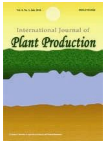

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Yield and water use efficiency of early potato grown under different irrigation regimes

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Abstract

Potato grown for early or off-season production plays a crucial role in the economy of several areas in the Mediterranean countries. Irrigation is important for determining yield and earliness, thus a better investigation of plant response under various pedo-climatic conditions can help to improve resource use efficiency and farmer income. A two-year field research (2009-2010) was carried out in Apulia region, southern Italy, on cv Spunta grown under three irrigation regimes: full irrigation (I_{100}), 50% of full irrigation (I_{50}) and rainfed (I_0). Treatments were arranged in a randomized complete block design with three replicates. Plant water status, plant growth and, at harvesting, water use efficiency, yield and quality parameters were quantified. Water stress significantly affected yield response: as an average of the two years, a marketable yield decrement of 25.9 and 63.6% was observed in I_{50} and rainfed compared with I_{100} treatment, respectively. On the contrary, tuber dry matter and specific gravity increased moving from irrigated treatments to the rainfed one and varied also as a function of experimental year. The results confirmed that irrigation is required for early potato cultivation because rainfall is not sufficient to meet crop water needs. In addition, the study indicated that the irrigation regime reduced by 50% of crop water requirements was able to furnish satisfactory yield, with tuber quality characteristics similar or even better than those obtained under full irrigation.

Keywords: *Solanum tuberosum* L.; Mediterranean climate; Leaf water potential; Deficit irrigation; Yield components; Tuber quality.

Introduction

After wheat, rice and corn, potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world (Fabeiro et al., 2001; Calabrese, 2011). In the Mediterranean Basin, potato occupies an overall area of about one million ha and produces 32 million Mg of tubers (FAO, 2012).

In many Mediterranean countries potato is not grown in the usual cycle (spring–summer) owing to the high temperatures and considerable demand for water, but, is mainly grown as off season crop (early potato), planted from December (warmer environments) to March (cooler environments) and harvested from March to June (Ierna, 2009). The climatic conditions during this period, characterized by short photoperiod, limited solar radiation and relatively low average temperatures, modify in a substantial way the morphological and phenological characteristics of the crop with respect to that cultivated in the spring-summer cycle.

Early potato is defined as “potato harvested before it is completely mature, marketed immediately after harvesting and whose skin can be easily removed without peeling” (UNECE, 2006). The off-season production has high economic value because tubers are usually exported to Northern European markets with high profits.

Abiotic stress factors, such as drought, have severe, adverse effects on potato growth and yield (Levy et al., 2013). In particular, a regular water supply is necessary to achieve a high quality yield (Ierna et al., 2011; Levy et al., 2013).

In comparison with other species, potato is very sensitive to water stress because of its shallow root system: approximately 85% of the root length is concentrated in the upper 0.3-0.4 m of the soil (Opena and Porter, 1999; Wang et al., 2006; Iwama, 2008). To obtain high yields the soil water content should not be lower than 50% of total available water in the root zone, especially during tuber formation, although other authors suggest threshold values of 25 or 75% (Schapendonk et al., 1989; Bertolacci et al., 1990; Foti et al., 1995). These differences can be explained by climatic, plant and soil characteristics variations (van Loon, 1981).

Plant response to water stress can be very different among cultivars (Hassanpanah, 2010), as a function of stress occurrence period (Kashyap and Panda, 2003). Among growth stages, early development phase, as compared with tuber formation and flowering, has been shown to be the most sensitive to water stress, hence the most responsive to irrigation.

Potato grown for early production is also particularly sensitive to water shortage, which adversely influences not only yields but also earliness (Foti, 1999; Ierna and Mauromicale, 2012). Water shortage during tuber differentiation can delay growth and reduce earliness, whereas during tuber growth and bulking can decrease tuber size and have a drastic effect on yield (Jefferies and MacKerron, 1993). In arid and semi-arid areas, early potato growing cycle is often subjected to long periods of drought and its cultivation usually requires irrigation throughout the spring during the stage of tuber bulking and growth (Ierna et al., 2011).

Considering the importance of early potato in the economy of several areas in the Mediterranean countries and the crucial role of irrigation in its production for determining yield and earliness, a greater attention should be paid to the optimization of irrigation management practices in different pedo-climatic conditions typical of the main growing areas (Fabeiro et al., 2001; Ierna and Mauromicale, 2006; Ierna et al., 2011). Among them Apulia region (southern Italy) is an important growing area significantly contributing to make available the off season production to Northern European markets (Marzi and Calabrese, 2011; Mauromicale, 2011).

From that already reported, our hypothesis is that a water regime under deficit conditions can improve water use efficiency, by allowing water saving and by maintaining a good level of both yield and quality of tubers. Thus, in order to verify it, the present study investigated the effect of irrigation management on water use efficiency, tuber yield and quality parameters of early potato grown in Apulia region.

Materials and Methods

Experimental site and weather conditions

A two-year research was carried out in Valenzano (Bari) (41° 03’ N, 16° 52’ E and altitude 72 m a.s.l.) at the experimental field of the Mediterranean Agronomic Institute (IAMB) during 2009 and 2010. The climate is typically Mediterranean, characterized by 30-year average annual rainfall of 523 mm mostly concentrated in autumn and winter months. Mean monthly air temperature ranges between 8 °C in January and 24.3 °C in July and August. Average 30-year annual “class A” pan evaporation is 1306 mm with a peak value in July of 227.8 mm month^{-1}. The main weather parameters, including solar radiation, air temperature, relative humidity, "class A" pan evaporation and precipitation, were collected from a standard agro-meteorological station located about 300 m from the experimental field. The soil, 0.5-0.6 m deep, is a sandy clay loam and defined as Lithic-Ruptic-Inceptic-Haploxeralfs (USDA, 2006). Chemical and physical characteristics of the soil at the beginning of the experiments (March 2009) were: pH 7.83 (1:2.5 soil/water extract), Kjeldahl total N 1.2 g kg^{-1}, Olsen extractable P 14.4 mg kg^{-1}, ammonium acetate extractable K 229 mg kg^{-1}, organic C 10.5 g kg^{-1}, total carbonate 81.9 g kg^{-1}, electrical conductivity (EC), on 1:2 soil/water extract, 0.28 dS m^{-1}, bulk density 1.3 kg dm^{-3}, the soil water content at field capacity and at permanent wilting point was 31 and 16% (v/v), respectively.

Crop management, experimental design and irrigation treatments

Potato (*Solanum tuberosum* L.) cv Spunta was grown under three irrigation regimes: I_{100}, I_{50}, I_0, corresponding respectively to full irrigation, 50% of full irrigation and rainfed. 'Spunta' is one of the most widely cultivated cultivar in the Mediterranean region (Ierna, 2010). 'Spunta' is a potato, with long, regular and very large tubers and it performs well in both spring and autumn seasons.

Treatments were arranged in a randomized complete block design with three replicates. Potato was planted on 17^{th} and 03^{rd} of March on 2009 and 2010 respectively, with a distance of 0.8 m between rows and 0.25 m between plants (5 plants m^{-2}). In the first year, the delay of the planting was determined by the heavy rainfall that occurred in the period between the end of February and mid-March. The main details of the experiments are reported in Table 1.

Irrigation was managed using an Excel-based irrigation tool (Todorovic, 2006) that employs meteorological, soil and crop data for a day-by-day estimation of the soil water balance in the effective root zone. Reference evapotranspiration (ET_o) was calculated on a daily basis from measured weather data using the FAO Penman–Monteith equation (Allen et al., 1998). The K_c values were determined on the basis of in-field observations of crop phenological stages and using the FAO 56 data (Allen et al., 1998). K_c values were fixed at 0.5, 1.15 and 0.75 respectively for the initial crop growth stages (up to the beginning of stem elongation), the crop development stage and mid-season (since stem elongation until flowering), the late season stage (maturity). Maximum root depth was fixed at 0.5 m. Crop evapotranspiration (ET_c) was estimated as the product of ET_o and K_c.

Table 1. Experimental details and dates of the main phenological stages for potato during the 2 years of experiment. In brackets, the days after planting (DAP) are reported.

Phenological stages	2009	2010
Planting	17 March	3 March
Emergence	6 April (20)	27 March (24)
Main stem elongation	24 April (38)	15 April (43)
Tuber initiation	8 May (52)	26 April (54)
Flowering	25 May (69)	12 May (70)
Maturity	14 June (89)	8 June (97)
Harvesting	10 July (115)	19 June (109)
Seasonal irrigation supply (mm)		
I_0	0	0
I_{50}	165	119
I_{100}	330	237
ET_c (mm)		
I_0	175	161
I_{50}	295	261
I_{100}	419	348
ET_o (PM*) (mm d^{-1})	4.1	3.5

* Penman-Monteith.

The allowable water depletion was assumed to be 0.55 of total available water (p=0.55) during the whole growing cycle, as suggested in FAO 56 (Allen et al., 1998).

When the water content in the root zone dropped below the threshold (p), ET_c was adjusted for water stress through a dimensionless reduction coefficient (K_s), depending on the level of depletion (0-1) of water below the threshold (Allen et al., 1998).

Runoff and capillary rise were assumed negligible due to karstic soil features and very deep soil water table, while deep percolation, caused by excessive precipitation and/or irrigation, was calculated as the surplus of water over field capacity in the root zone. The gravimetric method, based on the conventional oven-dry weight and multiplied by the bulk density (Qiu et al., 2001), was used during each growing season to measure the soil water content in the root zone and to make eventual adjustments of soil water content estimated by the model. Soil samples were collected at three points of the central zone of each plot at two-soil depths (0.10-0.30 and 0.30-0.50 m) after removing the top soil.

To ensure uniform water distribution, drip irrigation was used with one emitter line per row and drippers with 1.5 L h^{-1} flow rate, 0.2 m apart. A flow-meter, one for each irrigation treatment, was placed on the main lines of the experimental field to accurately measure the amount of water supplied at each irrigation event.

Plant water status and growth measurements

Leaf water potential was measured at predawn and midday on three fully-expanded and well-exposed leaves per plot by Scholander pressure chamber (Mod. 3000, Soil Moisture Equipment Corp., Santa Barbara, CA, USA).

The percentage of canopy ground cover (CGC) was measured during the whole growing cycle elaborating the photo images taken each two weeks over each plot on a fixed surface of 0.64 m^2.

At the end of the season, 18 plants per plot (on 3.6 m^2 ground surface) were individually hand harvested and separated into above-ground biomass (stems and leaves), roots, stolons and tubers, in order to measure fresh and dry biomass of each plant fraction. Dry biomass was determined by oven drying samples at 65 °C until constant weight was reached. Harvest index (HI) was calculated as the ratio of dry matter partitioned into tubers relative to the total plant biomass.

Yield and quality measurements

Harvest was carried out on July 10 in 2009 and June 19 in 2010 (Table 1). On the same samples used for dry matter determination, collected in the middle part of each plot, yield components and quality parameters were measured. Tubers were hand harvested, counted and weighed to determine total yield, number and average tuber weight. Deformed and diseased tubers and tubers that weighted <20 g were counted, weighted and classified as discarded tubers. Remaining tubers, classified as marketable tubers, were then selected by diameter classes (<35 mm - undersized: 35-70 mm - intermediate; >70 mm - oversized), counted and weighed.

Specific gravity of potato tubers was determined on a sample of 4 marketable tubers. The percentage of tuber dry matter was determined on the same 4 tubers used for specific gravity measurement. Each tuber was longitudinally divided in two halves; one part of them was sliced in 10 mm wide strips of differing lengths and put in oven at 65 °C up to reach a constant weight (AOAC, 2005). The source/sink ratio was determined by dividing plant dry weight by tuber dry weight; it gives an indication on the transfer efficiency of carbohydrates from the leaves to the tubers. The biomass water use efficiency (B_WUE) and the yield water use efficiency (Y_WUE) were calculated, respectively, as the ratio of the above dry biomass and marketable yield to the seasonal crop evapotranspiration.

Statistical analysis

Collected data were analysed according to a randomized complete block design. Each dependent variable was preliminary evaluated for normal distribution according to Shapiro-Wilk's test.

Combined analyses were run over 2009 and 2010, after verifying the homogeneity of error variances using Bartlett's chi-square test (Gomez and Gomez, 1984). Year was considered as a random effect.

Statistical analyses were performed through the GLM procedure of SAS/STAT. Least significant difference (LSD) at 0.05 probability level was used as mean separation test.

Results

Weather conditions and plant water status

The weather regime, in terms of maximum (T_{max}) and minimum air temperature (T_{min}), reference evapotranspiration (ET_o) and rainfall, during the two experimental years is shown in Figure 1.

The 2009 growing season was characterized by warmer and more rainy conditions than 2010: mean air temperature was 1.9 °C higher and the rainfall was 54% greater (272 mm), as compared with 2010 (177 mm). Average reference evapotranspiration (ET_o) during 2009 was 0.5 mm day^{-1} higher than in 2010.

In 2010, rainfall was distributed more regularly during the most sensitive phenological stages to water stress: in 2010, rainfall occurred during tuber initiation and flowering stages (Table 1) was 53.7% higher than that occurred in the same phenological stages during 2009. The rainfall distribution during the growing season greatly affected the behaviour and the response of crop to water deficit. Indeed, the more favourable rainfall pattern observed in 2010 implied lower irrigation requirements during this year, as compared with 2009 (Table 1).

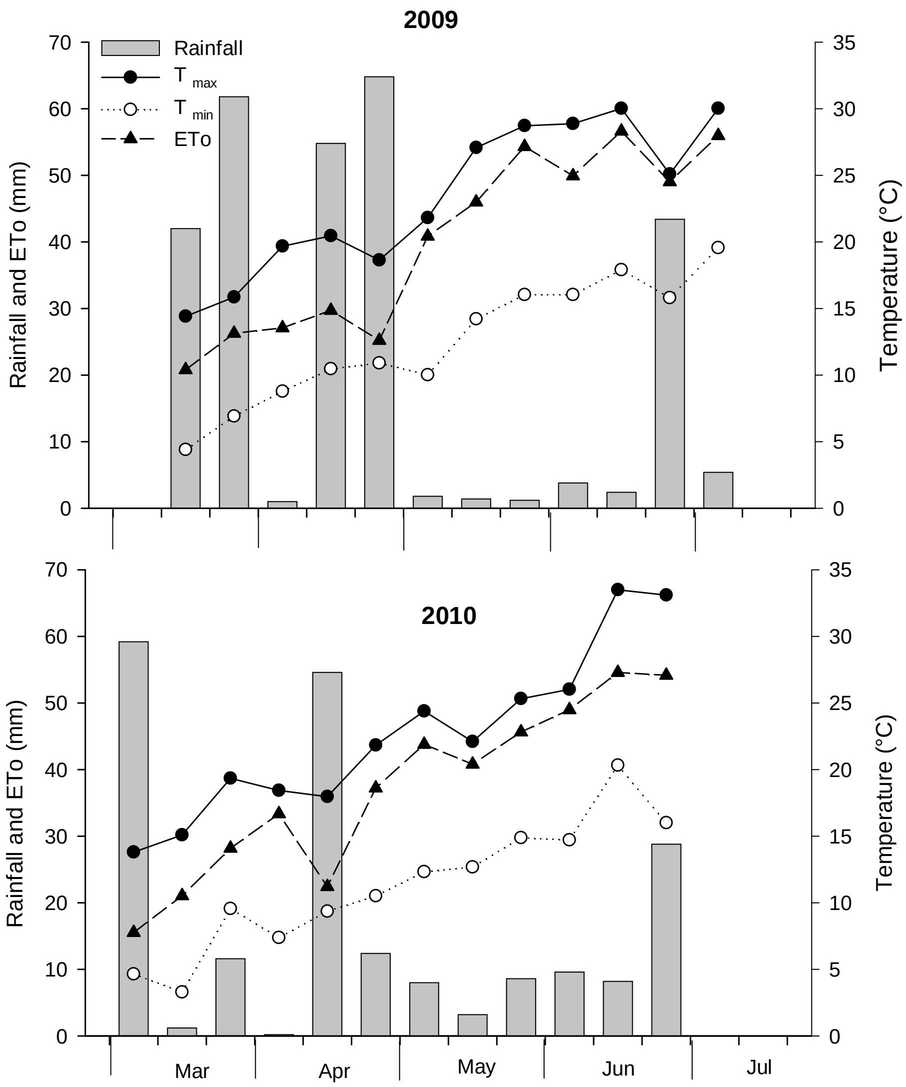

Figure 1. 10-days total rainfall and reference evapotranspiration (ET_o) and 10-days average minimum (T_{min}) and maximum (T_{max}) air temperature during the two experimental years.

Because of late sowing in 2009, the phenological stages of potato were delayed as compared with 2010 along the whole crop cycle (Table 1). As a consequence of the above described rainfall regime, the pre-dawn leaf water potential of the three water treatments varied in 2010 in a strict range between -0.13 and -0.24 MPa from 44 until 71 DAP, corresponding to the most sensitive phenological stages (stolon initiation, tuber initiation until the beginning of flowering) to water stress (Quiroz et al., 2012). Only at the end of the crop cycle the rainfed (I_0) treatment dropped down to -0.37 MPa (Figure 2a). On the contrary, in 2009 the three treatments had very different pre-dawn leaf water potential values, since the tuber initiation stage (60 DAP). Similar behaviour was found in terms of midday leaf water potential (Figure 2b), indicating that in 2009 both I_0 and I_{50} treatments experienced more severe stress conditions, as compared with 2010. In both years, midday leaf water potential strongly decreased at the end of the season in rainfed treatment, up to reach values of -0.87 and -0.81 MPa in 2009 and 2010, respectively. Midday leaf water potential values recorded during the last phenological stages indicate that potato experienced very severe water stress conditions, as values of about -0.35 MPa are indicative of stress conditions in this crop (van Loon, 1981).

Soil water depletion trend (Figure 2c) was in agreement with plant response to water stress, showing a narrower range of variation among the irrigation treatments during the whole crop cycle in 2010 with respect to 2009. In the latter year at 83 DAP, soil water depletion of I_0 treatment reached 90 mm as compared with about 36 mm in 2010.

Crop evapotranspiration over the whole season amounted to 419, 295 and 175 mm in 2009 and 348, 261 and 161 mm in 2010, for I_{100}, I_{50} and I_0 treatments, respectively. Irrigated plants were kept under optimal water conditions during the whole season, with irrigation maintaining root zone soil water content above allowable depletion threshold and returning soil water content back to field capacity. Potato was irrigated 9 and 8 times in 2009 and 2010 respectively, with total irrigation input of 165 (I_{50}) and 330 mm (I_{100}) in 2009 and 119 (I_{50}) and 237 mm (I_{100}) in 2010 (Table 1).

Growth, yield and quality parameters

The variation of canopy ground cover (CGC) during the season is shown in Figure 3.

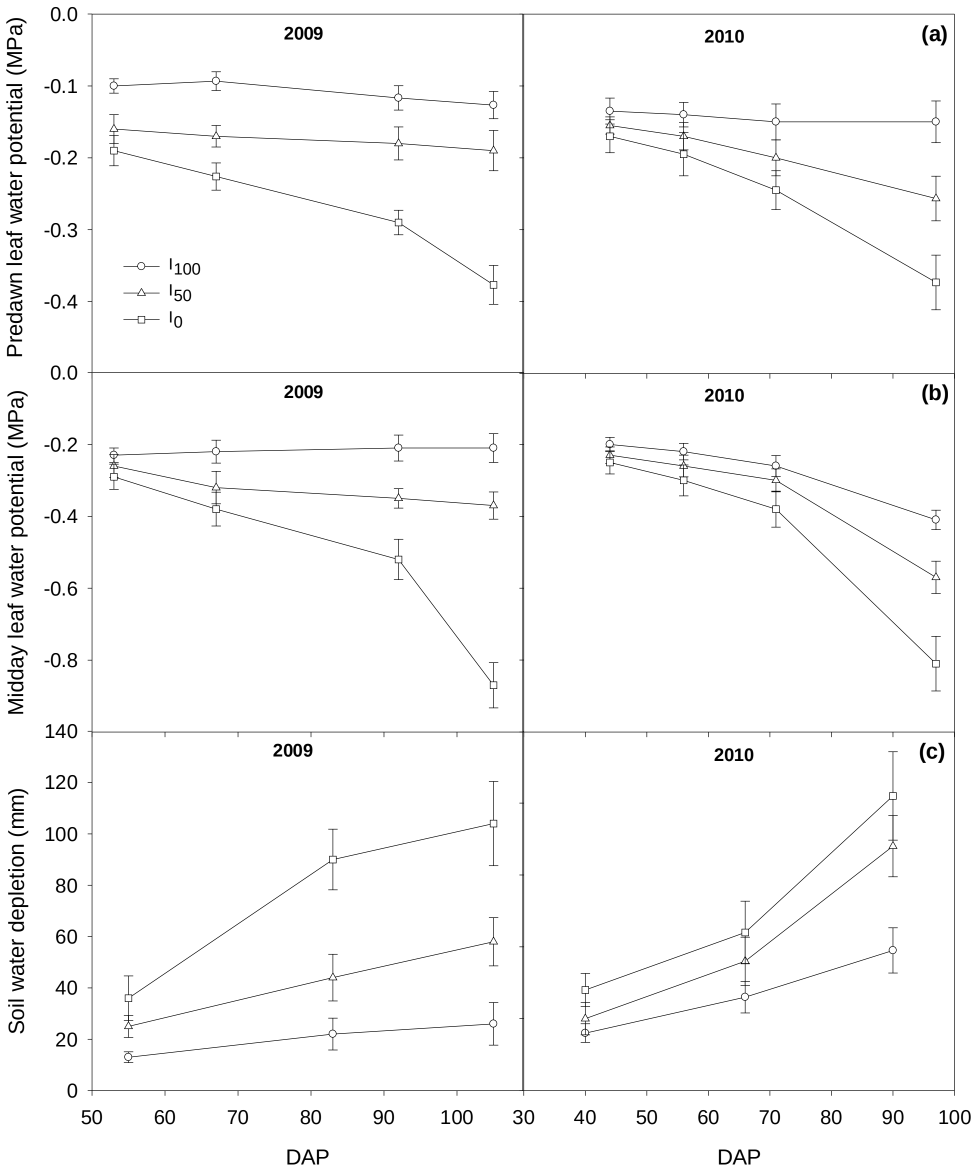

Figure 2. Predawn, midday leaf water potential and soil water depletion under different water regimes during the two experimental years. DAP=days after planting.

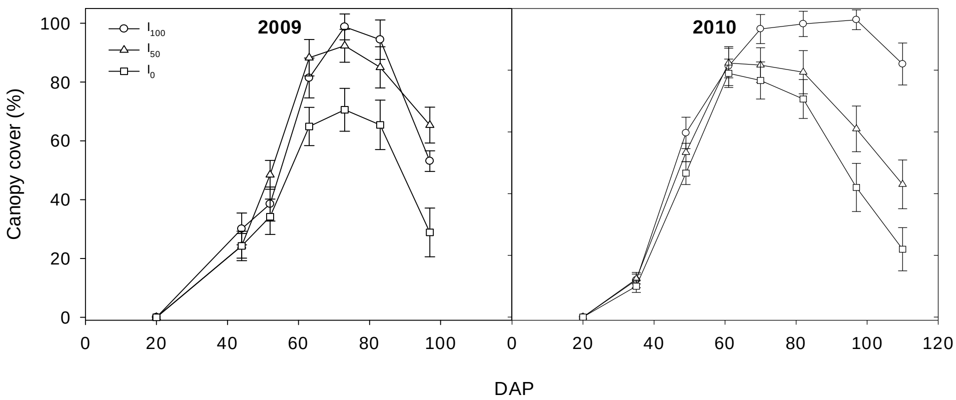

Figure 3. Canopy ground cover (CGC) under different water regimes during the two experimental years. DAP=days after planting.

In 2009, CGC showed similar values among treatments up to the third irrigation (59 DAP). The highest values were observed at 73 DAP for I_{100} and I_{50} (99 and 92%, respectively) and they were statistically different as compared with the rainfed treatment (70%).

In 2010, CGC steeply increased after emergence and no important differences among treatments were observed until flowering stage (70 DAP). After that, I_{100} reached 97%, while I_{50} and I_0 treatments started to decrease. The peak values were 82 and 77%, respectively for I_{50} and I_0 treatment, occurring at flowering stage.

Tables 2 and 3 report the analysis of variance results for the main examined variables. Overall yield response was significantly affected by irrigation regimes. Quality parameters (specific gravity, tuber dry matter) were instead mainly influenced by the experimental year.

Over the 2009-2010 period, aboveground biomass and total tuber yield were significantly affected by irrigation regime (Tables 2 and 3). Fully irrigated plants gave higher biomass (159.2 g m^{-2}) and greater total yield (44.9 Mg ha^{-1}) than I_{50} (133.5 g m^{-2} and 34.3 Mg ha^{-1}) and rainfed (69.9 g m^{-2} and 16.5 Mg ha^{-1}) treatment (Table 2).

Marketable yield varied significantly in relation to water availability: the highest tuber yield was recorded in I_{100} (40.9 Mg ha^{-1}), although it was not significantly different from I_{50} (30.3 Mg ha^{-1}). The lowest value was recorded in I_0 treatment (14.9 Mg ha^{-1}).

The significant effect of irrigation regime on tuber yield was mainly due to the average tuber weight (Table 2), because the differences in the number of tubers per unit surface were not significant (average values of 35.2 and 30.1 number m^{-2}, for total and marketable yield, respectively).

Table 2. Yield and tuber quality parameters as affected by year and water regime.

Source of variation	Total Yield		Marketable Yield		Tuber dry matter	Specific gravity
	(Mg ha^{-1})	(number m^{-2})	(Mg ha^{-1})	(number m^{-2})	(g 100 g^{-1})	(g cm^{-3})
Year (Y)	ns	ns	ns	ns	***	***
2009	32.03	35.70	29.09	30.54	20.25[b]	1.07[b]
2010	31.75	34.67	28.25	29.76	23.15[a]	1.09[a]
Water Regime (WR)	*	ns	*	ns	*	ns
I_0	16.53[c]	31.20	14.88[b]	27.50	23.13[a]	1.09
I_{50}	34.29[b]	33.05	30.27[a]	26.64	21.82[a]	1.08
I_{100}	44.85[a]	41.31	40.87[a]	36.30	20.13[b]	1.07
Y×WR	ns	ns	ns	0.08	ns	**

*, **, *** indicate respectively differences at P≤0.05, P≤0.01 and P≤0.001; ns indicates not significant difference.
Means followed by the same letter in each column are not significantly different according to the LSD test (P≤0.05).

Table 3. Above ground biomass (AGB), harvest index (HI), source/sink ratio and biomass and yield water use efficiency (B_WUE and Y_WUE) as affected by year and water regime.

Source of variation	Dry AGB	HI	Source/sink ratio	B_WUE	Y_WUE
	(g m^{-2})			(kg m^{-3})	
Year (Y)	ns	ns	ns	ns	ns
2009	116.82	0.84	0.191	0.39	9.30
2010	124.87	0.85	0.171	0.48	10.95
Water Regime (WR)	**	ns	ns	ns	ns
I_0	69.86[c]	0.85	0.184	0.42	9.02
I_{50}	133.51[b]	0.85	0.183	0.47	10.63
I_{100}	159.17[a]	0.85	0.177	0.42	10.73
Y×WR	ns	ns	ns	ns	ns

** indicates differences at P≤0.01; ns indicates not significant difference.
Means followed by the same letter in each column are not significantly different according to the LSD test (P≤0.05).

Numbers and weights of marketable tubers, expressed as percentage per diameter (Ø) class (from 35 to 70 mm -intermediate; under 35 mm -undersized; over 70 mm -oversized), under different irrigation regimes, are reported in Figure 4 for each experimental year.

In general, a greater percentage of undersized tubers, as regards both the number and the weight, was observed in I_0 (average values of about 45 and 14% for number and weight, respectively) in comparison with the irrigated treatments (average values of about 15 and 5% for number and weight, respectively). Oversized tubers were almost absent in I_0, while in irrigated treatments they reached average values of 8 and 17%, respectively for the number and the weight. The highest percentage of tubers was located in the intermediate class. In addition, within this class, I_0 treatment showed a lower percentage of tubers in terms of number, whereas a slightly greater percentage in terms of weight.

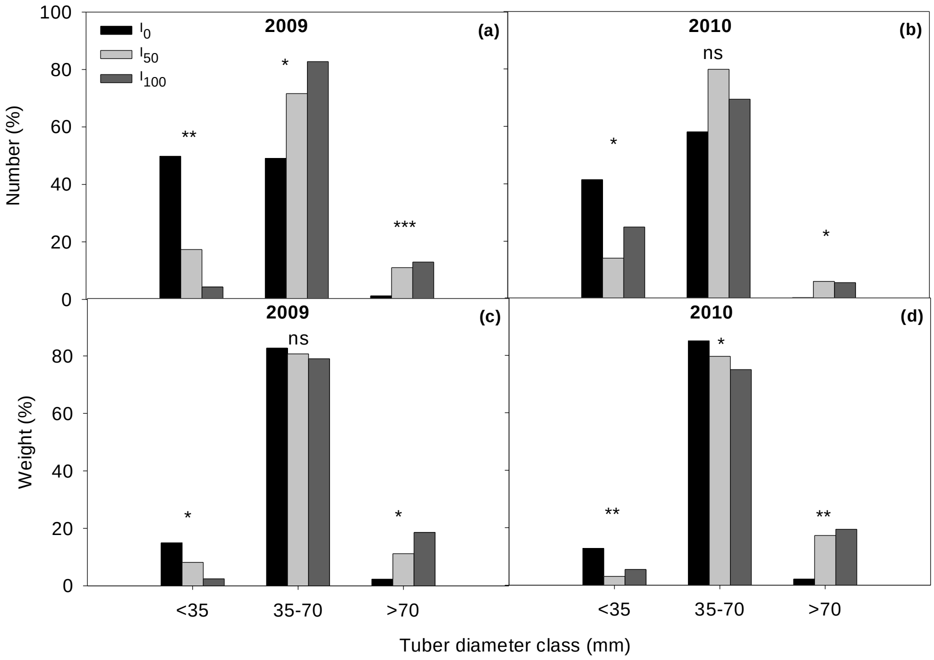

Figure 4. Number of tubers percentage (a, b) and weight of tubers percentage (c, d) for potato during the two experimental years.
*, **, *** indicate respectively differences at P≤0.05, P≤0.01 and P≤0.001; ns indicates not significant difference.

The amount of deformed tubers was negligible and did not vary within years and irrigation regimes (data not shown).

Harvest index (HI) was not affected by the irrigation regime over the two experimental years (Table 3). Tuber dry matter content was influenced by irrigation regime and year (Table 3). Over the 2009-2010 period, it decreased to increasing water availability with average values ranging from 23.1 (rainfed) to 20.1 g 100 g^{-1} (I_{100}); the highest value was recorded in 2010 (23.1 vs 20.2 g 100 g^{-1} in 2009). The lower values observed in 2009 were probably due to the heavy rainfall that preceded the harvest time. In any case, also in the less favourable conditions, tuber dry matter was always higher than 20%.

Specific gravity was affected by the year with an average value higher in 2010 (1.09 vs 1.07 g cm^{-3}) and varied more as a function of irrigation regime in 2009 (significant interaction YxWR) (Table 3). Source/sink ratio was not influenced by weather conditions (Table 3), and by water regime; however the data highlighted a slight trend to a better efficiency of assimilate translocation from leaves to tubers in the full irrigated treatment (I_{100}).

Water use efficiency

Both dry biomass water use efficiency (B_WUE) and yield water use efficiency (Y_WUE) were not significantly affected by irrigation regime and year (Table 3). Nevertheless, higher B_WUE and Y_WUE values were recorded in 2010 than in 2009, as a consequence of lower seasonal crop evapotranspiration and for B_WUE in I_{50} as compared with both I_{100} and I_0.

Discussion

Growth, yield and quality parameters

Irrigation regimes markedly affected plant growth and yield and induced a different partitioning of tubers, in terms of both weight and number, among diameter classes. The strong impact of irrigation on early potato production has been reported in other studies (Foti, 1999; Ierna et al., 2011; Ierna and Mauromicale, 2012) and confirms that under Mediterranean conditions irrigation is required for early potato cultivation.

In general, water stress causes a significant reduction in yield (Proietti et al., 2005; Ierna and Mauromicale, 2006; Ierna et al., 2011), tuber size (Steyn et al., 1998) and tuber number (Onder et al., 2005). Lower tuber number has also been found for fully irrigated regimes and attributed to the detrimental effect of continuous wet conditions during the growing cycle on early potato tuber yield and quality (Stylianou and Orphanos, 1981; Onder et al., 2005). However, interaction with genotype and other environmental factors (Walworth and Carling, 2002) may significantly modify plant response to different irrigation regimes (Dalla Costa et al., 1997). In any case, all these findings confirm the difficulty of obtaining satisfactory yield response for early potato grown in semi-arid areas under rainfed conditions and, at the same time, they highlight the great variability of plant response in terms of both yield and quality also under irrigation, indicating the need for a closer investigation of early potato response in different environments.

The rainfall pattern recorded over the two-year experimental period, with events of short intensity but regularly distributed during tuber growth phase, avoided the occurrence of malformed tubers also in water stressed treatments. The development of tuber malformation, often referred to as second growth, is usually caused by short stress periods during tuber bulking stage followed by crop re-watering. In fact, when re-watering occurs, tubers growth remains mainly restricted to specific parts of the tuber (the rose end and zones around the eyes) where cell division continues for longer periods (Parisi, 2011).

Both tuber dry matter and specific gravity, which are important quality parameters associated with the processing of tubers (Yuan et al., 2003) and closely correlated to tubers starch content, were affected by different climatic conditions occurred between the experimental years and, although at a different extent, by irrigation regime. On average the highest values were recorded for rainfed plants. These results are in line with several research findings. Tuber dry matter content is in fact known to be responsive to cultivar, climatic conditions and cultural practices, above all irrigation (Ierna and Mauromicale, 2012). As concerns specific gravity, Cantore et al. (2001) reported significantly higher values in rainfed early potato grown in a similar environment than in the irrigated crop; similar findings were observed by Porter et al. (1999) and Yuan et al. (2003). Gunel and Karadogan (1998) found that specific gravity declined as irrigation was more frequent at tuber bulking stage and as it was performed until late in the season and this was considered a consequence of higher moisture content of the tubers. Shock et al. (1993) reported that generally water stressed tubers had a higher total solid level than the control tubers, possibly due to limited available water.

Water use efficiency

Although it was hypothesized that water use efficiency would improve under water deficit conditions, our results showed that both biomass and yield water use efficiency were not significantly affected by irrigation regime.

Several studies have reported increase in WUE to the increase in water stress (Badr et al., 2010; Hassanpanah, 2010; Badr et al., 2012); however different behaviour has been observed in other researches, with no relation between water use and produced dry matter (Bodlaender, 1986), or even inverse relationships between stress intensity and WUE (Kashyap and Panda, 2003; Yarnia et al., 2009).

For instance, Hassanpanah (2010), comparing seven potato cultivars, observed that water stress increased Y_WUE (from average values of 6.65 kg m^{-3} for the well watered crop to values of 7.9 kg m^{-3} for the crop grown under water stress). On the contrary, Bodlaender (1986) observed no relation between water use and produced dry matter, but water use efficiency had a significant negative relation with drought resistance. Finally, Yarnia et al. (2009) indicated that increasing stress intensity decreased Y_WUE, as observed also by Kashyap and Panda (2003) passing from potato irrigated at the depletion of 10% of soil available water (ASW) to plants irrigated at the depletion of 75% of ASW; nevertheless Yarnia et al. (2009) reported also that under severe stress a higher Y_WUE occurred, as compared with mild stress conditions.

The different effect of drought on WUE observed in different studies can be attributed to the level of water stress encountered by the crop. Indeed, under mild water stress, when slight stomata closure occurs, transpiration decreases more than photosynthesis and, consequently, WUE increases. On the contrary, severe drought may lead to full closure of stomata and decrease water use efficiency and yield (Beukema and Van Der Zaag, 1990). Accordingly, under our experimental conditions, on average lower Y_WUE values were observed for rainfed plants which encountered higher stress levels.

In addition, besides water availability, interaction with other factors, such as cultivar, agronomic management or soil characteristics, can affect water use efficiency. To this regard, Nagaz et al. (2007) reported that Y_WUE varied from 6 to14 kg m^{-3} for autumn- winter- and spring-planted potato. Wright and Stark (1990) noticed that the Y_WUE of potato crops varied between 5.4 and 12.0 kg m^{-3} in relation to region, irrigation management and amount of applied fertilizers. Fabeiro et al. (2001) reported that Y_WUE values for potato crops in Spain ranged between 6.3 and 8.6 kg m^{-3}, while Ünlü et al. (2006) reported values ranging between 4.8 and 7.4 kg m^{-3}, as a function of both irrigation method and nitrogen level.

Conclusions

This study proves that, under a typical Mediterranean environment, water stress affected yield and quality parameters of “Spunta” potato, making irrigation strongly required for early potato cultivation. In fact, under rainfed conditions, early potato gives low and highly variable yield, while an irrigation regime reduced by 50% of crop water requirements can be able to provide satisfactory yield results, with a tuber quality similar or even better than that obtained under full irrigation regime.

This last result is particularly important as it may allow to increase farmer incomes, through a better tuber quality and lower production costs and also because water saved may be used more profitably to irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources.

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