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Tuber yield, water and fertilizer productivity in early potato as affected by a combination of irrigation and fertilization

Anita Ierna[a,*], Gaetano Pandino[b], Sara Lombardo[b], Giovanni Mauromicale[b]

[a] Istituto per i Sistemi Agricoli e Forestali del Mediterraneo, CNR, Sezione di Catania, Str.le V. Lancia, Zona Industriale, Blocco Palma, I-95121 Catania, Italy
[b] Dipartimento di Scienze delle Produzioni Agrarie e Alimentari, DISPA, Università degli Studi di Catania, Via Valdisavoia 5, 95123 Catania, Italy

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ABSTRACT

Excessive amounts of irrigation water and fertilizers are often utilized for early potato cultivation in the Mediterranean basin. Given that water is expensive and limited in the semi-arid areas and that fertilizers above a threshold level often prove inefficacious for production purposes but still risk nitrate and phosphorous pollution of groundwater, it is crucial to provide an adequate irrigation and fertilization management. With the aim of achieving an appropriate combination of irrigation water and nutrient application in cultivation management of a potato crop in a Mediterranean environment, a 2-year experiment was conducted in Sicily (South Italy). The combined effects of 3 levels of irrigation (irrigation only at plant emergence, 50% and 100% of the maximum evapotranspiration – ETM) and 3 levels of mineral fertilization (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) were studied on the tuber yield and yield components, on both water irrigation and fertilizer productivity and on the plant source/sink (canopy/tubers dry weight) ratio. The results show a marked interaction between level of irrigation and level of fertilization on tuber yield, on Irrigation Water Productivity and on fertilizer productivity of the potato crop. We found that the treatments based on 50% ETM and a medium level of fertilization represent a valid compromise in early potato cultivation management. Compared to the high combination levels of irrigation and fertilization, this treatment entails a negligible reduction in tuber yield to save 90 mm ha^{-1} year^{-1} of irrigation water and 200, 50 and 300 kg ha^{-1} year^{-1} of N, P_2O_5 and K_2O, respectively, with notable economic savings for farmers compared to the spendings that are usually made.

1. Introduction

Potato is a very important crop in the Mediterranean Basin, occupying an overall area of about one million ha and producing 18 million tonnes of tubers (FAO, 2008). In several countries such as Tunisia, Egypt, Cyprus, Israel, Lebanon, Turkey and in southern Italy, potatoes are not grown in the usual cycle (spring–summer) owing to the high temperatures and considerable demand for irrigation water, but are largely grown in a winter–spring cycle (planting from November to January and harvesting from March to early June) for early production. Early potatoes, defined as "potatoes harvested before they are completely mature, marketed immediately after harvesting and whose skin can easily be removed without peeling" (UNECE of Geneva, FFV-30/2001), are highly appreciated and are mainly exported to northern European countries, with considerable profit (Ierna, 2010). The substantial commercial value of the product and the intensive use of the land prompt farmers to supplement the potato crop with water, nutrients and other management needs, which have undoubtedly been responsible for increased early potato yields in recent decades.

In the Mediterranean area, irrigation plays a fundamental role in early potato cultivation. Indeed, the crop is planted during winter months when rainfall usually exceeds evaporation, but in the successive stages of growth of the aerial part and of tubers from the end of winter to the whole of spring, the rainfall decreases at the same time that evapotranspiration and temperatures increase thus causing substantial soil water deficits. In general, potato crops are affected by drought at all stages of growth, but during the periods of tuber initiation and bulking this has a drastic effect on yield (Jefferies and Mackerron, 1993; Van Loon, 1981). Therefore, early potato cultivation in this area usually resorts to irrigation throughout the spring, coinciding with the phase of tuber bulking and growth. The amount of water supplied, like the number of irrigations and irrigation intervals, is dependent on the rainfall distribution and may differ from one season to another; nonetheless, excessive water inputs are common due to inefficient irrigation methods (furrow, macro-sprinklers).

* Corresponding author. Tel.: +39 095 292871; fax: +39 095 292870.
E-mail address: anita.ierna@cnr.it (A. Ierna).

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Three macronutrient elements, namely nitrogen, potassium and phosphorus, are the predominant fertilizers applied. All have been shown to improve yield and quality of potato tubers where native soil supplies are limited (Westermann, 2005). In early potato crops, farmers may use as much as 600 kg ha^{-1} of N, 300 of P_2O_5 and 400 of K_2O (Bianco, personal communication). These are far greater than the usual crop uptake, which for an aerial production of 20 t ha^{-1} are equal to 102, 27 and 197 kg ha^{-1} of N, P_2O_5 and K_2O, respectively (Mauromicale et al., 2000). The excess of N fertilizers may increase nitrate concentration in the groundwater table (Darwish et al., 2003); P is thought to have very low solubility in soil systems and when applied excessively it can disperse through runoff and erosion and potentially affect the quality of surface waters. In addition, high amounts of nitrogen augment the nitrates in tubers to levels above the threshold allowed by the major European distributors which is set at 200 mg/kg f.w. (Ierna, 2009).

Considering that irrigation water is expensive and limited in the semi-arid areas of the Mediterranean basin, and that fertilizers above a threshold level often prove ineffective for production purposes while eventually damaging the environment, it is crucial to provide crop-specific irrigation and fertilization management. This would improve farmers' incomes by saving water and reducing fertilizer costs as well as minimising nutrient loss. Since water plays an important role in the fate and transport of nutrients and their absorption by crops, appropriate fertilizers and water application should be considered together in a comprehensive approach.

Extensive research has been conducted in the Mediterranean to determine yield response of potato crop to water (Fabeiro et al., 2001; Foti et al., 1995; Ierna and Mauromicale, 2006; Karafyllidis et al., 1996; Onder et al., 2005), and yield response to simultaneous application of water and nitrogen (Darwish et al., 2003; Mohammad et al., 1999; Papadoupolus, 1988; Pedreño Navarro et al., 1996). However, up to date literature is lacking on the effects of complete fertilization programmes (N, P and K) and on the interaction between water supply and fertilizer applications on yield performances. In addition, the understanding of the productive crop response to these resources is of crucial importance to reduce these inputs in cultivation management without sacrificing yield. Improvements in irrigation management are a way of increasing agricultural production and reducing the demand for water (Perry et al., 2009).

Environmental protection is one of the priorities of the new objectives of European agricultural policy (European Union, 2000); a compromise between the need to maximize yield and profit and an adequate use of irrigation water and N fertilizer is therefore required to reduce the impact of crop production on the environment.

The aim of the present work was to evaluate the effects of different combinations of amounts of irrigation water and nutrient application on (a) tuber yield and yield components; (b) Irrigation Water Productivity; (c) fertilizer productivity and (d) source/sink (canopy/tubers) ratio to achieve their appropriate combination in the cultivation management of a potato crop.

2. Materials and methods

2.1. Site, climate and soil

Experiments were conducted during 2007 and 2008 at the experimental station of the Catania section of I.S.A.Fo.M. – CNR (National Research Council of Italy) on the coastal plain, south of Siracusa (37°03 N, 15°18′ E, 15 m a.s.l.). This is a typical area for early potato cultivation in Sicily. 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 the 2 years of the experiment, we used two adjoining plots in the same field. A layer, 0.25 m thick (from −0.05 to −0.30 m), where more or less 90% of active roots were located, was considered for the soil analysis. The soil type is Calcixerollic Xerochrepts (USDA, Soil Taxonomy). Analysis made before the start of the trials indicated the following characteristics: 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}. All analyses were performed according to procedures approved by Italian Society of Soil Science (Violante, 2000).

2.2. Experimental design, plant material and management practices

In both 2007 and 2008, the experiment was conducted on potato (*Solanum tuberosum* L.) cv. Spunta using a randomized split-plot design with three replications, including 3 levels of irrigation [I1 (unirrigated control), I2 (50% of the maximum evapotranspiration – ETM) and I3 (100% of ETM) as main plots; and 3 levels of mineral fertilization (low F1: 50, 25 and 75 kg ha^{-1} of N, P_2O_5 and K_2O, medium F2: 100, 50 and 150 kg ha^{-1} of N, P_2O_5 and K_2O and high F3: 300, 100 and 450 kg ha^{-1} of N, P_2O_5 and K_2O)] as sub-plots. Subplot size was 4.2 m × 4.2 m, with 84 plants. The width of borders between irrigation treatments was 2 m. The level F2 coincides with the crop uptake determined in a previous study (Mauromicale et al., 2000) in which it was found that an early potato crop in the same environment had an average uptake of 102, 27 and 197 kg ha^{-1} of N, P_2O_5 and K_2O, respectively; levels F1 and F3 represent half and twice the nutrients uptake, respectively.

Spunta is a well-adapted and widespread cultivar in the Mediterranean region; it is an early potato, with long, regular and very large tubers; plants produce a moderate number of tall erect and vigorous stems (Mauromicale et al., 2003). In both years, virus-free seed-tubers of Spunta imported from North European countries were utilized for planting. In 2007, whole tubers with a mean weight of roughly 100 g were planted on January 12, whereas in 2008 half tubers with a weight of about 60–70 g were planted on February 5. The half tubers were always cut lengthwise to ensure an equal number of buds per tuber-seed unit. Both whole and half tubers were planted at 0.3 intervals, in rows 0.7 m apart (equivalent to a planting density of 4.76 plants m^{-2}). All plants emerged 40 days after planting (DAP) in the first year and 30 DAP in the second one.

ETM was calculated using the following formula:

$$ETM = \sum_{0}^{n} E\, Kc\, Kp$$

where n = the number of days since the last watering; E = daily evaporation from an unscreened class A pan placed about 100 m from the crop and mesh covered to prevent animals drinking the water; Kc = crop coefficient, which varied from 0.45 to 1.15 in relation to the phase of the crop's biological cycle (Doorembos and Kassam, 1979); Kp = pan coefficient, which was taken to be 0.8 in our conditions using the criteria set out by Doorembos and Kassam (1979) in Table 17. 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