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Title

Physiological responses of processing tomato in organic and conventional Mediterranean cropping systems

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Abstract

Processing tomato is a globally important horticultural crop. It is generally grown in high-input conventional systems, and there is little knowledge regarding its physiological responses in organic cultivation. Therefore, the aim of this work was to determine the influence of organic management on the physiological behavior of cultivars of processing tomato usually cultivated in conventional one in a Mediterranean area. The study was performed by means of: (1) field testing of a set of commercial cultivars for two years in two systems in one location in Southern Italy, and (2) crop physiological investigations during the growth cycle of processing tomato. Results of the two experimental years indicate that, under the organic cropping system, processing tomato showed in average higher intercellular CO_2 concentration (Ci) (+10.3%), transpiration (E) (+15.5%) and stomatal conductance (gs) (+16.5%). Average net assimilation (A) was similar in the two systems (13.21 µmol CO_2 m^{-2} s^{-1}), while average leaf area index (LAI) and average water use efficiency (WUE) were lower in the organic cropping system (-42% and -17.8%), as were average fruit (FDW) and average total (TDW) dry weight (-37.5 and -29%). In our conditions, LAI at the end of the cultivation was highly correlated with total and fruit dry weight. As differences in fruit and total dry weight of processing tomato cannot be explained by differences in net assimilation *per* leaf area unit, other reasons may be linked to the effects of the organic management on the crop as weeds and pests.

Keywords: processing tomato, organic system, conventional system, crop physiology

Highlights

- Equal average net assimilation *per* leaf area unit in both systems
- Lower dry matter production in the organic system
- Average LAI and WUE were lower in the organic system
- Average Ci, E, gs were higher in the organic system

Abbreviations

A = net assimilation

Ci = intercellular CO_2 concentration

E = transpiration

FDW = fruit dry weight

gs = stomatal conductance

LAI = leaf area index

TDW = total dry weight

WUE = water use efficiency

1. Introduction

Processing tomato (*Solanum lycopersicum* L.) is an important and widely consumed vegetable crop throughout the world (Gould 1992). The continuous and great use of external inputs such as water, fertilizers, pesticides etc., is diminishing and polluting the natural resources with a significant impact on environmental and agricultural sustainability. The urgent need for agricultural sustainability has been highlighted in several reports (Dale et al., 2012; Kates et al., 2001; Murmu et al. 2013;   Tilman et al. 2002;). Therefore, to study how to improve alternative agro-ecosystems, such as low input or organic systems, could help to support long-term ecological balance of agro-ecosystems. Organic systems that minimize the environmental effects on cropping environment and maintain soil health and fertility (Mehdizadeh et al., 2013), can represent a possible solution to produce food with fewer external inputs. During the green agriculture revolution, breeding programs developed hybrids and/or cultivars with a high yield potential *per* hectare, with increased disease tolerance and longer shelf life, so these improved plant materials showed a high response to synthetic fertilizers and water supply (Dorais et al., 2008). Therefore, almost all commercial tomato cultivars are suitable for systems that use high amounts of external inputs, as in conventional systems, and few cultivars are now suitable for cultivation in organic systems. Tomato requires large quantities of mineral nutrients, which are supplied by synthetic fertilizers in conventional cultivation, while in organic cropping only organic fertilizers are permitted (Bettiol et al., 2004, De Ponti et al., 2012). Studies on crop physiology and dry matter production of processing tomato suitable for organic system are thus needed. There are few studies on the crop physiology of processing tomato cultivated in organic *vs.* conventional systems, probably because a correct comparison between organic and conventional cropping systems entails plants being cultivated in similar soils and under similar climatic conditions, difficult to obtain especially for soil, because the “organic” soil is different from “conventional” one, for organic matter, nitrogen, bulk density and so on. Despite these issues, studies of crop physiology are crucial in order to understand the adaptation and possible use of cultivars developed for high input in low input systems. Crop physiology lays behind the application of agronomic techniques, which have great influence on dry matter production and dry matter distribution of total plant (Heuvelink, 1996). Dry matter production is an important parameter to compare crops in different cultivation systems or different treatments. Creamer et al. (1996) reported that conventional systems produce more dry matter than organic systems. Moreover, Bettiol et al., (2004), De Ponti et al. (2012), Murphy et al. (2007) and Seufert et al. (2012) reported that organic crop yield is lower than conventional. From a physiological point of view, dry matter production depends on several physiological processes such as net assimilation (A), intercellular CO_2 concentration (Ci), transpiration (E), stomatal conductance (gs) and water use efficiency (WUE) during cultivation. Other important crop parameters, such as leaf area index (LAI), are also very important in understanding differences in crop responses with different treatments or in different agro-ecosystems. To evaluate such parameters, gas exchange analysis is an approach used by several agronomists and physiologists to study crop behavior using different treatments, or to study specific aspects of plant metabolism (Magliulo, 1996).

In fresh-market tomato cultivated in greenhouse condition, gas exchange parameters such as Ci, A, E, gs, were reported in a single study as higher in organic systems than in conventional systems, while other correlated parameters such as WUE, were higher in conventional system than in organic one (Acatrinei, 2010). LAI is an important parameter linked to gas exchange. For processing tomato, LAI is higher in conventional than in organic systems (Cavero et al., 1996). In detailed surveys of organic and conventional systems, Drinkwater et al. (1995) and Stanhill (1990) concluded that other factors such as the different management techniques used, soil type and fertility, water availability, cultivar and yearly weather conditions, have also a great influence on organic and conventional systems. Additional and deep crop physiology research is needed for sustainable agriculture. In this view, the worldwide economically important crop processing tomato can be a reference for the study of crop physiological behavior, to understand how elite commercial cultivars that require high external inputs can adapt and yield in organic and low input systems. Thus, the aim of this work was to assess productivity and physiological parameters of tomato cultivars cropped in organic and conventional cropping systems.

2. Materials and methods

2.1 Plant material

Six commercial cultivars (Auspicio, Regent, Sibari, Augurio, Wally Red, Alican), were selected after an initial survey on a larger set. The six cultivars were selected as a representative sample of the genetic variability of processing tomato cultivated in conventional management in Southern Italy in recent years. Seed companies were also asked to suggest cultivars that, in their opinion, were probably suited also in organic management in Southern Italy. The characteristics of the processing tomato F1 hybrids used for this study are listed in Table 1.

2.2 Field trial and growth conditions

The study started in the Spring-Summer 2010 at Battipaglia, in the Sele Plain, Campania Region, Southern Italy, in two farms, with different organic and conventional managements (Table 2) and was repeated during the Spring-Summer 2011. The site has a Mediterranean climate with mild winters and dry-and-warm summers. The weather conditions of the two growing seasons are reported in the supplementary material (Figure S1). In the two growing seasons (2010 and 2011), the average minimum and maximum temperatures were 16.9-±1.0 and 29.0-±1.0 °C, respectively; the average seasonal rainfalls were 9.3-±1.0 mm *per* cropping season. The organic field trials took place at a privately-owned organic farm named Morella which adopts organic management over 10 years, while the conventional system was managed in fields of the CRA-ORT experimental farm (Table 2). At each sites and in different plots a four-years rotation was used as fallow-pumpkin-spinach-processing tomato and fallow-cauliflower-winter wheat-processing tomato at Morella farm and CRA-ORT, respectively. Crop rotation was selected to minimize the possible adverse effects on the plant health status.The organic and conventional fields had very similar soil types, classified as Typic Haploxerepts (Soil Taxonomy, USDA). Notwithstanding the common soil classification, there were some variations of soil properties within each farm and between each system, due to both geological and historical differences (Table S1).

2.3 Experimental design

Planting densities were three plants m^{-2} (30,000 plants ha^{-1}) for all cultivars tested in each year and in both environments. Plants were transplanted into twin rows, with a distance of 0.4 m between each row of the twin and 0.4 m between plants in the row, while the distance between twin rows was 1.67 m. Each treatment had three replicates each corresponding to 60 plants. The experimental design was set up in a completely randomized experiment whit three replicates, with unit plots of 4 x 5 m wide and contained three twin rows. To ensure uniform water distribution, a drip irrigation system was used with a two-emitter line for each combination of plant rows and drippers of 4 l h^{-1} flow. In both systems, the amounts of N-P-K were based on soil analysis, crop rotation and crop nutrients required. For the organic system, an organic nitrogen fertilizer (N 7%) was used, with the total N amount corresponding to 80 N kg ha^{-1}. For the conventional cropping system, only a mineral nitrogen fertilizer was used, with the total N amount corresponding to 150 N kg ha^{-1},P and K fertilizers were applied before transplanting together as single superphosphate and potassium sulfate respectively with 1/3 of total N requested as ammonium sulfate; the remaining N fertilizer as ammonium nitrate was applied periodically by fertirrigation. The water supply was based on crop evapotranspiration for both environments. For irrigation scheduling, evapotranspiration of the crop (ETc) was calculated as ETc = ETo x Kc, where ETo (reference evapotranspiration) was calculated according to Hargreaves and Samani (1985), and Kc was the crop coefficient of tomato, as reported by Allen et al. (1998), adjusted for the environmental conditions. In each plot 100% ETc was restored when 40% of total available water was depleted, according to the evapotranspiration method of Doorenbos and Pruitt (1977). In the two years of experiment, 370 and 440 mm of irrigation water were applied respectively, a twice-a-week irrigation schedule in both cropping systems. Weeds and pests were controlled according to the production rules of Campania Region. In particular, weeds were controlled by nonchemical management in both cropping systems using mechanical and hand hoeing control. As regards the pests control biological fungicides (sulphur and copper oxychloride) and biological pesticides (azadirachtin A, spinosad and pyrethrins) were used for the organic system, while chemical and biological fungicides (sulphur, copper oxychloride, difenoconazole and aluminum-fosetil) and pesticides (azadirachtin A, imidacloprid, spinosad, abamectin and emamectin benzoate) were used for the conventional system. The main pests and diseases noticed in both cropping systems were Myzus persicae, Tuta absoluta and Tetranychus urticae and Septoria lycopersici and Alternaria alternata respectively.

2.4 Growth and physiological parameters

During the growing seasons, starting from one month after transplant, growth and physiological parameters were assessed every two weeks in two plants *per* plot. The parameters were recorded at the following four stages through the crop cycle: 1) beginning of flowering (stage 6.1; Meier 2001); 2) full flowering (stage 6.3); 3) beginning of fruit development (stage 7.1); 4) fruit and seed ripening (stage 8.1). Leaf gas exchanges A, E, gs, Ci and other correlated parameters, such as WUE, LAI and SPAD, were measured bi-weekly using an open portable system ADC model LCA-4 infrared gas analyser, (Analytical Development Co., Hoddesdon, UK). The system was used in conjunction with a portable temperature and humidity controlled leaf chamber with a surface area of 6.25 cm^2, on young fully expanded leaves, between 11:00 a.m. and 1:00 p.m. with environmental light condition. WUE was calculated as the ratio between net assimilation and transpiration rate (A/E). The leaf area was measured using an area meter LI-3000A. A sub-sample of fresh leaves was run through the leaf area meter to calculate LAI. SPAD values were recorded on the youngest fully expanded leaf using Minolta SPAD-502 (Minolta, Japan) to evaluate the foliar nitrogen status. Two plants were collected at each sampling date for destructive analyses. In both years, destructive plant measurements were performed by digging plants to a soil depth of 40 cm, after which the soil of the undisturbed roots was washed away. The plants were then oven-dried at 65 °C until constant weight was obtained and fruit (ripe and un-ripe) and total (aboveground and underground biomass) dry weights were calculated.

2.5 Statistical analysis

Experimental data were analysed using GenStat software for Analysis of Variance (ANOVA) calculations and using PLS Toolbox software (Eigenvector Research Inc, Wenatchee, WA, USA) for the calculation of Principal Component Analysis (PCA) models (Wold et al., 1987; 1987; Jackson, 1991). The ANOVA was performed using average values of the four measurements during the cropping seasons. The analysis of variance tables (3, 4 and 5) report the average genotypic values of all the stages recorded, while Table 6 reports the analysis of variance of the fourth stage.

The ANOVA tables are divided into two parts: A and B. A shows the genotypic values in organic (ORG) and conventional (CONV) cropping systems in the two separate growing seasons. The P-value shows the difference between the same cultivar in the two cultivation systems, while the Fisher's least significant difference (*lsd*) was calculated for each cropping system and allows to highlight the differences between the cultivars in the same cropping system. B shows the main effects and their interactions for the parameters reported in each table in the two years of cultivation.

Moreover, for each cropping system and each year of cultivation, a Principal Component Analysis (PCA) model was calculated considering, for each cultivar, the average values of the different replicates recorded for the crop physiology parameters and the dry weight. In order to evaluate also the relationships between the analysed objects and the original variables (e.g., to highlight those variables which are mainly responsible for the characterization of a

particular sample or of a group of samples) a graph named *biplot* can be used, which simply consist in the superimposition of the loading plot to the corresponding score plot.
The number of significant PCs, i.e., the number of PCs bearing useful information, indicates the number of fundamentally different properties exhibited by the data set; in the present work, two significant PCs were selected for each analysed dataset.

3. Results

3.1 Physiological parameters

An optimal leaf area index (LAI) plays a fundamental role on photosynthesis of the plants. In the present study, only cropping system had a high influence on LAI, as average of four sampling dates, -42% in organic cropping system (Table 3). The LAI (m^2 m^{-2}) of processing tomato was lower in the organic system than in the conventional system in 2010 (0.82 *vs.* 1.44 m^2 m^{-2}) and in 2011 (0.84 *vs.* 1.42 m^2 m^{-2}). Auspicio, Sibari and Wally Red, showed lower values of LAI when cultivated in the organic system than in the conventional system in 2010, while Regent, Augurio and Alican showed similar values in the two cultivation systems. All cultivars showed similar value of LAI in each cropping system. A similar trend of different responses between genotypes was highlighted in 2011, except for the cultivar Wally Red that showed a similar LAI value in both systems (Table 3). The effect of cropping system on LAI is also shown in the supplementary figures S2 which show the SPAD values and S3, S4, S5, S6 and S7, which report the correlation among the principal parameters investigated in this study during the growing season and showing different slopes of regression equations in the two cropping systems. In these correlations, the trend of LAI assumes consistently lower values in organic system than in conventional one. A useful measure of the photosynthetic efficiency of the plants is net assimilation (A) (µmol CO_2 m^{-2} s^{-1}). In the present study, the year had a high influence on net assimilation (Table 3). The A value was lower in the organic than in the conventional system only in 2010 (12.56 *vs.* 13.21 µmol CO_2 m^{-2} s^{-1}), while in 2011 the same values were recorded in both cultivation systems. However, if we analyze the two years together, net assimilation was similar in both cropping system (Table3). Furthermore, the six cultivars had the same A values in both systems in each year. When each system is analyzed separately, the cultivars tested showed differences in the conventional system only in 2011, with Regent having the highest value (Table 3). Net assimilation is strongly influenced by availability of carbon dioxide: therefore, intercellular CO_2 concentration (Ci) was investigated. For this parameter, the effects of year and system showed a great influence on intercellular CO_2 (Table 4). The Ci (µmol mol^{-1}) was found higher in the organic system than in the conventional system in both years (246.42 *vs.* 222.71 in 2010 and 227.79 *vs.* 206.97 in 2011) and in average was +10.3% in the organic cropping system.

Transpiration is another important character in crop physiology correlated with A and gs. It is driven by differences in vapor pressure and is influenced by environmental factors. Year and cropping system impacted considerably on transpiration (Table 4). Transpiration (E) (mmol H_2O m^{-2} s^{-1}) was higher in the organic than in the conventional system in 2010 and in 2011 (4.49 *vs.* 4.04 and 4.10 *vs.* 3.42) and in average was +15.5%. None of the cultivars showed any differences between the two systems apart from Regent, which in 2010 had a higher value of transpiration in the organic than in the conventional system. Sibari, Alican and Wally Red had the highest transpiration values in the conventional cropping system in 2010, while Augurio had the highest value of E in the conventional cropping system in 2011 (Table 4). Net assimilation rate, intercellular carbon dioxide concentration and transpiration are directly influenced by stomatal conductance. The average stomatal conductance (gs) (mol H_2O m^{-2} s^{-1}) was higher in the organic than in the conventional system in each year of cultivation (0.64 *vs.* 0.59 and 0.61 *vs.* 0.49; Table 5) and in average +10.3%. Not only cropping system, but also year and the interactions genotype × cropping system, genotype × cropping system × year and cropping system × year had a high influence on gs (Table 5). As suggested by the significant interactions, the behavior of cultivars for this parameter was rather different through years and systems. In 2010 Regent had highest gs in the organic system (0.73), while Sibari a lower one, with the highest value in the conventional system (0.75). On the other hand, in 2011, all cultivars showed higher values in the organic system, except for Wally Red. When testing cultivars in the organic management, the year had no effect, while in the conventional system an effect of the season and of the interaction was evident, with Sibari the highest value in 2010 and a far lower one in 2011, with Augurio and Wally Red recording the highest gs values of 2011 (Table 5).

Stomatal conductance is mainly influenced by abiotic stress, in particular water stress; gs also depends on the water status in the plant and, therefore, could influence water use efficiency. In our study, the WUE (µmol CO_2 mmol H_2O^{-1}) (Table 5) was lower in the organic than the conventional system in each year of cultivation (3.30 *vs.* 4.05 and 4.24*vs.* 5.11) and in average -17.8%. The effects of year and cropping system had a significant influence on WUE. Most cultivars did not differ for WUE in terms of management system, in both years, apart from Regent and Augurio that showed higher values in conventional system in 2010. When the six cultivars were analyzed *per* system, Alican and Regent had the highest value in the conventional system in 2011.

3.2 Fruit and Biomass yield

In crop physiology, gas exchange and biomass dry weight data are useful information to understand the responses of horticultural crops in different cropping systems (Magliulo, 1996; Beadle, 2014). Results of fruit and total dry weights collected at the fourth sampling dates (stage 8.1, fruit and seed repening) are shown in Table 6. For FDW (g plant^{-1}), genotype, year and cropping system were statistically significant. The interactions among genotype, year and cropping system, apart from the interaction between genotype and cropping system, were also statistically significant (Table 6). As average among cultivars, FDW was lower in the organic system than in the conventional one in 2010 (108.3 *vs.* 140) and in 2011 (100.7 *vs.* 193.5); in average -37.5%. Each cultivar showed a similar behavior in organic and conventional cropping systems in 2010, except for Auspicio, which showed higher values in conventional one. On the other hand, all cultivars had lower fruit yields in the organic system in 2011, except Sibari and Augurio which reported similar values in both cropping systems. When the six cultivars are analyzed within each cultivation system, Regent showed the highest value of FDW in the organic system in both years (140.5 and 133.0 g plant^{-1}), while in the conventional system the same genotype Regent showed the highest fruit dry weight in 2011 only (293.5 g plant^{-1}), followed by Auspicio (204.0 g plant^{-1}).

If fruit dry weight is the most important component of biomass, total dry weight is a useful trait to improve crop yield as well. TDW (g plant^{-1}) was lower in the organic system than in the conventional one only in 2011 (192.1 *vs.* 326.4), as also highlighted in Figure S7. However if we analyze the two years together, organic cropping system reported -29.0% of TDW (Table 6). The effect of year on TDW was in fact highly significant, as of the cropping system and of the cropping system × year, together with the significance of genotype and genotype × year . In 2011, all cultivars had higher TDW values in the conventional system. Overall, Regent had the highest total dry weight in the organic system in both years of cultivation and the same cultivar showed the highest value in conventional in 2011 only.

3.3 Relationships between physiological parameters and yield

The correlation between physiological parameters and yield was studied by means of PCA. Figure 1 (for organic) and Figure 2 (for conventional) report the biplots of the PCA models calculated for each cropping system in each year of cultivation. To better highlight the associations between physiological behavior, final fruit and total dry weight and the six cultivars during the crop growth cycle, the values corresponding to all four growth stages are represented for each physiological parameter. In both the PCA models calculated for each of the two years, the two first components always represented more than half of variation in the datasets, with PC1 ranging from 30.14 to 43.69%, and PC2 from 24.0 to 27.51%. In both years and in each system it was not possible to identify clear separations into clusters, therefore the results are described in relation to the two important parameters such us final fruit and total dry weight. In general, FDW and TDW, as expected, are always highly associated in all years and systems, since they are close each other in all the four plots (Figures 1 and 2).

For the organic system in 2010 both FDW and TDW do not make a significant contribution to the variations between the different genotypes, since they both lie close to the axes origin (Figure 1a). As far as the parameters that mainly characterize the various genotypes, Wally Red has the highest values of LAI2, Ci3, WUE2 and LAI1, Sibari has the highest values of A2, gs1, E1 and A1, Alican has the highest values of WUE3 and, together with Auspicio, also of LAI3 and gs2; this latter genotype has also the highest values of E2. Regent has the highest values of A3, WUE4, gs3, gs4 and E3, while Augurio, which lies close to the axes origin, in general shows intermediate values for the considered parameters.

As far as the results of 2011are regarded, FDW and TDW are associated to the latest value of LAI (LAI 4, at stage 8.1) in the organic system (Figure 1b). If we consider single cultivars, both the FDW and the TDW values are particularly high for Regent.

Figure 2a shows relationships between physiological parameters and dry weights in the conventional system in 2010. In this case FDW and TDW were highly correlated and mainly influenced by gs 4, Ci 4, LAI 3, and LAI 4. This cluster of variables was the tightest of all the four representations; on the other hand, several physiological parameters seem not associated to the fruit and biomass yields, in opposite orientation, such as WUE 4 and A 4. Among cultivars, Sibari is the genotype most associated to FDW and TDW, while Regent that lies on the opposite side to FDW and TDW with respect to the axes origin is the genotype with the lowest values of dry weight.

If we compare these results with those of the conventional system in 2011 (Figure 2b), a different situation is observed. WUE 3 is more associated to dry weight than in 2010, and A 4 showed a contrasting behavior in the two years: related to DW in 2011, while far distant from it in 2010. Among cultivars, Regent instead of Sibari is the genotype most associated to FDW and TDW, while Augurio is the cultivar showing the lowest dry weight values. Summarizing across systems, LAI in the later stage, (LAI 4), is the physiological parameter most consistently associated to fruit and total dry weight. The positive correlation between LAI 4 and dry matter production is also highlighted in Figures S5 and S6. Among cultivars, Regent is more often associated to both fruit and total dry weights across systems, except for the conventional cropping system in 2010, where conversely it shows the lowest values.

4. Discussion

Organic systems could be one of the ways to improve agricultural sustainability. Although there are several studies on the productivity and quality of horticultural crops in organic and conventional systems (Bettiol et al., 2004; Creamer et al., 1996, De Ponti et al. 2012; Herencia et al., 2011; Murphy et al. 2007; Pieper and Barrett, 2009; Seufert et al. 2012), to the authors knowledge scarce are the papers about physiological investigations of processing tomato in the organic management systems. Although in a single location, the experimental data were obtained in a panel of six modern cultivars, from two years of replicated field trials, in a specialized tomato-growing area of Mediterranean basin.

Table 3 shows that the cropping system had a high effect on LAI, in turn associated to dry weight by PCA in Figures 1 and 2, while net assimilation was greatly influenced by year. The yearly variability is mainly explained by different weather condition as reported in Figure S1 and by Rinaldi et al. (2007b). An adequate leaf area index is necessary for the optimal cultivation of processing tomato, and we observed a reduction in LAI in the organic management. The average leaf area index (LAI) reported in Table 3 ranged from 0.72 to 0.97 (m^2 m^{-2}) in the organic cropping system and from 1.11 to 1.94 (m^2 m^{-2}) in the conventional one, as average through the growth cycle. In the present study, the lowest LAI recorded in the organic cropping system is probably directly due to the organic form of fertilizers and biological pesticides used. In fact as reported in Figure S2 and in TableS1 the organic cropping system showed a lower availability of nitrogen in leaves especially in the end of crop cycle (Figure S2) confirmed also by higher presence of total nitrogen in the soil at fourth sampling date (Table S1). As far as cultivar response is regarded, interestingly some of them, *e.g.* Regent, did not reduce significantly their LAI under organic cultivation, while others, such as Auspicio, Sibari and Wally Red, did (only in 2010; Table 3). This might be an important consideration for breeding, if one jointly observes results of Table 6, where Regent is among the highest fruit yielding varieties in 2010 and 2011 in organic system (140.5 and 133.0 g plant^{-1}). The values of LAI of the present work obtained in the conventional system are in accordance with other studies performed only in conventional management (Cantore et al., 2009; Galmes et al., 2011; Maggio et al., 2004; Patanè et al., 2011; Rinaldi et al., 2007a; Topcu et al., 2007). Although other authors have reported different LAI values (Matsuda et al., 2011; Heuvelink, 1996), notably these studies were implemented in greenhouse conditions and on fresh market tomato. Other interesting information on LAI is shown in figure S6 and S7. These figures highlight how the leaf area index increased more in the conventional system than in the organic one, with highest differences in the fruit development stage.

The health and the functionality of leaves could affect the net assimilation. In this study, average net assimilation (A) ranged from 12.17 to 14.09 (µmol CO_2 m $^{-2}$ s $^{-1}$) in the organic cropping system and from 11.92 to 14.38 (µmol CO_2 m $^{-2}$ s $^{-1}$) in the conventional one (Table 3). The factors that influenced LAI and net assimilation are most likely related to crop management, *i.e*. the mineral nitrogen nutrition and the protection of the green leaf area from pathogens by chemical foliar spray application. The present results of A for processing tomato in conventional system are in accordance with other studies performed on processing tomato cultivated in open field (Cantore et al., 2009; Valerio et al., 2013), and with two reports of fresh market tomato cultivated in greenhouse conditions (Matsuda et al., 2013; de Groot et al., 2003). However, they are not in accordance with the two greenhouse studies of Lovelli et al. (2012) and Matsuda et al. (2011). Moreover, Matsuda et al. (2011) worked with high CO_2 concentration. The differences observed are probably due to the different genetic materials tested and to the different cultivation environment, open field *vs.* greenhouse.

As the net assimilation rate is linked to leaf transpiration rate, we found that also the average intercellular CO_2 concentration (Ci) and average transpiration (E) were affected by cropping system and year. The Ci shown in Table 4 ranged from 215.92 to 264.75 (µmol mol^{-1}) in the organic cropping system and from 201.08 to 251.33 (µmol mol^{-1}) in the conventional one. The highest Ci in the organic system could well be caused by higher stomatal conductance, which allowed more CO_2 intracellular concentration. The results are in accordance with Karanatsidis and Berova (2009) in pepper. These authors reported similar trends between organic and conventional cropping systems, with higher values of Ci in organic systems than conventional ones. Other authors who worked only in conventional systems (Cantore et al., 2009; Lovelli et al., 2012) reported similar Ci values for processing tomato. The average values of E were ranging from 3.85 to 4.76 (mmol H_2O m^{-2} s^{-1}) in the organic cropping system and from 3.29 to 4.45 (mmol H_2O m^{-2} s^{-1}) in the conventional one (Table 4), with average transpiration being higher in the organic cropping system than the conventional one. The highest E in the organic system linked to higher stomatal conductance in the same system would suggest that organically grown plants, possibly under nutritional stress, as reported in Figure S2 a and b in the last part of crop cycle, tried to increase the uptake of mineral nutrients from the soil through an increase of transpiration. Acatrinei (2010) and Karanatsidis and Berova (2009) reported a similar E trend, while different E values have been reported for tomato cultivated only in conventional systems (Campos et al., 2009; Cantore et al., 2009; Lovelli et al., 2012; Ozbahce et al., 2010; Patanè et al., 2011). However, some of these authors worked in greenhouse conditions, and Ozbahce et al. (2010) in semi-arid conditions. Higher values of E were reported by Cantore et al. (2009) and Patanè et al. (2011) which worked in similar field conditions to ours, but different plant densities 2.6 plant m^{-2} and 2.5 plant m^{-2} respectively together with a different environmental cropping system could explain differences. Furthermore Cantore et al. (2009) used system with (PAR_{in}) at 2000 μmol_{photon} m^{-2} s^{-1}, and CO_2 concentration, provided by an external CO_2 tank, at 360 μmol mol^{-1}.

The physiological behavior of plants and physiological parameters, such as photosynthesis, are strongly influenced by stomatal opening, which also influences water use efficiency. In this research, results on stomatal conductance (gs) and water use efficiency (WUE) showed that in organic cropping system processing tomato had higher gs and lower WUE (Table 5). Interaction of genotype × cropping system, cropping system × year and genotype × cropping system × year had a significant effect only for gs. Stomatal conductance (gs) was the most sensitive character and good indicator of poor irrigation and water stress found in two physiological studies in tomato (Jensen et al., 2010; Medrano et al., 2002). In the present study, where adequate water supply was guaranteed to plots, the higher value of stomatal conductance in the organic system could be due to higher nutritional stress. In fact, although the field trials were designed and managed to supply the same amount of nutrients to both systems, organic fertilization with a slower release of readily available nitrogen probably led the plants towards higher E and greater stomata opening. In fact, as highlighted in Table S1, organic cropping system reported higher level of total nitrogen in the soil at fourth stage. The higher gs measured in the organic system could also have a physiological explanation. In fact, with same weather and irrigation, we measured a lower LAI, that means lower transpiration surface *per* plant and consequently a higher transpiration rate for unit leaf area (E). Finally, as hypothesized before, plants in the organic system could have tried to increase the uptake of nutrients from the soil through transpiration.

In the present study WUE was measured as the ratio between A and E, therefore it is directly dependent on these two variables. Average WUE in this research ranged from 3.04 to 4.59 (µmol CO_2 mmol H_2O^{-1}) in the organic cropping system, and from 3.76 to 5.80 (µmol CO_2 mmol H_2O^{-1}) in the conventional one (Table 5). The conventional system had higher average WUE values than the organic one. The higher stomatal opening and higher transpiration in the organic system *vs*. conventional are likely the main reasons for the lowest WUE in the organic management. A similar WUE trend in the two systems was reported by Acatrinei (2010). The results obtained in the conventional system are also in accordance with WUE values reported by Lovelli et al. (2012) and Campos et al. (2009).

Table 6 separately reports fruit and total dry weight. Genotype, year, cropping system, and most interactions, except for genotype × cropping system, had a great effect on fruit and total dry weight, suggesting a complex control of the trait, depending by several factors. A second highlight is about the observation of a conspicuous dry matter gap. Organic system showed an average reduction of 29% of total dry matter production compared to the conventional system, being more in accordance with De Ponti et al. (2012) and Seufert et al. (2012) than with other report dealing with quality of organic foods (e.g. Pieper and Barrett, 2009). The recorded FDW of the present study is the sum of ripe and un-ripe fruit; it ranged from 77.0 to 133.0 (g plant^{-1}) in the organic cropping system and from 105.5 to 293.5 (g plant^{-1}) in the conventional one (Table 6). TDW, calculated as the sum of aboveground and belowground biomass, ranged from 145.0 to 276.0 (g plant^{-1}) in the organic cropping system and from 184.0 to 334.0 (g plant^{-1}) in the conventional one (Table 6). The differences in fruit and total dry weight between systems cannot be explained by differences in net assimilation *per* leaf area unit. Other reasons for them could be the effects of the organic management such as the abundance of weeds as reported by Farneselli et al., 2013 and abundance of fungi and pests (data not shown) especially in the last phase of the growing cycle. Furthermore as reported in Figure S2 and in Table S1, SPAD values were lower in organic cropping system in the end of crop cycle and in addition, the amount of total nitrogen in the soil was higher in organic one at fourth stage. All together, these management factors likely contributed to limit LAI together with dry matter production.

The FDW results obtained in the conventional system in the present study are in accordance with Jensen et al. (2010), who worked on processing tomato in similar conditions in Northern Italy, and in accordance with Zotarelli et al. (2009), who worked on processing tomato in Florida (USA). However, other authors have reported different values of FDW in conventional agriculture (Elia and Conversa, 2012; Johannes et al., 2000). Elia and Conversa (2012) reported values ranged from 214.0 and 285.0 (g plant^{-1}) used a standard determinate processing tomato cultivar (Perfectpeel) in Southern Italy, with 2.8 plants m^{-2}, at slightly lower density than ours, but using 300 N units per hectare, at double dosage respect to N fertilization of the present study. Johannes et al., (2000) reported higher values of FDW but studied the standard commercial variety Sunny in Florida, a bushy-type semi-vining (determinate) cultivar with large fruits, but at the lower density of 0.9-1.2 plants m^{-2}, which could be the main reason for the differences observed. The TDW results in the conventional system are in accordance with some previous studies (Jensen et al., 2010; Valerio et al., 2013), while other authors have reported values up to 500 - 900 g dry weight *per* plant (Elia and Conversa 2012; Johannes et al., 2000). The probable reasons for the different results obtained by Elia and Conversa (2012) and by Johannes et al. (2000) are those explained above for FDW.

The multivariate analysis reported in Figure 1 and Figure 2 illustrates the complexity of the interactions among the physiological variables and their possible effects on fruit and total DW. Differences between systems and years are evident. For example, in 2010, many crop physiology parameters resulted correlated with fruit and total dry weight, and the effect of net assimilation was not evident. In 2011, on the other hand, dry matter production was correlated with fewer parameters and in particular with leaf area index (LAI 4). Notwithstanding complexity, the PCA results indicated the high importance of maintaining an adequate LAI not only as average through the growth cycle, as discussed before, but especially in the last phase of the growing season, for fruit and total dry weight in both systems. From multivariate analysis, other correlations of physiological parameters with FDW and TDW are less clear and consistent through years.

The results of multivariate analysis, together with the evidences about LAI stability under organic cultivation, as discussed before, suggest Regent as a suitable processing tomato genotype for the organic cropping system in Southern Italy. It would deserve deeper studies to understand if Regent corresponded to a specific ideotype. However, this is a first indication that cultivars with elongated fruit, medium vegetative force and medium level of resistance to pathogens (Table 1) could be more suitable than the other cultivars assayed in organic cultivation, in the environment of study.

5. Conclusions

The organic system negatively influenced leaf area index, water use efficiency, fruit and total dry weight of processing tomato. On the other hand, the organic cropping systems increased intercellular CO_2 concentration, transpiration and the stomatal conductance of processing tomato. The higher transpiration level and the higher intercellular CO_2 concentration in the organic system is, however, not correlated with a reduction in net assimilation, while the higher transpiration level in the organic system is coupled to lower WUE and higher stomatal conductance in the organic system. For all genotypes investigated, an adequate leaf area index is necessary for a good dry matter production in the last phase of the growing cycle in both cropping systems. In particular, cultivars that show a stable LAI in both cropping systems, medium force and elongated fruit can be better suited for organic cultivation.

6. Appendix A. Supplementary data

Table S1, Figure S1, S2, S3, S4, S5, S6, S7.

7. Acknowledgements

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Tables

Table 1.

Cultivars tested in the organic and conventional cropping systems. Resistances as declared by the seed companies.

Cultivar	**Company**	**Resistances**	**Vegetative Vigour**
Long fruit			
AUSPICIO F1	CLAUSE	V, F1-2, N, Pto, TSWV*	high
REGENT F1	ISI SEMENTI	V, F1, N, Pto	medium
SIBARI F1	SATIVA	V, F2	high
Blocky fruit			
AUGURIO F1	CLAUSE	V, F1-2, N, Pto*, TSWV	medium
WALLY RED F1	ESASEM	V, F1-2, N*	medium/high
ALICAN F1	ISI SEMENTI	V, F1	high

V= *Verticillium* spp.
F= *Fusarium oxysporum* f.sp. l*ycopersici* (1 and 2)
N= Galligen Nematoda (*Meloidogyne incognita, arenaria, javanica*)
Pto= *Pseudomonas syringae* pv. *tomato*
TSWV= Tomato Spotted Wilt Virus
*= partial resistance

Table 2.

Field trial sites of processing tomato in the two systems for the 2010 and 2011 harvests.

Site	Year	Location (Lat Long)	Sowing date	Harvest date	Average T min (°C)	Average T max (°C)	Average seasonal rainfall (mm)
ORG	2010	Morella 40° 36' N; 14° 56' E	30/04/2010	02/08/2010	14.4	30.3	14.2
ORG	2011	Morella 40° 36' N; 14° 56' E	06/05/2011	17/08/2011	16.9	28.0	4.1
Average					**15.7**	**29.2**	**9.2**
CONV	2010	CRA-ORT 40° 35' N; 14° 58' E	30/04/2010	09/08/2010	18.6	29.2	11.3
CONV	2011	CRA-ORT 40° 35' N; 14° 58' E	07/05/2011	11/08/2011	17.3	28.2	7.5
Average					**18.0**	**28.7**	**9.4**

Lat = latitude, Long = longitude, T = temperature, min = minimum, max = maximum

ORG = organic system, CONV = conventional system

Table 3.

Analysis of variance of leaf area index (LAI) and net assimilation (A) during the 2010 and 2011 growing seasons.

Source of variation	**LAI (m^{2} m^{-2})**			**A (μmol CO_2 m^{-2} s^{-1})**		
	ORG	**CONV**	**p-value**	**ORG**	**CONV**	**p-value**
A. Average genotypic values in organic (ORG) and conventional (CONV) cropping systems in the two growing seasons. n.s., not significantly different at P ≤.05.						
2010 growing season						
AUSPICIO	0.82	1.68	<.05	12.39	12.64	n.s.
REGENT	0.84	1.11	n.s.	12.35	12.31	n.s.
SIBARI	0.87	1.94	<.05	13.19	13.87	n.s.
AUGURIO	0.80	1.31	n.s.	12.17	13.13	n.s.
WALLY RED	0.72	1.34	<.05	12.75	13.95	n.s.
ALICAN	0.88	1.26	n.s.	12.54	13.35	n.s.
average	*0.82*	*1.44*	*<.05*	*12.56*	*13.21*	*<.05*
lsd	*0.44*	*0.98*		*1.75*	*2.10*	
2011 growing season						
AUSPICIO	0.75	1.41	<.05	13.65	11.92	n.s.
REGENT	0.84	1.36	n.s.	14.09	14.38	n.s.
SIBARI	0.90	1.56	<.05	13.86	12.32	n.s.
AUGURIO	0.97	1.45	n.s.	13.24	14.30	n.s.
WALLY RED	0.74	1.28	n.s.	13.54	14.06	n.s.
ALICAN	0.86	1.42	n.s.	13.03	14.17	n.s.
average	*0.84*	*1.42*	*<.05*	*13.57*	*13.52*	*n.s.*
lsd	*0.33*	*0.31*		*2.65*	*2.21*	
B. Significance of variables and of their interactions for LAI and A.						
GENOTYPE			n.s.			n.s.
RIP			n.s.			n.s.
YEAR			n.s.			<.01
CROPPING SYSTEM			<.001			n.s.
GENOTYPE*YEAR			n.s.			n.s.
GENOTYPE*CROPPING SYSTEM			n.s.			n.s.
CROPPING SYSTEM*YEAR			n.s.			n.s.
GENOTYPE*CROPPING SYSTEM*YEAR			n.s.			n.s.

Table 4.

Analysis of variance of intercellular CO_2 concentration (Ci) and transpiration (E) during the 2010 and 2011 growing seasons.

Source of variation	**Ci (µmol mol^{-1})**			**E (mmol H_2O m^{-2} s^{-1})**		
	ORG	**CONV**	**p-value**	**ORG**	**CONV**	**p-value**
A. Average genotypic values in organic (ORG) and conventional (CONV) cropping systems in the two growing seasons. n.s., not significantly different at P >.05.						
2010 growing season						
AUSPICIO	240.50	217.50	n.s.	4.55	3.90	n.s.
REGENT	243.70	219.06	n.s.	4.55	3.61	<.05
SIBARI	264.75	251.33	n.s.	4.76	4.45	n.s.
AUGURIO	240.92	209.33	n.s.	4.48	3.88	n.s.
ALICAN	236.83	214.80	n.s.	4.23	4.17	n.s.
WALLY RED	251.83	224.25	n.s.	4.38	4.21	n.s.
average	*246.42*	*222.71*	*<.05*	*4.49*	*4.04*	*<.05*
lsd	*96.50*	*108.20*		*0.61*	*0.53*	
2011 growing season						
AUSPICIO	219.17	218.17	n.s.	3.93	3.30	n.s.
REGENT	215.92	201.92	n.s.	3.98	3.29	n.s.
SIBARI	231.17	201.08	n.s.	3.96	3.35	n.s.
AUGURIO	235.08	211.08	n.s.	4.41	3.86	n.s.
WALLY RED	231.50	216.17	n.s.	4.47	3.40	n.s.
ALICAN	233.92	193.42	n.s.	3.85	3.33	n.s.
average	227.79	206.97	<.05	4.10	3.42	<.05
lsd	71.24	87.20		0.77	0.34	
B. Significance of variables and of their interactions for Ci and E.						
GENOTYPE			n.s.			n.s.
RIP			n.s.			n.s.
YEAR			<.001			<.001
CROPPING SYSTEM			<.001			<.001
GENOTYPE*YEAR			n.s.			n.s.
GENOTYPE*CROPPING SYSTEM			n.s.			n.s.
CROPPING SYSTEM*YEAR			n.s.			n.s.
GENOTYPE*CROPPING SYSTEM*YEAR			n.s.			n.s.

Table 5.

Analysis of variance of stomatal conductance (gs) and water use efficiency (WUE) during the 2010 and 2011 growing seasons.

Source of variation	**gs (mol H_2O m^{-2} s^{-1})**			**WUE (μmol CO_2 mmol H_2O^{-1})**		
	ORG	**CONV**	**p-value**	**ORG**	**CONV**	**p-value**
A. Average genotypic values in organic (ORG) and conventional (CONV) cropping systems in the two growing seasons. n.s., not significantly different at P >.05.						
2010 growing season						
AUSPICIO	0.58	0.56	n.s.	3.34	3.82	n.s.
REGENT	0.73	0.50	<.05	3.23	4.24	<.05
SIBARI	0.60	0.75	<.05	3.04	3.76	n.s.
AUGURIO	0.60	0.56	n.s.	3.24	4.15	<.05
WALLY RED	0.68	0.58	n.s.	3.49	3.97	n.s.
ALICAN	0.64	0.59	n.s.	3.53	3.98	n.s.
average	*0.64*	*0.59*	*<.05*	*3.30*	*4.05*	*<.05*
lsd	*0.18*	*0.11*		*0.53*	*1.16*	
2011 growing season						
AUSPICIO	0.60	0.46	<.05	4.43	4.65	n.s.
REGENT	0.63	0.44	<.05	4.43	5.60	n.s.
SIBARI	0.55	0.46	<.05	4.59	4.79	n.s.
AUGURIO	0.63	0.55	<.05	3.91	4.74	n.s.
WALLY RED	0.61	0.56	n.s.	3.97	5.08	n.s.
ALICAN	0.63	0.46	<.05	4.10	5.80	n.s.
average	*0.61*	*0.49*	*<.05*	*4.24*	*5.11*	*<.05*
lsd	*0.10*	*0.04*		*0.75*	*0.53*	
B. Significance of variables and of their interactions for gs and WUE.						
GENOTYPE			n.s.			n.s.
RIP			n.s.			n.s.
YEAR			<.001			<.001
CROPPING SYSTEM			<.001			<.001
GENOTYPE*YEAR			n.s.			n.s.
GENOTYPE*CROPPING SYSTEM			<.001			n.s.
CROPPING SYSTEM*YEAR			<.05			n.s.
GENOTYPE*CROPPING SYSTEM*YEAR			<.05			n.s.

Table 6.

Analysis of variance of fruit dry weight (FDW) and total dry weight (TDW) during the 2010 and 2011 growing seasons measured at fruit and seed ripening (stage 8.1).

Source of variation	**FDW (g plant^{-1})**			**TDW (g plant^{-1})**		
	ORG	**CONV**	**p-value**	**ORG**	**CONV**	**p-value**
A. Genotypic dry weight values in organic (ORG) and conventional (CONV) cropping systems at the fourth stage in the two growing seasons. n.s., not significantly different at P >.05.						
2010 growing season						
AUSPICIO	86.0	165.5	<.05	165.5	262.5	n.s.
REGENT	140.5	105.5	n.s.	235.5	184.0	n.s.
SIBARI	95.0	165.0	n.s.	187.5	267.0	n.s.
AUGURIO	124.5	137.0	n.s.	207.0	220.0	n.s.
WALLY RED	81.0	120.0	n.s.	145.0	203.0	n.s.
ALICAN	122.5	150.5	n.s.	213.5	257.5	n.s.
average	*108.3*	*140.6*	*<.05*	*192.3*	*232.3*	*n.s.*
lsd	*49.8*	*83.5*		*79.3*	*131.7*	
2011 growing season						
AUSPICIO	77.0	204.0	<.05	164.0	334.0	<.05
REGENT	133.0	293.5	<.05	276.0	439.0	<.05
SIBARI	97.5	156.5	n.s.	192.0	309.0	<.05
AUGURIO	110.5	154.0	n.s.	183.5	279.5	<.05
WALLY RED	94.0	183.5	<.05	170.5	323.5	<.05
ALICAN	92.0	169.5	<.05	166.5	273.5	<.05
average	*100.7*	*193.5*	*<.001*	*192.1*	*326.4*	*<.001*
lsd	*43.5*	*15.3*		*69.4*	*97.7*	
B. Significance of variables and of their interactions for FDW and TDW.						
GENOTYPE			<.05			<.05
RIP			n.s.			n.s.
YEAR			<.05			<.001
CROPPING SYSTEM			<.05			<.001
GENOTYPE*YEAR			<.05			<.05
GENOTYPE*CROPPING SYSTEM			n.s.			n.s.
CROPPING SYSTEM*YEAR			<.001			<.001
GENOTYPE*CROPPING SYSTEM*YEAR			<.05			n.s.

Figure Captions

Figure 1.

Biplots of PCA results for organic cropping system in 2010 (a) and 2011 (b). All parameters investigated (A, LAI, Ci, gs, WUE, E, FDW, and TDW) are in relation with the tested cultivars (names in capital letters). Numbers 1 to 4 following the parameter investigated indicate the growth stages, as described in materials and methods.

Figure 2.

Biplots of PCA results for conventional cropping system in 2010 (a) and 2011 (b). All parameters investigated (A, LAI, Ci, gs, WUE, E, FDW, and TDW) are in relation with the tested cultivars (names in capital letters). Numbers 1 to 4 following the parameter investigated indicate the growth stages, as described in materials and methods.

Supplementary Tables

Table S1.

Soil characteristics of the four fields where trials were conducted in the 2010 and 2011 growing seasons.

Soil characteristics	**ORGANIC**		**CONVENTIONAL**	
	2010	**2011**	**2010**	**2011**
Sand (%)	17.0	20.4	28.0	26.8
Silt (%)	43.0	44.5	41.0	40.8
Clay (%)	40.0	35.1	31.0	32.4
pH	7.9	8.1	7.1	7.8
Limestone (%)	4.2	7.2	4.5	2.4
K_2O (mg/Kg)	441.0	465.0	264.0	324.0
P_2O_5 (mg/kg)	96.0	64.1	91.0	126.0
N. tot. (‰)	1.0	1.8	1.0	1.3
Organic matter (%)	3.1	2.6	1.6	1.6
CSC (meq/100 g)	25.2	27.9	10.5	18.3
N. tot. (‰) at fourth sampling	1.6	1.7	0.9	1.3

Supplementary Figures

Figure S1.

Weather data: minimum temperature, maximum temperature and rainfall were collected for both environments and in each growing season. O = organic cropping system. C = conventional cropping system. Hist. = Historical data. Min. = minimum. Max = maximum. Temp. = temperature. A red arrow indicates the beginning of cultivation in both systems, a green arrow indicates the end of the cultivation in the conventional system, while a blue one the end of the cultivation in the organic system. (a) Weather conditions in 2010. (b) Weather conditions in 2011.

Figure S2.

SPAD values in organic and conventional cropping systems. a) SPAD values in the 2010 growing season. b) SPAD values in the 2011 growing season. Green line is for the organic and blue is for the conventional systems. Asterisks indicate the statistically significant differences at $P < 0.05$

Figure S3.

Net assimilation (A) correlated with other physiological parameters (gs, E, Ci, and LAI). a) Correlation between data collected in the 2010 growing season. b) Correlation between data collected in the 2011 growing season. Color scale (from dark to light) indicates the four stages from 1 to 4. Green symbols are for the organic and blue are for the conventional systems. Rhombus = Augurio, square = Wally Red, triangle = Alican, long hyphen = Auspicio, short hyphen = Regent, circle = Sibari. A green line indicates linear regression of data in the organic system, while the straight a blue line linear regression of data in conventional system. The equation and regression coefficient of organic cropping system is on the left of figure while the equation and regression coefficient of conventional one is on the right.

Figure S4.

Stomatal conductance (gs) correlated with other physiological parameters (E, Ci, and LAI). a) Correlation between data collected in the 2010 growing season. b) Correlation between data collected in the 2011 growing season. Color scale (from dark to light) indicates the four stages from 1 to 4. Green symbols are for the organic and blue are for the conventional systems.

Rhombus = Augurio, square = Wally Red, triangle = Alican, long hyphen = Auspicio, short hyphen = Regent, circle = Sibari. A green line indicates linear regression of data in the organic system, while the straight a blue line linear regression of data in conventional system. The equation and regression coefficient of organic cropping system is on the left of figure while the equation and regression coefficient of conventional one is on the right.

Figure S5.

Transpiration (E) correlated with other physiological parameters (Ci and LAI), and Ci correlated with LAI. a) Correlation between data collected in the 2010 growing season. b) Correlation between data collected in the 2011 growing season. Color scale (from dark to light) indicates the four stages from 1 to 4. Green symbols are for the organic and blue are for the conventional systems. Rhombus = Augurio, square = Wally Red, triangle = Alican, long hyphen = Auspicio, short hyphen = Regent, circle = Sibari. A green line indicates linear regression of data in the organic system, while the straight a blue line linear regression of data in conventional system.

The equation and regression coefficient of organic cropping system is on the left of figure while the equation and regression coefficient of conventional one is on the right.

Figure S6.

Fruit dry weight (FDW) correlated with physiological parameters (A, gs, E, Ci, and LAI). a) Correlation between data collected in the 2010 growing season. b) Correlation between data collected in the 2011 growing season. Color scale (from dark to light) indicates the four stages from 1 to 4. Green symbols are for the organic and blue are for the conventional systems. Rhombus = Augurio, square = Wally Red, triangle = Alican, long hyphen = Auspicio, short hyphen = Regent, circle = Sibari. A green line indicates linear regression of data in the organic system, while the straight a blue line linear regression of data in conventional system.

The equation and regression coefficient of organic cropping system is on the left of figure while the equation and regression coefficient of conventional one is on the right.

Figure S7.

Total dry weight (TDW) correlated with physiological parameters (A, gs, E, Ci, and LAI). a) Correlation between data collected in the 2010 growing season. b) Correlation between data collected in the 2011 growing season. Color scale (from dark to light) indicates the four stages from 1 to 4. Green symbols are for the organic and blue are for the conventional systems. Rhombus = Augurio, square = Wally Red, triangle = Alican, long hyphen = Auspicio, short hyphen = Regent, circle = Sibari. A green line indicates linear regression of data in the organic system, while the straight a blue line linear regression of data in conventional system. The equation and regression coefficient of organic cropping system is on the left of figure while the equation and regression coefficient of conventional one is on the right.