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# Effects of deficit irrigation on biomass, yield, water productivity and fruit quality of processing tomato under semi-arid Mediterranean climate conditions

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ABSTRACT

Processing tomato is a high water demanding crop, thus requiring irrigation throughout growing season in arid and semiarid areas. The application of deficit irrigation (DI) strategies to this crop may greatly contribute to save irrigation water. A two-year study was carried out in order to assess the effects of DI upon water productivity, final biomass, fruit yield and some quality traits of open-field processing tomato cv. Brigade in a typical semi-arid Mediterranean environment of South Italy. Four irrigation treatments were studied: no irrigation following plant establishment (V0); 100% (V100) or 50% (V50) evapotranspiration (ETc) restoration up to fruit maturity, 100% ETc restoration up to flowering, then 50% ETc restoration (V100-50). Total dry biomass accumulation was significantly depressed by early soil water deficit in V0; irrigation at a reduced rate (50% ETc) from initial stages (V50) or from flowering onwards (V100-50) did not induce any losses in final dry biomass. The marketable yield did not significantly differ among plots irrigated, but an averaged irrigation water saving of 30.4% in V100-50 and 46.2% in V50 was allowed as compared to V100. Marketable yield was negatively affected by the early water shortage in V0, due to the high fruit losses (>44%). The effects of DI on fruit quality were generally the converse of those on fruit yield. DI improved total soluble solids content, titratable acidity and vitamin C content. Water use efficiency was positively affected by DI, suggesting that the crop does not benefits from the water when this last is supplied to fulfil total crop requirements for the whole season. Yield response factor, which indicates the level of tolerance of a crop to water stress, was 0.49 for total dry biomass (*Kss*) and 0.76 for marketable yield (*Ky*), indicating that in both cases the reduction in crop productivity is proportionally less than the relative ET deficit. In conclusion, the adoption of DI strategies where a 50% reduction of ETc restored is applied for the whole growing season or part of it could be suggested in processing tomato, to save water improving its use efficiency, minimizing fruit losses and maintaining high fruit quality levels. This aspect is quite important in semi-arid environments, where water scarcity is an increasing concern and water costs are continuously rising.



## 1. Introduction

Agriculture is often associated with the image of inefficiency, being less profitable than other sectors. This mostly derives from a frequent low ‘irrigation water use efficiency’, calculated from the ratio between the irrigation water used by the crop and the amount of water actually applied with irrigation. Indeed, irrigated agriculture is a major consumer of water and accounts for about two thirds of the total fresh water assigned to human uses (Fereres and Evans, 2006). Therefore, the sustainable use of water in agriculture has become a priority and the adoption of irrigation strategies which may allow saving irrigation water and maintaining satisfactory yields, thus improving water use efficiency (WUE), may contribute to the preservation of this even more restricted resource (Parry et al., 2005; Topcu et al., 2007). In particular, in areas of water scarcity, such as those of the Mediterranean basin, maximising water productivity may be more profitable to the farmer than maximizing crop yield (Pereira et al., 2002).

WUE can be optimized by the adoption of more efficient irrigation practices (Costa et al., 2007). To this regard, drip irrigation has contributed to improve WUE by significantly reducing runoff and crop evapotranspiration (ETc) losses (Stanghellini et al., 2003; Jones, 2004; Kirnak and Demirtas, 2006). For these reasons, drip irrigation systems have seen widespread use in the world in current years.

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A recent positive approach to attain the goal of improving water use efficiency in agriculture is conventional deficit irrigation. Deficit irrigation (DI) is a water-saving strategy under which crops are exposed to a certain level of water stress either during a particular period or throughout the whole growing season (English and Raja, 1996; Pereira et al., 2002). The expectation is that any yield reduction will be insignificant compared with the benefits gained deriving from the save of water (Eck et al., 1987). The goal of deficit irrigation is to increase crop water use efficiency (WUE) by reducing the amount of water applied with watering or by reducing the number of irrigation events (Kirda, 2002). DI involves the use of appropriate irrigation schedules, which mostly derive from field trials (Oweis and Hachum, 2001), and this because crop sensitivity to water deficit during growing season changes with the phenological stage (Istanbulluoglu, 2009). In this case, the optimal irrigation schedules are often based on the concept of water productivity (Oweis and Zhang, 1998).

Most of horticultural production areas are located in hot and dry climates (e.g., Mediterranean) due to favorable wheatear conditions (high light, high temperature). However, in these areas, soil water deficit is rather frequent. Water saving irrigation strategies such as DI may allow to optimize water productivity in such areas, stabilizing yield and improving quality (Costa et al., 2007). The effects of DI have been widely investigated for many vegetable crops. However, their effects are crop-specific. Moreover, the climate of a given cultivation site, which determines the evaporative demand on the crop, and the soil type, which determines the available water for plant uptake, play crucial roles in determining the effects of deficit irrigation. Therefore, it is important to assess the impact of deficit irrigation strategies with multi-years open field experiments, before suggesting the most appropriate irrigation scheduling method to be adopted in any location for a given crop (Scholberg et al., 2000; Igbadun et al., 2008).

Processing tomato is a high water demanding crop, thus requiring irrigation throughout growing season in arid and semiarid areas, where rainfall from May to August are vary rare. In these last, the application of DI strategies to this crop may greatly contribute to save irrigation water (Zegbe-Domìnguez et al., 2003). Moreover, studies have shown that water deficit during certain stages of growing season improves fruit quality, although water limitations may also determine fruit yield losses (Patanè and Cosentino, 2010).

In this paper, the results of a two-year study aiming at assessing the effects of DI regimes upon seasonal evapotranspiration, water use efficiency, final biomass, fruit yield and some quality traits of processing tomato cultivated in a typical Mediterranean environment in South Italy, are reported.

## 2. Materials and methods

### 2.1. Open-field experiment

Field experiments were conducted during the years 2001 and 2002, in a hilly site of inland Sicily, South Italy (550 m a.s.l., latitude: 37°27′ N, longitude: 14°14′ E) on a typical Xerorthents sandy soil (USDA, 1999). The soil characteristics of the field site are presented in Table 1.

### 2.2. Crop management

The cultivar 'Brigade' (Asgrow Italia Vegetable Seeds, Lodi, Italy) of processing tomato (*Lycopersicon esculentum* Mill.) was used for the experiments. Plants were transplanted at four-leaf stage on 4 May 2001 and 10 May 2002, in a single plot of 38.4 $m^2$ (4.8 m × 8 m) with a plant density of 2.5 plants $m^{-2}$. Before transplanting 75, 100 and 100 kg $ha^{-1}$ of N (as ammonium sulphate), P (as mineral perphosphate) and K (as potassium sulphate), respectively, were distributed. A month after transplanting, a further 75 kg $ha^{-1}$ of N (as ammonium nitrate) was applied as top dressing.

The crop was hand harvested when ripe fruit rate reached about 95% (early August).

**Table 1**
Characteristics of the upper soil layer (0–50 cm) of the experimental site.

| Soil characteristic | Value |
|---|---|
| Sand (%) | 64.0 |
| Silt (%) | 23.5 |
| Clay (%) | 12.5 |
| pH (in water solution) | 8.3 |
| Total N (‰) | 1.01 |
| $P_2O_5$ avail. (mg $kg^{-1}$) | 35.1 |
| $K_2O$ avail. (mg $kg^{-1}$) | 403.1 |
| Total calcareous (%) | 28.1 |
| Organic matter (%) | 1.51 |
| Bulk density (g $cm^{-3}$) | 1.2 |
| Field capacity at −0.03 MPa (g $g^{-1}$ dry weight) | 0.21 |
| Wilting point at −1.5 MPa (g $g^{-1}$ dry weight) | 0.11 |

### 2.3. Weather conditions

The following meteorological variables were recorded daily throughout the crop growing season: maximum and minimum air temperature, air relative humidity, rainfall, class-A pan evaporation, using a data logger (CR10, Campbell Scientific, USA) located approximately 50 m from the experimental field. Meteorological data were those of a typically Mediterranean environment (Table 2). Maximum temperatures during the growing period (May–July) ranged from 23.4 to 33.1 °C in 2001 and from 22.6 to 30.7 °C in 2002, those minimum from 12.8 to 19.6 °C and from 12.8 to 19.4 °C in the first and second year of experiment, respectively. In the year 2001, average reference evapotranspiration during the experiment was 2 mm higher than that of long-term average for the same period. Total rainfall was quite negligible in both years (<20 mm). Therefore, soil water availability was almost totally due to irrigation.

### 2.4. Irrigation treatments

Four irrigation treatments based on crop evapotranspiration ($ET_0$), including a non-irrigated treatment, were studied in a randomised complete block experimental design with three replicates (Table 3). A drip irrigation system was used for irrigation. This last was applied following the evapotranspiration (ETc) method according to soil water balance ($ETc = ET_0 \times Kc$) as proposed by Doorenbos

**Table 2**
Main monthly climate parameters in the two years of field experiment during processing tomato growing season and for a long period.

| Year | Climate parameter | Months | | |
|---|---|---|---|---|
| | | May | June | July |
| 2001 | $T_{max}$ (°C) | 23.4 | 28.3 | 33.1 |
| | $T_{min}$ (°C) | 12.8 | 15.4 | 19.6 |
| | Rainfall (mm) | 13.6 | 0 | 0 |
| | $ET_0$ [a] (mm $d^{-1}$) | 6.1 | 8.6 | 9.8 |
| 2002 | $T_{max}$ (°C) | 22.6 | 27.8 | 30.7 |
| | $T_{min}$ (°C) | 12.8 | 16.9 | 19.4 |
| | Rainfall (mm) | 17.4 | 0 | 1.5 |
| | $ET_0$ [a] (mm $d^{-1}$) | 5.4 | 7.0 | 7.6 |
| Long term | $T_{max}$ (°C) | 23.0 | 28.5 | 31.8 |
| | $T_{min}$ (°C) | 12.3 | 16.6 | 19.7 |
| | Rainfall (mm) | 14.5 | 1.1 | 4.6 |
| | $ET_0$ [a] (mm $d^{-1}$) | 5.2 | 6.1 | 7.1 |

[a] $ET_0 = E_0\ k_p$ where $E_0$ = class 'A' pan evaporation and $k_p$ = pan coefficient (0.8).