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 management strategies based on soil variability in combination with yield and terrain attributes (Bitella et al., 2015). Geo-electrical techniques have been used in the last decade for assisting site-specific management 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. Precise 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).

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).

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 Gauchetrou, 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), \( \theta_{MD} = \theta_s \);
- light deficit irrigation (LD), \( \theta_{MD} = 90\% \theta_s \);
- moderate deficit irrigation (MD), \( \theta_{MD} = 80\% \theta_s \);
- severe deficit irrigation (SD), \( \theta_{MD} = 65\% \theta_s \),

where \( \theta_s \) = soil water content corresponding to no-stress (yield reduction <0.005 in the model output); \( \theta_{MD} \) = 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 phenological data for the local field 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 only allows 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 (%) | Sand (%) | Fine earth <2 mm | 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       |
Table 2. ISAREG model simulation outputs for artichoke.

| Year | Strategy | Dry | Average | Wet |
|------|----------|-----|---------|-----|
|      |          | 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 | 0.017 | 0.081 | 0 | 0.01 | 0.017 | 0.075 |
| A3   |          | 0   | 0.008   | 0.017 | 0.092 | 0 | 0.013 | 0.017 | 0.082 | 0 | 0.011 | 0.018 | 0.065 |
| A4   |          | 0   | 0.006   | 0.014 | 0.073 | 0 | 0.013 | 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     | 200  | 160 | 220 | 200 | 180 | 140 | 220 | 160 | 160 | 120 |
| A3   |          | 260 | 240     | 200  | 160 | 220 | 200 | 200 | 160 | 220 | 200 | 200 | 140 |
| A4   |          | 240 | 240     | 200  | 160 | 240 | 200 | 200 | 160 | 220 | 200 | 200 | 140 |
| A5   |          | 240 | 240     | 200  | 160 | 240 | 200 | 200 | 160 | 220 | 200 | 200 | 180 |
| A6   |          | 240 | 220     | 200  | 160 | 220 | 200 | 180 | 140 | 220 | 200 | 160 | 120 |

Table 3. ISAREG model simulation outputs for dry bean.

| Year | Strategy | Dry | Average | Wet |
|------|----------|-----|---------|-----|
|      |          | 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   | 0.023 | 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 | 0.016 | 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 | 0.065 |
| **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 | 160 | 114.5 | 59 | 173 | 119.1 | 172.9 | 53 |
| A2   |          | 163 | 110.9   | 74.1 | 26.7 | 190 | 133 | 90 | 43.6 | 155 | 104.2 | 154.7 | 43.8 |
| A3   |          | 206 | 179.8   | 140.5 | 110.1 | 247 | 180 | 173.2 | 136.2 | 200 | 161 | 140.6 | 105.3 |
| A4   |          | 176 | 121.5   | 86.1 | 38.7 | 203 | 146 | 103.4 | 52.8 | 168 | 116.4 | 167.6 | 46.4 |
| A5   |          | 222 | 164.2   | 116.1 | 63.1 | 255 | 191 | 140.7 | 81.9 | 201 | 145 | 114 | 61.5 |
| A6   |          | 204 | 152.5   | 101.3 | 51 | 238 | 172 | 129.5 | 69.7 | 184 | 131.7 | 183.7 | 53 |

**Fluctuations:** 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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