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Growth response and radiation use efficiency in tomato exposed to short-term and long-term salinized soils

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ABSTRACT

Farmlands are increasingly exposed to degradation phenomena associated to climate change and agricultural practices, including irrigation. It is estimated that about 20% of the world's irrigated land is salt affected. In this paper we aimed at evaluating the effect of seasonal and multiannual soil salinization on growth, yield, and radiation use efficiency of tomato in open field. Two field experiments were carried out at the Experimental Station of the University of Naples Federico II (latitude 40°31′ N longitude 14°58′ E) (Italy) on tomato during 2004 and 2005 to study the effect of five levels of water salinity: NSC (EC = 0.5 dS m^{-1}), SW1 (EC = 2.3 dS m^{-1}), SW2 (EC = 4.4 dS m^{-1}), SW3 (EC = 8.5 dS m^{-1}) and SW4 (EC = 15.7 dS m^{-1}) in a soil exposed to one-season salinization (ST = short-term) and an adjacent soil exposed to >20 years salinization (LT = long-term). Plant growth, yield and fruit quality (pH, EC, total soluble solids and the concentration of reducing sugars and of titratable acids), and plant water relations were measured and radiation use efficiency (RUE) was calculated. Increasing water salinity negatively affected the leaf area index (LAI), radiation use efficiency (RUE) and above-ground dry weight (DW) accumulation resulting in lower total and marketable yield. Maximum total and marketable yield obtained with the NSC treatment were respectively 117.9 and 111.0 Mg ha^{-1} in 2004 and 113.1 and 107.9 Mg ha^{-1} in 2005. Although the smaller leaf area of salinized plants was largely responsible for reduced RUE, we found approximately 50% of this reduction to be accounted for by processes other than changed crop architecture. These may include an increased stomatal resistance, increased mesophyll resistance and other impaired metabolic functions that may occur at high salinity. Remarkably, we found that LT salinized plants had a slightly better efficiency of use of intercepted radiation (RUE_{IR}) at a given EC of soil extract than ST salinized plants indicating that LT salinization, and consequent permanent modifications of the soil physical properties, may trigger additional physiological mechanisms of adaptation compared to ST salinized plants. These differences are relevant in light of the evolution of salinized areas, also in response to climate change.

1. Introduction

Salinization is a major constraint to crop production and is increasingly expanding in agricultural areas of the world. Approximately 20% of worldwide irrigated land is salt-affected (Rozema and Flowers, 2008). Accumulation of salts in the soil profile is being exacerbated by improper use of saline water for irrigation and reduced rainfall, the latter having a role in alleviating seasonal salinization by washing out the excess of salt from the root zone (Maggio et al., 2005). The need to contrast the impact of salinization through optimal irrigation regimes, suitable agronomic practices and improved plant ability to adapt to salt stress is dictated by an increasing demand for food by a growing population and adverse effects of climate change that are expected to enhance the progression of salinization (United Nations, 2009; Royal Society, 2009). Genetic improvement of agricultural crops for increased ability to cope with salt stress has been partially successful, with scattered examples of plant tolerance that could be transferred to the field (Munns, 2005; Pardo, 2010). This is partly due to the complexity of crop stress responses with respect to diverse agricultural contexts.

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The diversity of salt stress responses has been recently addressed in regard to seasonal (short-term) and multiannual (long-term) effects of salinization which may involve different aspects of plant adaptation to additional modifications of the soil characteristics that a recurrent salinization may cause (De Pascale et al., 2012). Framing salinization in specific agricultural contexts, as well as scaling up from single-plant responses and inherent stress tolerance mechanisms (e.g. water and ion homeostasis) to crop systems may lead us to identify adaptation traits that may have relevance at plant community level, an area that has been largely overlooked. Little attention, for instance, was given to the relationship between the amount of intercepted solar radiation, the biomass production and yield (i.e. radiation use efficiency, RUE) and changes in RUE in response to higher and/or broader range of salinities and/or other cultural/environmental variables (e.g. seasonal vs. multiannual salinization). Nevertheless, insights on how salt stress may affect RUE could be useful to identify optimal cultivation schemes in salinized environments and/or provide useful information for improving crop salt stress adaptation.

In the absence of stress, RUE is strictly associated to the maximum leaf photosynthetic rate (Sinclair and Horie, 1989; George-Jaeggli et al., 2013) and correlates well with those effectors that increase the photosynthetic activity such as the leaf nitrogen content (Miranzadeh et al., 2011; Elia and Conversa, 2012). Upon exposure to environmental stresses, lower RUE may be one of the main causes of biomass reduction as shown for water (Stone et al., 2001; Earl and Davis, 2003; Srivastava et al., 2010) and cold stresses (Louarn et al., 2008). RUE seems to be not much affected by salinity in quinoa (Razzaghi et al., 2012) or by water shortage in cowpea (Tesfaye et al., 2006), whereas it is depressed by salinity in soybean (Wang et al., 2001). Within species, there is in general not much variability in RUE; however it has been shown to be significantly greater in the Stay-Green sunflower hybrids compared to standard hybrids (De la Vega et al., 2011) and Higashide and Heuvelink (2009) have reported that modern tomato cultivars obtain a higher yield than old cultivars because of higher RUE. The response of RUE to various stresses depends on the crop developmental stage (Ridao et al., 1996; Tesfaye et al., 2006) and cultivation practices (Lecoeur and Ney, 2003) also, which can both be effectively exploited to improve stress tolerance (Miranzadeh et al., 2011).

Considering that under the pressure of climate change agriculture will be forced to deal with permanent salinization phenomena rather than occasional/seasonal salinization events (Maggio et al., 2004; Srivastava et al., 2010) we begun to analyse, in a long-standing study, crop responses to seasonal vs. multiannual salinization with the twofold objective of (1) highlighting possible differences in short- and long-term salinized environments (De Pascale et al., 2012) and (2) anticipating research needs that may emerge under permanent salinization. Although tomato is among the most important horticultural crops in the world, often exposed to salinization problems, data on variations of tomato RUE under saline stress are rather scarce, if not lacking. As this may help identifying key processes affecting plant response to salinity and their relevance in a cultural context, in this paper we compared salt stress effects on RUE in tomato exposed to seasonal and multiannual salinization and we attempted to separate effects resulting from reduced light interception from other effects.

2. Materials and methods

2.1. Experimental design

The research was conducted in Southern Italy at the Experimental Station of the University of Naples Federico II (latitude 40°31′ N longitude 14°58′ E). During two growth seasons (2004 and 2005), a comparative analysis of physiological and growth responses to short-term (ST) vs. long-term (LT) salinization was conducted on processing tomato (*Solanum lycopersicum* L.) cv Montericco (plum shape, determinate growth, generally used for canned peeled or paste/sauce preparation). The long-term salinized field used for the experiment was a clay-loam soil (42% sand, 27% silt, 31% clay, and trace amounts of lime) whose initial characteristics were: 1.57% organic matter; 0.92 g kg^{-1} total N; pH 7.1; available P_2O_5 (Olsen) 96 mg kg^{-1}; exchangeable K_2O 570 mg kg^{-1}; field capacity (in situ) and −1.5 MPa water contents of 0.345 and 0.175 cm^3 cm^{-3}, that had been irrigated since 1988 with the same salinity levels as used for the ST salinized plots described in the following. The ST salinized plots were adjacent to the long-term salinized ones with the same soil but had not been previously irrigated with saline water (De Pascale et al., 2012). The treatments consisted of five levels of water salinity: a non-salinized control (NSC) and four saline concentrations SW1, SW2, SW3 and SW4, corresponding to electrical conductivity of the irrigation water (EC) = 2.3 dS m^{-1}, 4.4 dS m^{-1}, 8.5 dS m^{-1} and 15.7 dS m^{-1} at 25 °C respectively. The saline water was obtained by adding commercial sea salt (Na^+ 12.3 mol kg^{-1}, K^+ 3.8 mol kg^{-1}, Ca^{2+} 0.02 mol kg^{-1}, Mg^{2+} 0.04 mol kg^{-1}, Cl^- 14.4 mol kg^{-1}, $SO_4{}^{2-}$ 0.03 mol kg^{-1}) to the irrigation water (Na^+ 0.53 mol m^{-3}, K^+ 0.05 mol m^{-3}, Ca^{2+} 1.55 mol m^{-3}, Mg^{2+} 0.84 mol m^{-3}, Cl^- 0.38 mol m^{-3}, $SO_4{}^{2-}$ 0.15 mol m^{-3}, $HCO_3{}^-$ 4.73 mol m^{-3}) to a final concentration of 0.125% (w/v) (SW1), 0.25% (SW2), 0.5% (w/v) (SW3), and 1.0% (w/v) (SW4). No salt was added to the irrigation water of non-salinized control plants (EC = 0.5 dS m^{-1} at 25 °C). In 1988, when the soil salinization was begun in the LT salinized soil, the salinity treatments were arranged in a randomized block design replicated three times. To assess cumulative effects of salinization over the years, however, the salinity treatments had to be re-assigned to the same experimental field plots in each of the following years. Consequently, since 1988, each plot of the LT field has received irrigation water with the same EC.

2.2. Growth conditions

Tomato plantlets (at the 4th true-leaf stage) were transplanted from the nursery into the field at a density of 4.0 plants/m^2 (0.35 m apart within rows and 0.7 m between rows) on 20 May (2004) and 26 May (2005). Every year, prior to transplanting, 60 kg ha^{-1} of N [as $(NH_4)_2SO_4$], and 114 kg ha^{-1} of P (as superphosphate) were applied to the soil and 98 of kg ha^{-1} K_2O (as K_2SO_4). Plants were fertilized with two additional applications of 52 kg ha^{-1} of N (as NH_4NO_3), on 9 June and 2 July (2004) and on 14 June and 4 July (2005). To ensure the establishment of the plantlets, 30 mm of non-salinized water were applied from transplanting to the beginning of all treatments. Saline irrigation was initiated on 23 June (2004) (34 days after transplanting, DAT) and 25 June (2005) (30 DAT). Plots were irrigated at 4-day intervals, using a drip irrigation system with 2 L h^{-1} emitters (5 emitters m^{-2}). The amount of water applied at each irrigation was equal to the net evaporation between two irrigation events using a Class "A" pan evaporimeter. Considering, that under saline irrigation, an excess of water (Leaching Requirement, LR) should be provided in addition to the amount estimated with standard methods for crop water requirements, we decided to use a crop coefficient (K_c) of 1 for the entire growth season to include a leaching fraction in the total volume of applied water. As a consequence, we were providing an excess of water at early stages of development, but at the same time we were also sure to provide the same volume of water to all plots under assessment. This excess of water was needed as LR but was also critical to maintain constant soil humidity throughout the experiment, so to avoid any stress due to water shortage. All treatments received 468 mm (2004) and 531 mm (2005) of water from beginning of the saline