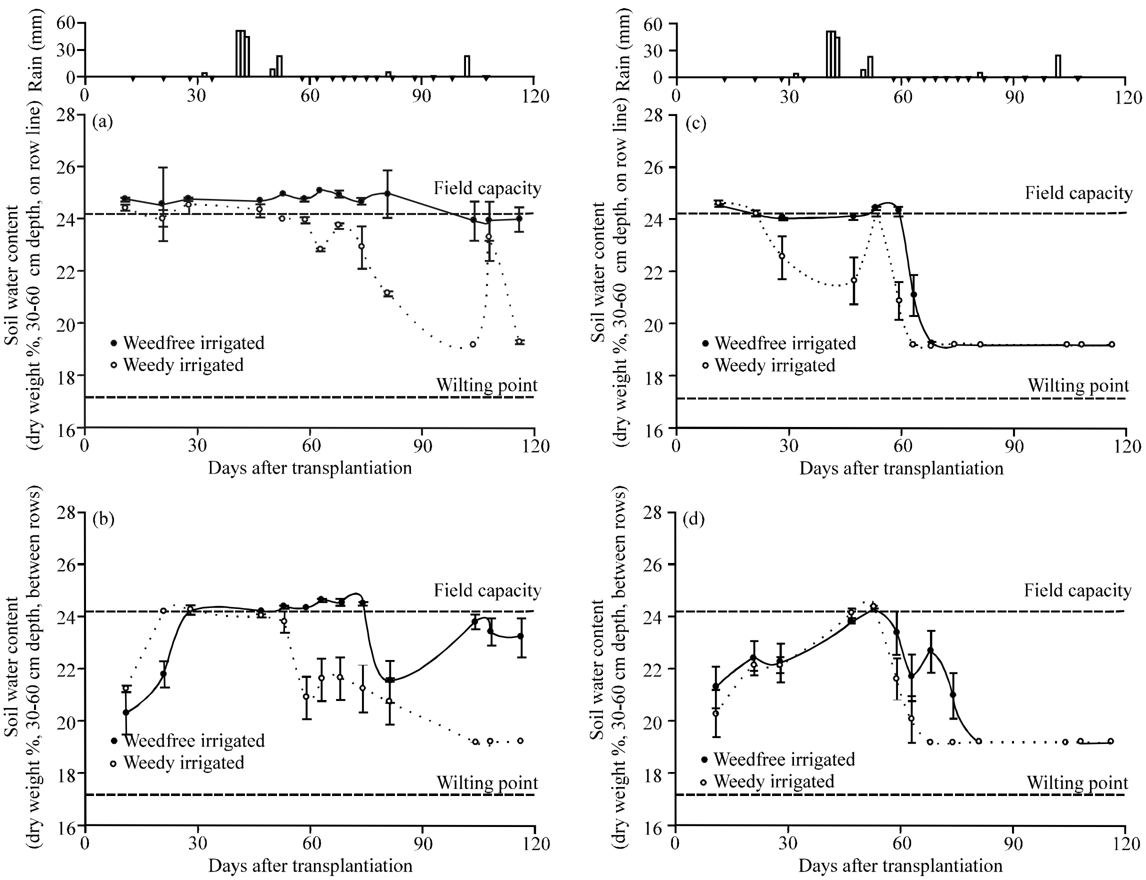

Fig. 4(a-d): Time course of soil water content at 30-60 cm depth measured weekly (weedy plots open symbols, weed-free plots closed symbols), irrigated (a, b) and rainfed treatments (c, d) in 2009. Vertical bars represent standard error of the mean

conditions. Moreover the lack of irrigation and the presence of weeds significantly reduced the growth pepper plants in the rainfed treatment (V0), as indicated by dry matter measurements. Higher dry matter was recorded in weed-free plots in the first year, while it was lower in weedy plots in the first year, 325 and 13.4 g m^{-2}, respectively. Consequently weed presence reduced pepper yield. It was observed differences in productivity in the two years as a consequence of different meteorological trends (Table 3 and Fig. 1). Interaction of irrigation regime and weed interference was highly significant. In 2008 weed-free pepper yield in the irrigated treatment was equal to 36.5 t ha^{-1}, while in the 2009 it was 43.4 t ha^{-1}. Obviously lower yield was obtained in rainfed weedy treatment in both years, 0.2 and 0.5 t ha^{-1}, respectively. Water Use Efficiency (WUE) was influenced by irrigation and weed competition (Table 3). In irrigated plots the presence of weeds had lower influence on soil water depletion especially in first few centimetres of soil but WUE was also reduced (Table 3). Weed-crop competition influences on WUE was due to both impacts on pepper yield and water use. Otherwise Berger *et al.*

Table 3: Yield and water use efficiency measure at pepper harvest in 2008 and 2009

Parameters	Yield (t ha^{-1})		WUE (kg ha^{-3})	
	V0	V100	V0	V100
2008				
Weed-free pepper	1.5	36.5	0.16	0.70
Weedy pepper	0.2	2.7	0.02	0.05
2009				
Weed-free pepper	2.1	43.4	0.09	0.72
Weedy pepper	0.5	11.1	0.02	0.18
LSD				
Year	*	3.3 ($p<0.05$)	*	0.1 ($p<0.05$)
Irrigation	**	8.7 ($p<0.01$)	**	0.03 ($p<0.01$)
Weed interference	**		*	
Year×irrigation	*		*	
Year×weed Interference	ns		ns	
Irrigation×weed Interference	**		ns	
Year×irrigation×weed Interference	ns		ns	

LSD: Represents the least significant difference between means, **Highly significant ($p<0.01$), *Significant ($p<0.05$), ns: Not significani

(2010) observed that competition influences on WUE was driven by yield reduction rather than soil water reduction. The same authors say that in drier condition a more deeper impact on WUE by weeds is expected. It was also showed in another paper that relative crop losses (per weed biomass unit) actually declined as water availability increased (Valerio *et al*., 2013).

CONCLUSION

In semiarid environment on pepper crop it was observed from a single field experiment that different weed populations had a great impact on pepper growth and yield, both in rainfed and irrigated conditions. The experimental data showed that a weed-free agrosystem, especially in a drought condition, is necessary to maximize yield and water use efficiency. Obviously additional researches are needed to confirm these results.

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