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Biomass production and dry matter partitioning of processing tomato under organic *vs* conventional cropping systems in a Mediterranean environment

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ABSTRACT

Modern agriculture should increase crop sustainability while feeding the growing population. The organic cropping system has emerged as an interesting alternative and more sustainable crop management than conventional one. Unfortunately, the current yield gap between organic and conventional systems is significant for most crops, and this limits the organic system's value. Hence, the objective of this study was to investigate biomass production and partitioning of processing tomato genotypes cultivated in organic *vs* conventional cropping systems in a processing tomato growing area in the Mediterranean. From 2010–2012, field trials were carried out in two farms in Southern Italy. At the end of the crop cycle and in average among years, processing tomato cultivated in organic cropping system showed reductions of: total biomass dry weight (−25%), leaf area (−36%) and radiation use efficiency (−24%). The biomass distribution to fruits and leaves was highly similar under both managements, while a higher fraction of total biomass was allocated to stems (+34%) and to roots (+41%) in the organic cropping system. In the studied environment, a major cause of different fruit dry weight and, consequently, of yield gap between organic and conventional cropping systems was the reduction of the source, *i.e.* the lower leaf area, that led to a reduction of total biomass dry weight.

1. Introduction

The challenges that farmers are currently facing are how to increase the sustainability of agricultural production while feeding a growing population and how to minimize its global environmental impacts (Godfray et al., 2010; Foley et al., 2011). Intensive farming systems are often based on monoculture, that leads to a great loss of biodiversity with a growing decrease of environmental sustainability, and make great use of external inputs (Frison et al., 2011). Agricultural sustainability could be improved by adopting cropping systems that use reduced external inputs. The increasing costs of external inputs in the conventional cropping system (CCS) have aroused the interest of farmers in alternative managements such as the organic cropping system (OCS) and other low input ones (Coulter et al., 2011). OCS is considered an attempt to improve biodiversity and soil conservation and shows increasing sustainability (Aldanondo-Ochoa and Almansa-Sáez, 2009). In the OCS, most agrochemicals and mineral fertilizers are not allowed, weeds are controlled using only manual or mechanical tillage, and nutrients are supplied by green or animal manure. In many areas of the world, the OCS has met with significant interest (de Ponti et al., 2012). However, on average, only 4.6% of the total land is under organic management in Europe (Eurostat, 2014); in addition, the OCS shows lower yields and, therefore, could need more hectares to produce the same amount of food as the CCS. Hence, this might undermine the environmental benefits of organic management (Trewavas, 2001).

Cavigelli et al. (2008) compared organic and conventional cropping systems, highlighting lower yields of soybean, corn, winter wheat and winter rye all in an OCS. The yield reduction ranged from 18% to 31%

Abbreviations: OCS, organic cropping system; CCS, conventional cropping system; LA, leaf area; LAI, leaf area index; SLA, specific leaf area; PAR, photosynthetically active radiation; DAT, day after transplant

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and the explanation of lower crop yield in the OCS was identified in poor weed control coupled with lower nitrogen availability in the soil. In addition, Thorup-Kristensen et al. (2012) reported an average yield gap higher than 20% between the systems that, however, varied strongly within crop species. An interesting study analyzed 34 different crop species with 316 organic-to-conventional yield comparisons and reported that yield differences ranged from 5% to 34% depending on system and site characteristics, such as soil pH, crop species, irrigation management and high quality of practices (Seufert et al., 2012). Ponisio et al. (2015) and de Ponti et al. (2012) obtained similar results, and concluded that crop yield in the OCS corresponded on average to 80% of the yield obtained in the CCS; furthermore, a yield gap higher than 20% was hypothesized in some specialized cropping systems.

In the OCS, the main factors affecting yield are the control of weeds, pests and diseases, and the management of soil fertility (Ferron and Deguine, 2005; Graziani et al., 2012; Watson et al., 2002). Other authors highlighted that the most important factor in yield limiting of low input systems is the insufficient content in the soil, or mobilization, of organic nitrogen (Doran et al., 1987; Karlen and Doran, 1991; Nelson and King, 1996). When nitrogen availability is scarce, leaves and stems are used as a source of nitrogen by the crop through remobilization (Rajcan and Tollenaar, 1999), total photosynthesis decreases and leaf senescence increases (Wada et al., 1993).

Yield is the main parameter used for comparison among cropping systems and/or cultivars. Heuvelink et al. (2004) reported that in fresh market tomato, high yield is obtained with about 3.0–4.0 leaf area index (LAI) and about 90% of light interception. Moreover, when tomato LAI increased from 3.0 to 4.0, yield was improved by about 4% (Heuvelink et al., 2004). Furthermore, high specific leaf area (SLA) increases the assimilates available for fruit growth (Heuvelink, 1996). Leaf senescence and chlorophyll concentration in leaves are fundamental parameters that could influence final crop yield (Horst et al., 2003). On the contrary, factors that could decrease yield are the low leaf area index, the abortion of the fruits and the low solar radiation (Atherton and Harris, 1986; Papadopoulos and Ormrod, 1991; Heuvelink, 1995; Heuvelink and Buiskool, 1995).

However, other important crop parameters, such as dry matter production and distribution of photoassimilates, affect the final crop yield (Mosisa and Habtamu, 2007; Osorio et al., 2014), and should be taken into consideration in studies on plant growth and crop yield improvement, especially in low input cropping systems. Dry matter production depends on the concept of sink-source relationship, and yield is correlated with both source capacity and sink strength. Source-sink relationship and nitrogen content are the main factors that influence leaf senescence in plants (Crafts-Brandner et al., 1984; Feller and Fischer, 1994). High allocation of biomass to fruits is a key crop goal to obtain high fruit yields. Heuvelink (1996) reported that dry matter distribution is influenced by sink strength. Hence, sink/source ratio could influence dry matter distribution between fruits and vegetative organs. Some factors such as management, nutrients and weather conditions might affect source organs and allocation of dry matter production (Venkateswarlu and Visperas, 1987). Only a few studies reported dry matter partitioning of processing tomato (Elia and Conversa, 2012; Scholberg et al., 2000) and fresh market tomato (Heuvelink, 1997; de Koning, 1994), and, however, only with a CCS. To the authors' knowledge, there are very few reports on processing tomato cultivated in an OCS in the scientific literature and no information is available on dry matter partitioning. Therefore, studies on dry matter partitioning are required to understand how to improve crop yield in low input cropping systems, such as the OCS, in order to make them totally more sustainable than the conventional system. Hence, the objective of the present study was to analyze differences in processing tomato yield between organic and conventional production systems, based on underlying yield components in open field, in a Mediterranean growing area.

2. Materials and methods

2.1. Plant materials

Six modern cultivars of processing tomato commonly cultivated in the Campania Region in Southern Italy were tested. Genotypes with different characteristics were chosen: three cultivars with blocky fruits (Augurio, Wally Red and Alican) and three cultivars with long fruits (Auspicio, Regent and Sibari). Within each type (blocky and long), the cultivars were selected also for their different resistance/tolerance to biotic stresses such as virus, fungi, bacteria and nematodes. They were selected according to three different levels of resistance/tolerance, derived from the number of introgressed resistance genes and classified as: highly resistant, medium resistant and low resistant types, as summarized in Table S1.

2.2. Growth conditions and experimental design

Field trials were carried out in two farms located in the Campania Region, Southern Italy (Table S2) in three growing seasons, 2010, 2011 and 2012, one managed with an OCS and the other with a CCS. The climate of this Region is typically Mediterranean. The mean maximum and minimum air temperatures during the cropping cycles (May to August) were 29.3 and 16.1 °C in the OCS managed farm and 28.5 and 17.6 °C in the CCS managed farm (Table S2). For both cropping systems the soil was a Typic Haploxerepts (USDA, 2006) and the chemical and physical characteristics are reported in Table S3. The cultivation management was conducted as described by Ronga et al. (2015). In both cropping systems and in each year of cultivation, planting densities were 3 plants m^{-2} (30,000 plants ha^{-1}). Seedlings were transplanted into twin rows, with a distance of 0.4 m between each row of the twin and 0.4 m between seedlings in the row, while the distance between twin rows was 1.7 m. The six cultivars of processing tomato were transplanted in open field within the first week of May 2010, 2011 and 2012. In both systems, the amounts of N–P–K supply were based on soil analysis, previous crops and crop nutrient requirements. Nitrogen fertilizers were applied after calculation of N balance to reach the same quantity of total nitrogen (150 N kg ha^{-1}) in both cropping systems. Organic and mineral nitrogen fertilizers were used in the organic and conventional system, respectively. Nitrogen was supplied 90% and 33% at transplant and 10% and 67% from full flowering to fruit and seed ripening in OCS and CCS, respectively. A total of 370, 400 and 400 mm of irrigation water were applied in 2010, 2011 and 2012 respectively, by drip irrigation. Weeds and pests were controlled according to the cultivation protocols of the Campania Region, Italy. During the cropping season, the main meteorological data were collected on a daily basis.

A single harvest was carried out in each cropping system at the end of the growing seasons, i.e. within the first ten days of August 2010, 2011 and 2012, with ripe fruits accounting for approximately 85% of the total fruit harvest. A randomized complete block design was adopted with three replicates in both cropping systems. Each replicate was 4.0 × 5.0 m and contained 60 plants.

2.3. Physiological parameters

During the growing season, physiological parameters were assessed every 15 days in two plants *per* plot starting one month after transplant. The parameters were recorded at 30, 45, 60, 75 and 90 days after transplant (DAT), corresponding to the following five growth stages of crop cycle: 1) beginning of flowering (stage 6.1); 2) full flowering (stage 6.3); 3) beginning of fruit development (stage 7.1); 4) fruit and seed ripening (stage 8.1); 5) fruit maturity (stage 8.9) (Meier, 2001). For the destructive analyses, each year two plants were collected at each sampling date leaving at least another two neighbouring plants on each side. Destructive measurements were performed by digging plants to a