Irrigation scenarios for artichokes and dry bean as a result of soil variability on the basis of resistivity mapping in southwest Italy

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Abstract

This work aims at comparing irrigation strategies on the basis of deficit irrigation and soil spatial variability assessed through electrical resistivity mapping (ERM) conducted by an automatic resistivity profiler on-the-go sensor. Profiles chosen along a range of soil electrical resistivity showed different soil properties linked to water holding capacity within a field, with total available water (TAW) values of the coarser-textured zone corresponding to about 50% of TAW in the finer-textured zone within the field. Multi-year weather data were obtained on a daily basis and scenarios were developed for climatic demand conditions representing dry average and wet years. The ISAREG water balance and irrigation scheduling model was afterwards applied to the different soil profiles and with different strategies for full and deficit irrigation, to compute water and irrigation requirements as well as related yield impacts of deficit irrigation for artichokes and dry beans. Deficit irrigation allowed calculated water savings up to about 50% for the winter crop and 33% for the summer crop with yield losses lower than 10%. Irrigation requirements within irrigation strategy were 10 to 44% different between profiles, and this indicates that soil visualization techniques such as ERM can be used for the identification of zones for site-specific irrigation management.

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Introduction

The availability of water for irrigation is a crucial problem (Fereres and Soriano, 2007), especially in Mediterranean regions, linked to unfavourable distribution of precipitation, and to pollution, salinity, seawater intrusion and water prices which have been an issue for a considerable amount of time (Sagardoy and Vermillion, 1999). Water scarce areas need guidelines to determine irrigation schedules that maximize water productivity and farm profitability. Incomplete replenishment of soil water in the profile has been described as an important measure to address water saving, especially in areas where the probability of precipitation during the crop cycle is high (Ritchie and Amato, 1990), and it has henceforth been recognized as a more general tool for increasing water use efficiency by allowing a small amount of water stress (Pereira *et al*., 2002). There is room for further assessment of the appropriateness of deficit irrigation in Mediterranean regions, especially in view of the changing distribution of precipitation linked to recent weather trends and climate change. Precision irrigation is also a potentially important water saving strategy, based on the variability in space of soil properties and crop responses (Ritchie and Amato, 1990). It is based on the identification of differences in soil properties relevant to irrigation. Geo-electrical exploration is based on the measurement of soil electrical resistivity (ER) or its reciprocal, conductivity. ER is a function of multiple soil properties like soil texture, structure, organic matter, water content and root density (Samouelian *et al*., 2005; Rossi *et al*., 2013a). Particles size and especially the content of clay are well correlated with ER across a range of field conditions (Bitella *et al*., 2015). Geo-electrical techniques have been used in the last decade for assisting site-specific management based on soil variability in combination with yield and terrain attributes (Kitchen *et al*., 2005; Rossi *et al*., 2013b).

This work aims at comparing irrigation management strategies based on different degrees of deficit irrigation in different zones within a field in Southern Italy, identified through electrical resistivity mapping (ERM).

Materials and methods

Soil spatial variability of a farm field (7 ha) located at Sicignano (SA, Italy) (approximately 40° 36' 49'' N lat. and 15°18' 07'' E long.) was assessed through ERM, conducted by an automatic resistivity profiler (ARP ©Geocarta, Paris, France) on-the-go sensor with an onboard global positioning system (GPS) up to 200 cm of depth. Data were real-time referenced by the dual GPS, which also provided topographic information to compute a digital elevation model and slope.

The field was divided in six different zones based on ER (Ωm), ranging from <8 (very low) to >45 (high). Soil texture up to 200 cm depth was determined in the U.S. Department of Agriculture framework (Pansu and Gautheyrou, 2003) in each zone on soil samples taken along profiles, which were denoted A1 through A6. Total available water (TAW) was calculated according to Saxton and Rawls (2006) for each profile; then for the whole field, average TAW and weighted TAW were calculated, the latter based on surface area of each of the six zones on the ER maps.

The ISAREG irrigation scheduling model (Teixeira and Pereira, 1992; Pereira *et al*., 2003) was then applied to each soil zone to compute irrigation requirements as well as relative yield decrease (RYD) for different irrigation strategies. Simulations were conducted with one full irrigation and three deficit strategies, which differed in the soil water content at which irrigation was triggered:

- full irrigation (FI), $\theta_{MAD} = \theta_p$;
- light deficit irrigation (LD), $\theta_{MAD} = 90\%\theta_p$;
- moderate deficit irrigation (MD), $\theta_{MAD} = 80\%\theta_p$;
- severe deficit irrigation (SD), $\theta_{MAD} = 65\%\ \theta_p$.

where θ_p = soil water content corresponding to no-stress (yield reduction <0.005 in the model output); θ_{MAD} = management allowed depletion of the profile (soil water content at which the irrigation is triggered).

All irrigation strategies were simulated assuming drip irrigation methods with fixed net irrigation amounts of 20 mm.

Simulations were conducted for two horticultural crops which are commonly grown in the area: artichoke (a winter crop) and dry bean (a summer crop). Crop input data include dates of crop development stages, the corresponding crop coefficients; root depths, crop height, soil water depletion fraction for non stress, and yield response factor were collected from local data sources and FAO irrigation paper no. 56 (Allen *et al*., 1998). For artichoke simulations were run using phenolgical data for the late local variety *Bianco di Pertosa* and the crop cycle was not interrupted at the time of heads harvest for fresh consumption (April-May), but it continued up to flowering (June), to account for the harvest of flowers as a substitute of rennet. Weather input data were based on daily time series for 15 years (1999-2013) provided by the Buccino agrometeorological station included in the Campania region weather station network, and three climate years were identified, representing different annual precipitation (dry, average and wet year).

Results and discussion

Total available water was different among the 6 profiles identified along a gradient of ER, and TAW ranged from 66 to 120 mm over 100 cm depth, and from 121 to 216 mm over 200 cm depth (Table 1). For each of the 6 soil zones and for wet, dry and average years the results of ISAREG simulation scenarios were analysed for each crop separately focusing on the most important simulation outputs: RYD, net irrigation requirements (NIR) and excess irrigation (EXI).

Simulations resulted in different values of model outputs for the different soil profiles (Tables 2 and 3). In artichokes (Table 2) NIR was lowest in A1 (characterized by the highest TAW), In two out of four cases within each climatic year for all strategies and climate year, since the high TAW allowed for a better storage and use of precipitation. The largest NIR value occurred in A3 (a stony profile, characterized by the lowest TAW) for the FI strategy within the dry year. Differences among soil profiles were remarkable: up to 15.3% for the FI strategy and up to 44% for the SD strategy.

For artichoke, the winter crop, the modelling results prescribe a first irrigation in the last week of March. In early varieties head harvest for fresh consumption occurs around or shortly after this date, so they can be managed as rainfed or by just applying a supplementary irrigation. For our late variety heads are collected throughout the month of May and flowers for rennet in June, therefore 200 to 260 mm of irrigation are required to avoid yield losses, and reduction can be limited to less than 10% in a dry year if at least SD strategy is adopted. No EXI was observed in the artichokes crop for all strategies and demand years, given the deep root system of the plant. The relative advantage of deficit strategies in terms of water saving was higher in profiles with high TAW (A1, A2, A6) especially in the wet weather, with savings up to 50% of irrigation water with SD strategy and corresponding yield losses of 8.8% (in A1). In dry year SD allowed to save about 25% (in A3) to 30% (in A2 and A6) of irrigation water with a yield reduction of 6.2% (in A3) to 9.4% (in A2 and A6). Higher water saving with deficit irrigation in rainy years is due to the contribution of precipitation to water stored in the profile and available for use by plants. From the plant side, deficit irrigation is defined as *the application of water below full crop water requirements (evapotranspiration)* (Fereres and Soriano, 2007). From the soil side, it allows only partial replenishing of the soil profile with water at each irrigation, therefore soil total water holding capacity is not reached, and this allows soil water storage and water use by plants and use by plants of at least a part of precipitation and therefore the deficit irrigation it displays its full potential advantages in rainy years (Ritchie and Amato, 1990) with the minimum effects on yield decrease due to the fact that evapotranspiration is met at least partly by rainfall (Fereres and Soriano, 2007). In full irrigation strategies, precipitation has a lower chance to find the soil profile partially dry, therefore rainfall has a higher chance of not being retained and not contributing to plant growth.

For dry bean (Table 3) there were differences among the soil profiles, in NIR and EXI, for all strategies and especially SD, and over all climatic years (dry, average and wet). The difference in NIR when evaluated among soil profiles ranged from 10% between A5 and A3 to 25% between A1 and A3. For high TAW profiles in the wet year NIR was about 14-18% lower than for dry and average years. Water saving due to

Table 1. Soil particle size distribution in six profiles chosen along a range of soil electrical resistivity in a farm field at Buccino (SA).

Soil profiles	Coarse fragments >2 mm (%)	Fine earth <2 mm		
		Sand (%)	Silt (%)	Clay (%)
A1	-	27	26	47
A2	-	32	19	49
A3	50%	48	2	50
A4	-	52	22	26
A5	-	31	22	47
A6	-	33	16	51

deficit irrigation ranged between 19.3% (A3) and 33.3% (A6) both in the wet year, and was not strongly affected by the year precipitation amount since dry bean is a summer crop and even in the wet year most precipitation did not occur during the crop cycle. Simulation results showed an excess irrigation in dry bean with all strategies, especially for the A3 soil profile, which had a higher amount of coarse fragments (>2 mm) and therefore low TAW (65.83 mm). Water losses from excess irrigation occurred early in the crop cycle due to the assumption that most of the root system in the first growth stage is concentrated in the top 20 cm, to the use of a fixed irrigation amount of 20 mm. The problem can be minimized by reducing the irrigation amount at the beginning of the crop cycle and/or applying deficit irrigation. The SD strategy resulted in RYD lower than 8%, for all profiles and the minimum level of excess irrigation, which was <60 mm for all profiles except A3 (characterized by lowest TAW). Fereres and Soriano (2007) discuss the occurrence of excess irrigation linked to deficit irrigation mainly in terms of insufficient irrigation system's uniformity, and this adds a further dimension to the issue.

Conclusions

Modelling suggests that severe deficit irrigation may be recommended in the case study, where simulations were conducted, both for artichoke and dry bean, with water savings up to about 50% for the winter crop and 33% for the summer crop with yield losses lower than 10% in all soil profiles and climatic years. Also, deficit irrigation reduced water losses due to excess irrigation in the initial stages of dry bean, the shallow-rooted crop. Advantages of deficit strategies are more pronounced in periods when precipitation may occur and replenish the profile.

Soil zones with different properties related to irrigation management were identified along a range of electrical resistivity values. Irrigation requirements within irrigation strategy were 10 to 44% different between profiles, and this indicates that site-specific irrigation strategies can achieve considerable water savings. Differences between profiles were higher with deficit irrigation and in wet years. Results suggest that modelling can indicate areas of further research on deficit irrigation

Table 2. ISAREG model simulation outputs for artichoke.

	Year	Dry				Average				Wet			
	Strategy	FI	LD	MD	SD	FI	LD	MD	SD	FI	LD	MD	SD
RYD	A1	0	0.009	0.021	0.095	0	0.011	0.019	0.099	0	0.009	0.016	0.088
	A2	0	0.008	0.017	0.092	0	0.007	0.019	0.081	0	0.01	0.017	0.075
	A3	0	0.008	0.017	0.062	0	0.013	0.017	0.082	0	0.011	0.018	0.085
	A4	0	0.006	0.014	0.073	0	0.01	0.014	0.074	0	0.008	0.012	0.065
	A5	0	0.006	0.014	0.073	0	0.01	0.014	0.073	0	0.007	0.012	0.073
	A6	0	0.009	0.014	0.094	0	0.007	0.021	0.086	0	0.005	0.017	0.071
NIR	A1	220	220	200	160	220	180	180	120	200	160	160	100
	A2	240	220	220	160	220	200	180	140	220	160	160	120
	A3	260	240	220	200	220	200	200	160	220	200	200	140
	A4	240	240	240	180	240	200	200	160	220	200	200	140
	A5	240	240	240	180	240	200	200	160	220	200	200	180
	A6	240	220	220	160	220	200	180	140	220	200	160	120

FI, full irrigation; LD, light deficit irrigation; MD, moderate deficit irrigation; SD, severe deficit irrigation; RYD, relative yield decrease (w:w); NIR, net irrigation requirement (mm).

Table 3. ISAREG model simulation outputs for dry bean.

	Year	Dry				Average				Wet			
	Strategy	FI	LD	MD	SD	FI	LD	MD	SD	FI	LD	MD	SD
RYD	A1	0	0.011	0.032	0.082	0	0.008	0.019	0.033	0	0.01	0.006	0.042
	A2	0	0.011	0.028	0.078	0	0.008	0.015	0.036	0	0.01	0.006	0.043
	A3	0	0.006	0.019	0.059	0	0.006	0.01	0.026	0	0.006	0.012	0.035
	A4	0	0.01	0.025	0.068	0	0.008	0.016	0.038	0	0.009	0.006	0.036
	A5	0	0.01	0.026	0.069	0	0.008	0.016	0.043	0	0.01	0.022	0.041
	A6	0	0.01	0.029	0.078	0	0.008	0.018	0.037	0	0.01	0.006	0.05
NIR	A1	840	760	680	580	840	760	680	600	720	640	720	500
	A2	800	720	660	560	800	720	660	560	680	620	680	480
	A3	700	680	620	560	740	680	620	580	620	560	540	500
	A4	800	740	680	580	820	740	660	580	700	620	700	500
	A5	880	800	720	620	880	800	720	620	740	660	620	520
	A6	840	780	700	580	860	760	700	600	720	640	720	480
EXI	A1	189	137.9	96.1	41.7	220.6	160	114.5	59	173	119.1	172.9	53
	A2	163	110.9	74.1	26.7	190.4	133	90	43.6	155	104.2	154.7	43.8
	A3	206	179.8	140.5	110.1	247.9	180	173.2	136.2	200	161	140.6	105.3
	A4	176	121.5	86.1	38.7	203.3	146	103.4	52.8	168	116.4	167.6	46.4
	A5	222	164.2	116.1	63.1	255.6	191	140.7	81.9	201	145	114	61.5
	A6	204	152.5	101.3	51	238.6	172	129.5	69.7	184	131.7	183.7	53

FI, full irrigation; LD, light deficit irrigation; MD, moderate deficit irrigation; SD, severe deficit irrigation; RYD, relative yield decrease (w:w); NIR, net irrigation requirement (mm); EXI, excess irrigation (mm) in dry, average and wet year.

strategies for Mediterranean crops and electrical resistivity mapping can be an effective tool for exploring irrigation strategies.

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