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Potato growth, yield and water productivity response to different irrigation and fertilization regimes

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ABSTRACT

To achieve improvement in irrigation management and maximize water productivity (WP), knowledge on potato crop growth and seasonal crop evapotranspiration (ETc) in relation to combined irrigation and fertilization, are needed. In a two-year experiment conducted in Sicily (South Italy), the combined effects of 3 irrigation levels [irrigation only at plant emergence, irrigation at 50% of maximum evapotranspiration (ETm) and irrigation at 100% ETm] and 3 N-P-K fertilization rates (low: 50, 25 and 75 kg ha^{-1}, medium: 100, 50 and 150 kg ha^{-1} and high: 300, 100 and 450 kg ha^{-1} of N, P_2O_5 and K_2O) on ETc, crop growth rate, aboveground dry biomass and tuber dry yield, sink/source (tuber yield/aboveground biomass yield) ratio, water productivity and crop drought response factor, were studied. Irrigation water amounts were 25 mm in plots irrigated only at plant emergence in both years, 87 and 96 mm in plots irrigated at 50% of ETm, 174 and 192 mm in plots irrigated at 100% of ETm, respectively in the two years. Irrigation based on 100% of ETm + high rate of N-P-K fertilization proved the best combination to promote ETc, crop growth, and improve aboveground biomass, tuber yield, and sink/source ratio but not WP. Fertilization played a crucial role in enhancing WP of this crop especially in plots irrigated only at plant emergence, where both low and medium fertilization rates allowed maximizing WP (2.3 kg m^{-3} dry weight) ensuring an acceptable tuber yield (about 3.7 t ha^{-1} dry weight). These results are of considerable importance to farmers to achieve more efficient and rational use of water by potato grown in very limited water availability environments.

1. Introduction

Potato is an important staple food in the Mediterranean Basin, occupying an overall area of a little less than 1 million ha and producing 30 million t of tubers (FAOSTAT, 2017). In the Mediterranean coastal regions of several countries such as Tunisia, Egypt, Cyprus, Israel, Lebanon, Turkey and Italy, potatoes are usually grown in the winter-spring cycle (planting from November to January and harvesting from March to early June) for early production, which is highly appreciated and mainly exported to northern European countries, with considerable profit (Mauromicale et al., 2003; Ierna, 2010). To promote earliness and high yields, as well as meet the quality standards demanded by the fresh vegetable market, early potato crops are usually irrigated and fertilized during vegetative growth and tuber bulking. In particular, irrigation plays a decisive role since early potatoes are very sensitive to water stresses during tuber initiation and tuber bulking stages, which adversely influence not only yields but also earliness (Foti et al., 1995; Ierna and Mauromicale, 2012). A regular and adequate water supply is required from tuber initiation until near maturity for high yields and good grade and quality (Ierna and Mauromicale, 2006). Fertilizers are generally used inefficiently by the crop, also due to large nutrient losses through seepage or percolation, above all under conventional methods of irrigation like furrows or sprinklers (Foti et al., 1995). As a result, appropriate fertilizers and water application should be considered together in a comprehensive approach. Ierna et al. (2011) in a study conducted in the same environment, demonstrated that the right combination of irrigation level and N + P + K fertilization rate are an effective means to increase tuber yield. However, considering that irrigation water is costly exploitable and limited in the semi-arid areas of the Mediterranean basin, it is crucial to maximize water savings and water productivity (WP). This may be defined as the ratio between the crop yield achieved and crop water consumption or evapotranspiration (Pereira et al., 2012). It is known that WP of crops, besides water availability, could be affected by other factors, such as soil characteristics, cultivar, and fertilization management. A proper nutrient balance of the crop would therefore lead to increased yields and, thus, increase WP. However, fertilization also contributes to increasing evapotranspiration (ET), and as a result WP may decrease. Extensive research

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has been conducted in the Mediterranean area to study crop growth, seasonal ET, ET - yield (Y) relationships and yield response to water irrigation (Islam et al., 1990; Unlu et al., 2006; Cantore et al., 2014; Camargo et al., 2015) or to simultaneous applications of water and nitrogen (Badr et al., 2012; Darwish et al., 2006; Ferreira and Conçalves, 2007). To date, information for this crop regarding the combined effect of the level of irrigation water and fertilizer application rate on crop growth, yield-ET relationship, WP and crop yield response factors, are lacking. This study was therefore undertaken to (1) examine the effects of irrigation levels in combination with fertilization application rate on crop growth rate, aboveground biomass and tuber yield, (2) analyse the ET-Y (as aboveground biomass and tubers) relationships and the corresponding WP, and 3) estimate crop yield response factors to drought.

2. Materials and methods

2.1. Field experiment

Experiments were conducted during 2007 (from January to May) and 2008 (from February to June) on the coastal plain, south of Siracusa in Sicily (37°03 N, 15° 18′ E, 15 m a.s.l.), a typical area for early potato cultivation in Italy, in a moderately deep soil classified as Calcixerollic Xerochrepts on the basis of USDA Soil Taxonomy Classification (1999). Before the start of the trials soil characteristics were the following: clay 30%, silt 25%, sand 45%, organic matter 2.0%, pH 8.4, total nitrogen 1.8‰, assimilable P_2O_5 78 kg ha^{-1}, exchangeable K_2O 337 kg ha^{-1}. The field capacity at −0.03 MPa was 0.29 g g^{-1} dry weight, the wilting point at −1.5 MPa was 0.11 g g^{-1} dry weight and bulk density was 1.2 g cm^{-3}. The climate is semi-arid Mediterranean, with mild winters, and commonly rainless springs. Frost occurrence is virtually unknown (two events in 30 years). During the potato crop season for early production (from January to May), the mean maximum day temperatures and the mean minimum night temperatures of the 30 year period 1977–2006 were, respectively, 15.4 and 7.1 °C in January, 16.2 and 7.6 °C in February, 17.7 and 8.8 °C in March, 20.2 and 10.9 °C in April, 24.3 and 14.4 °C in May. Rainfall over the same period averages about 180 mm.

In both years, the experiment was conducted on potato (*Solanum tuberosum* L.) cv. Spunta using a split-plot design (Gomez and Gomez, 1984) with three replications, including 3 levels of irrigation [I_1 (irrigated only at plant emergence), I_2 (irrigated treatment at 50% of maximum evapotranspiration - ETm) and I_3 (irrigated treatment at 100% of ETm)] as main plots, 3 rates of N-P-K fertilization [low, F_1 (50, 25 and 75 kg ha^{-1} of N, P_2O_5 and K_2O), medium, F_2 (100, 50 and 150 kg ha^{-1} of N, P_2O_5 and K_2O) and high, F_3 (300, 100 and 450 kg ha^{-1} of N, P_2O_5 and K_2O)] as sub-plots.

ETm was calculated using the following formula:

$$\mathrm{ETm} = \sum_{0}^{n} \mathrm{E\ Kp\ Kc} \tag{1}$$

where: n = the number of days since the last watering; E = daily evaporation from an unscreened class A Pan 100 m away from the experimental plots (the class A pan has a protection mesh); Kc = crop coefficient, which varied from 0.45 to 1.15 in relation to the phase of the crop's biological cycle (Doorenbos and Kassam, 1979); Kp = pan coefficient, which was taken to be 0.8 in our conditions using the criteria set out by Doorenbos and Kassam (1979). Water was applied by drip irrigation when the accumulated daily evaporation corrected for rain reached about 30 mm, which corresponded to 50–60% of available soil water content at 0.30 m depth in the plots irrigated with 100% ETm.

Irrigation started on 3 March and on 11 March, respectively in 2007 and 2008, and finished on 10 May and 29 May. Following the above formula, 8 irrigations were done in 2007 and 9 in 2008. The interval between one irrigation and the next in both years ranged between 7 and 12 days. The plot irrigated at plant emergence (I_1) received only 25 mm that were applied at emergence to assure crop establishment. The total quantity of irrigation water supplied to plots receiving 100% of ETm (I_3) was 174 and 192 mm in the first and in the second year, respectively.

In both years, phosphorus (as triple superphosphate) and potassium (as potassium sulphate) were applied at planting, whereas 50% of nitrogen (as ammonium nitrate) was supplied at complete emergence [40 and 30 days after planting (DAP), respectively in 2007 and 2008] and the remaining 50% 2 weeks after tuber initiation (62 and 51 DAP, respectively in 2007 and 2008).

Plot areas, plant density and irrigation and fertilization management were extensively reported by Ierna et al. (2011).

2.2. Data collection and calculations

Maximum and minimum daily air temperatures and rainfall were recorded with a CR 21 data logger (Campbell Scientific, Inc., Utah, U.S.A.) located at the experimental station near the potato field. From each subplot, the seasonal crop evapotranspiration (ETc, mm) was estimated by the soil water balance equation:

$$\mathrm{ETc} = \mathrm{P} + \mathrm{I} + \mathrm{CR} - \mathrm{Dp} - \mathrm{R} \pm \Delta\mathrm{S} \tag{2}$$

where P is precipitation; I the depth of irrigation water applied; CR, capillary rise; Dp, deep percolation, R the run off and ΔS, the change in soil moisture content, with all terms expressed in mm. The amount of water obtained from capillary rise was negligible. Deep percolation was assumed negligible because field capacity was medium-high (29%), rainfall was well distributed during crop seasons and never exceeded the water soil retention; in addition,irrigation was conducted using controlled amounts of water. Runoff was assumed equal to zero because the soil was flat, and no runoff was observed during both seasons. Soil moisture was measured before sowing and after harvest of the crop and also before and 48 h after each irrigation along the maximum root development of the potato roots from −0.2 to −0.3 m depth in both years using the gravimetric method. As CR, Dp and R were negligible, ETc was calculated as

$$\mathrm{ETc} = \mathrm{P} + \mathrm{I} \pm \Delta\mathrm{S} \tag{3}$$

Five whole plants per subplot and replicate were sampled at 86, 111, 121 and 139 (when 100% of leaves were dry) DAP in 2007 and at 76, 87, 94, 107, 114, 123 and 133 (when 100% of leaves were dry) DAP in 2008 and separated into aboveground biomass (stems + leaves), roots + stolons and tubers. Roots, stolons and tubers were washed in gently running water. All plant parts were weighed separately to measure fresh weight. Leaf area was measured by a LI-3100C area meter (Li-COR Inc., Lincoln, Nebraska, USA). Samples of about 50 g of aboveground biomass, tubers and roots + stolons were oven-dried at 70 °C until reaching an invariable dry weight.

The following were calculated (Gardner et al., 1985)

$$\mathrm{LAI} = [(\mathrm{LA2} + \mathrm{LA1})/2](1/\mathrm{GA}) \tag{4}$$

where LAI is leaf area index, LA2 and LA1 are leaf area at time 2 (t2) and time 1 (t1), respectively, GA ground area covered by the crop.

$$\mathrm{CGR} = 1/\mathrm{GA}\ (\mathrm{W2\text{-}W1})/(\mathrm{t2\text{-}t1}) \tag{5}$$

where CGR is crop growth rate expressed in g m^{-2} day^{-1}, W2 and W1 are dry plant biomass (stems + leaves) (g) at times t2 and t1, determined when maximum LAI was achieved (86 DAP in 2007 and 94 DAP in 2008).

When 80% of leaves were dry (130 and 123 DAP in the 2007 and 2008, respectively), plants of each subplot were collected, tubers were