YIELD AND QUALITY OF EGGPLANT (*Solanum melongena* L.) AS AFFECTED BY COVER CROP SPECIES AND RESIDUE MANAGEMENT

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ABSTRACT

The aim of this study was to assess the effect of winter cover crops (hairy vetch, oat and oilseed rape) and their residue management (conventionally tilled and no-tilled soil) on eggplant yield and fruit quality. Hairy vetch residues showed high nitrogen accumulation, low C:N ratio and they improved the marketable yield, size, firmness, dry matter and soluble solids content of eggplant fruit (var. Mirabella) as well as potentially affecting pericarp color and lead to early fruit maturation. However, oat and oilseed rape residues showed poor nitrogen accumulation which affected both low eggplant yield and fruit quality due to high phenol content causing significant changes in color after slicing. Titratable acidity did not differ among treatments, while pH was slightly higher in fruit from tilled than no-tilled soils. The results suggest that hairy vetch residues placed on the soil surface as organic mulch could effectively improve eggplant yield and fruit quality.

KEYWORDS: sustainable agriculture, cover crop, residue management, color development, maturation stage

INTRODUCTION

Vegetable crops are commonly grown in tilled soil in order to prepare the bed for transplanting. Moreover, fertilizers, drip irrigation, and polyethylene mulches are also used to ensure high crop yield and control weeds. Although these practices are aimed at improving crop performance, they can also lead to a rapid decline of the agro-ecosystem characteristics and consequently cause a reduction in both crop yield and fruit quality (Tilman et al., 2002). In particular, yield decline appears to be related to poor soil fertility conditions mainly attributed to the reduction of organic matter levels combined with an increase in the incidence of soil-borne diseases (Fageria et al., 2005). Consequently, it is essential to develop sustainable farming practices such as cover cropping as alternative solutions (Tilman et al., 2002). The term cover crop is used to indicate a wide range of plants that are grown in rotation for various agro-ecological benefits (Hartwig and Ammon, 2002). Cover crops could play a key role in sustainable cropping systems (Sarrantonio and Gallandt, 2003) as they protect and feed the soil, promote nutrient availability and balance, reduce weed pressure and provide habitat for beneficial insects (Hartwig and Ammon, 2002). In the Mediterranean environment, before transplanting the following summer vegetable crops, winter cover crop residues can be incorporated into the soil as a green manure in conventional agriculture systems, or alternatively the cover crops aboveground biomass can be left, uniformly by the adoption of roller crimper (Canali et al., 2013) or in strips by the adoption of hay-conditioner (Campiglia et al., 2011b), on the soil surface as organic dead mulches in conservation agriculture systems. Recently, the adoption of organic dead mulches in no-till strategy has received increasing interest in vegetable cropping systems due to their capability to supply plant nutrients (Canali et al., 2013), control weeds (Ciaccia et al., 2015; Radicetti et al., 2013) and maintain soil quality (Mancinelli et al., 2015). Although cover-crop mulches provide valuable benefits (Canali et al., 2013), several agronomical constrains, such as cover crop re-growth and poor crop planting, could limit the success of conservation tillage strategy based on cover-crop mulch (Luna et al., 2012).

The eggplant (*Solanum melongena* L.) is one of the top ten vegetable foodstuffs in the Mediterranean diet and the main producer of eggplant fruits of all European Countries is Italy where it is cultivated in open field during the spring-summer period or in greenhouses from September to December (Moncada et al., 2013). The eggplant has a high antioxidant capability due to its content of chlorogenic acid, anthocyanin pigments and/or nasunin (Mennella et al., 2012). In general, the phenolic content of the eggplant fruit mainly depends on cultivar and pre-harvest factors such as environment and agricultural practices (Moncada et al., 2013; Singh et al., 2009). Moreover commercially, eggplant are harvested and consumed when the fruit are immature, before a substantial seed development (Arasimowicz and Gajewski, 2004). Mature eggplant fruits are considered unmarketable due to their unpleasant fruit color, texture, pithy and bitter taste as well as the large amount of mature seeds. In general, eggplant pericarp color is considered to be a pre-maturity indicator of the fruit (Cantwell and Suslow, 1997); in fact, the dark-purple color and pericarp glossiness gradually increase prior to maturation stage. Moreover, tissue texture, which depends on both softening enzymes and water loss, is a limiting factor for fresh-market eggplant fruit (Beaulieu et al., 2004). In fact, texture is related to the intrinsic characteristics of the fruit such as size, maturity stage, cuticle thickness and natural wax on the fruit surface (Díaz-Pérez et al., 2007). Consequently, maturation indices such as firmness, peel luminance and soluble solid and phenol contents are strictly related to the quality attributes of the eggplant fruit (Mennella et al., 2012).

It is well-known that some agricultural practices which produce high marketable yields often result in less than optimal organoleptic and nutraceutical fruit qualities (Kader, 2008). At present, research and development are aimed at identifying the best agricultural practices to maximize the organoleptic qualities of marketable fruit by promoting the development of non-conventional strategies aimed at reducing the use of chemical inputs (Shewfelt and Prussia, 2009). However, non-conventional practices present serious technical challenges since they require a good understanding of crop physiobiology, abiotic/biotic stress pressure and their impact on the quality of the produce (Raigón et al., 2010; Zhao et al., 2007). Fortunately, the eggplant grows well in non-conventional practices, showing resistance and tolerance against many types of biotic stress which are common in *Solanaceae* as well as high yield in hot-wet environments (Hanson et al., 2006; Sherf and MacNab, 1986). We hypothesized that using different winter cover crops species and residue managements could affect the yield characteristics of an eggplant crop. The main objectives of this study were to evaluate the effects of different cover crop species and residue managements in no-tillage or in conventional tillage on marketable fruit yield and fruit quality of eggplant crop, and to find a management package capable of minimizing agronomical inputs and improving vegetable fruit quality in the Mediterranean environment of central Italy.

MATERIALS AND METHODS

Experimental site and design

A field experiment was carried out during the 2009/2010 and 2010/2011 growing seasons at the experimental farm of Tuscia University in Viterbo, Italy (Latitude 42° 24' 53'' N, Longitude 12° 03' 55'' E, Altitude 310 m a.s.l.) in a two adjacent fields previously cropped with durum wheat (*Triticum durum* Desf.). The soil in the experimental area is classified as *Typic Xerofluvent* (Soil Survey Staff, 2009) with the following characteristics in the 0 – 30 cm layer: sand 45 %, silt 17 %, clay 38 %; pH 6.79 (water,1:2.5); organic matter 1.32 % (Lotti method); and total nitrogen 0.094 % (Kjeldahl). The area has a typically Mediterranean climate. Rainfall ranges from 700 to 900 mm per year and falls mainly from October to April. The annual average temperature is 14°C, with a maximum of 35°C observed in July and a minimum of -2°C observed in February.

The 2-year experiment consisted in: (a) four winter soil managements {three different cover crops [hairy vetch (*Vicia villosa* Roth., var. Capello), oat (*Avena sativa* L., var. Donata), and oilseed rape (*Brassica napus* L., var. Licapo)] and a control plot without cover crop (hereafter called bare soil)}; (b) two different soil tillage for managing cover crop residues [green manure residues at 30 cm of soil depth to simulate conventional tillage; and residues left on the soil surface to simulate no-tillage]. The experimental design was a split-plot, where the winter soil management was the main factor and the soil tillage was the split factor. The treatments were replicated three times for a total of 24 basic plots. The main plot size was 48 m^2 (6 m x 12 m) and the sub-plot size was 24 m^2 (6 m x 4 m).

Field experiment description

At the beginning of each cover crop–eggplant sequence, the soil was ploughed to a depth of 30 cm, fertilized with 100 kg P_2O_5 ha^{-1} as triple superphosphate, and harrowed for seedbed preparation. In both years, all cover crops were sown manually in September and the seeds were superficially buried by harrowing. The seed rate was 60, 100, and 15 kg ha^{-1} for hairy vetch, oat, and oilseed rape, respectively. The bare soil plots were managed similarly to the cover crop plots. In May, all cover crops were mechanically suppressed at the same time and managed as follows: (a) chopped by means of a straw chopper and immediately incorporated into the soil at a depth of 30 cm with a mold-board plough (conventional tillage); and (b) mowed approximately 5 cm above the soil surface and placed in strips as mulch layers with a hay-conditioner farm machine (no-tillage). The mulch strips consisted in 50 cm wide uniform layers of cover crop residues that were arranged at a distance of 1-m centre strip from one another alternating a mulched strip with a 50 cm wide strip of un-mulched soil (Campiglia et al., 2011b) (Fig. 1). The mulch strips of cover crop residues were used as transplanting beds for the eggplant seedlings. In the bare soil, the transplanting bed was prepared at cover crop suppression with a mold-board plough and rotary hoe to simulate conventional tillage or a herbicide (glyphosate) to simulate no-tillage, respectively.

Just after cover crop suppression, one-month old eggplant seedlings (*Solanum melongena* L. var. Mirabella) of 10-cm height were transplanted by hand at a density of 3 plants m^{-2}. The same arrangement was maintained in all treatments. In the no-tillage, the eggplant seedlings were transplanted in the middle of the mulch strips with a minimal disturbance of the soil and the mulch layer. Irrigation water was supplied by means of drip irrigation tape installed over the mulch layer (in no-tillage) and on the soil surface (in conventional tillage) at a distance of 5 cm from plant rows. Each pipe had on-line emitters with a capacity of 3 L h^{-1}. The amount of water input was determined by evapo-transpiration estimated by class A pan evaporimeter and converted by crop coefficients (Allen et al., 1998). All plots were maintained weed-free by hand-weeding. No chemical fertilizers were applied throughout the eggplant cultivation to assess the effects of the cover crops and their residue managements on eggplant fruit yield and fruit quality.

Field measurements and sample preparation

The rainfall and temperature data were collected from an automatic weather station located about 200 m from the experimental site. The eggplant fruit–samples were collected 30 days after flowering when the fruits within the plot were deemed to be in the same dark-purple maturity stage with fresh green calyx, discarding those which were not fully developed or over-mature. In both years, fruit harvesting was performed four times from early August through to mid-September. At the first harvest, fruits of 10 plants were harvested from the two middle rows (5 plants per row) of each sub-plot (number and fresh weight). At each harvest time (hereafter called HT), the marketable fruits of the same 10 plants were collected and immediately taken to the laboratory for analytical measurements. At the last HT, the same 10 plants were harvested by cutting manually at the soil surface in order to determine the residual plant weight (oven dried at 70 °C until constant weight).

SPAD-502 (Konica Minolta, Osaka, Japan) was used to estimate the chlorophyll concentration of the eggplant crop on the 4^{th} fully grown leaf from the top of the plant. The chlorophyll content was measured at every HT on the same harvested plants. Ten readings (one reading per plant) were taken in each replication and averaged (Minotti et al., 1994).

Physical and chemical analysis on fruits

Peel color assessment was carried out with digitalization techniques according to Moscetti et al. (2012) Image was acquired at a resolution of 480 dpi. ImageJ software v1.48 (National Institute of Health, Bethesda, US-MD) was used to collect data on a 3 10^5 pixel square area for each fruit. Results were expressed according to the CIELab color space by $L*$ (luminance), h (hue angle, $h = \text{tang}^{-1}\, b*/a*$; expressed as -180° < h < +180°) and $C*$ (saturation index or chroma, $C* = [a*^2 + b*^2]^{1/2}$) coordinates.

Flesh color was measured with a colorimeter mod. CM-2600d (Konika Minolta, Osaka, Japan). The fruits were equatorially cut between blossom and stem end and three readings per fruit slice were taken along the peripheral-endocarp surface. The mode used for acquiring data was CIE Standard Illuminant D65 (Daylight), Observer 10° and 8-mm diameter of measurement aperture. The results were expressed according to the CIELab color space. Moreover, Browning Index ($BI = [(100 - L_0*)^2 + a_0*^2 + b_0*^2]^{1/2} - [(100 - L_{10}*)^2 + a_{10}*^2 + b_{10}*^2]^{1/2}$) and CIE 1976 color difference ($\Delta E* = [\Delta L*^2 + \Delta a*^2 + \Delta b*^2]^{1/2}$) were calculated by comparing color coordinates taken immediately after cutting (L_0*, a_0* and b_0*) and 10-min later ($L_{10}*$, $a_{10}*$ and $b_{10}*$). BI and $\Delta E*$ were acquired to obtain complementary information related to changes in color after cut (Raig et al., 2007) $\Delta E*$ was expressed according to the evaluation scale used by Cecchini et al. (2011).

The number of seeds was measured with a Perfection V350 Photo (Epson, Suwa, Japan) flat scanner, which was used to perform the digital image acquisition of berry slice, equatorially cut between blossom and stem. Scanner profiling and data collection were performed according to Moscetti et al. (2014) with some modifications: the resolution of the digital image was 1340 × 1142 pixels (300 dpi), the image processing algorithm was developed using Python 3.4.3 software (www.python.org) coupled with OpenCV 3.0 (www.opencv.org) and the Particle Analysis, which was applied to measure the seeds area, was performed with a minimum particle size set to 150 pixel cutoff threshold (Fig. 2). The number of seeds (i.e. seed index, SI) was expressed as a percentage of the fruit-slice area.

Peel firmness was measured on the two opposite sides along the equatorial of the same fruit surface. A digital penetrometer mod. 53205 (TR Turoni & Co., Forlì, Italy) with an 8-mm-diameter tip was used and the results were expressed as the maximum force (N) required to penetrate the 7-mm probe into the eggplant pulp.

The total phenols index (TP) was assayed by means of a slight modification of the Folin-Ciocalteu method (Contini et al., 2008). Phenolic compounds were extracted for 24 h at room temperature (20 ± 1 °C) in the dark, using 70% (v/v) of aqueous acetone with lyophilized and powdered flesh tissue at a solvent ratio of 1:10 (w/v). The supernatant was removed after centrifugation at 1800 g for 15 min at 4°C and subsequently stored at -80 °C. The extraction was repeated for a further 24 h. The supernatant was combined and filtered through a Whatman GF/F glass microfibre filter (0.7 µm). The crude phenolic extract was stored at -80 °C for further analysis. The results were expressed as mg gallic acid equivalent (GAE) per gram of dried weight (DW).

The pH was monitored using the official method 'pH Measurement of Water' (AOAC 973.41) with a pH-meter mod. FE20 (Mettler Toledo, Milan, Italy) (Horwitz, 2005).

Titratable acidity (TA) was measured following the official method 'Acidity (Tritatable) of Fruit Products' - AOAC 942.15 (Horwitz, 2005). The results were expressed in percentages of malic acid.

Soluble solids content (SSC) was measured with a digital refractometer mod. WM-7 (Atago, Tokyo, Japan). The vortexed and centrifuged extract of 30 mg of flesh with 1 mL of 1 mM HCl was measured (Mennella et al., 2012). The results were expressed as % SSC on fresh weight. The SSC:TA ratio was also calculated.

Eggplant fruit size was measured as length (distance from blossom and stem-end) (cm), equatorial diameter of each fruit (cm), volume (cm^3) and weight (g).

Dry matter (DM) was measured following the official method 'Dry Matter on Oven Drying' - AOAC 934.01 and was expressed as a percentage (Horwitz, 2005).

Data handling and statistical analysis

For the data obtained in each experimental year the analysis of variance (ANOVA) was carried out to assess cover crop parameters (aboveground biomass, nitrogen content, and C:N ratio). A split-split-plot experimental design was adopted for all eggplant fruit yield characteristics and all measurement, where the harvesting time was treated as the main factor, the winter soil management as the split factor and the soil tillage as the split-split factor. The analysis of variance of agronomical data was carried out for the 2-year period, considering the year as repeated measures across time (Cody and Smith, 1997). Results regarding physical and chemical analysis on fruit refer to a single typical experiment since the pattern of data was similar in both years (Botondi et al., 2000). Before statistical analysis, both results relative to nitrogen content and number of fruits per plant were subjected to angular (arcsine $[x]^{1/2}$) and square root ($[x+0.05]^{1/2}$) transformations, respectively, to homogenize the variance (Bartlett's test) (Gomez and Gomez, 1984). The data reported in the tables and figures were back transformed. Fisher's protected least significant difference at 5% level of probability was computed for comparing the main and interaction effects.

Principal Component Analysis (PCA) was applied to evaluate between-treatment similarity. The original data was converted into score and loading vectors by PCA analysis. The screen-plot criterion was used to select the required number of principal components (PCs) for describing the dimensionality of the data (Moscetti et al., 2015).

Pearson's linear correlation test was computed to detect significant bivariate correlations between the measured features.

Statistical analyses were performed using R v3.1.2 software in combination with 'agricolae' v1.2-1 and 'pcaMethods' v1.56.0 R-packages (CRAN, 2014).

RESULTS AND DISCUSSION

Weather conditions

The total rainfall measured in the cover crop growing season (from September to May) tend to be higher in 2010/2011 than 2009/2010 experimental years (i.e. 809 vs. 731 mm, respectively). However, both seasons were wetter than the historical average (i.e. 604 mm). In the same period, air temperatures were similar to the long term average in both cropping cycles, except in December 2010 and February 2011, when the air temperatures dropped below 0 °C for several times. Throughout the eggplant cultivation, the 2010 growing season was wetter (i.e. 412 mm) and 2011 was similar (i.e. 250 mm) than the historical means (i.e. 235 mm, Fig. 3). In the same period, the air temperatures were similar to the long-term average in both cropping seasons, except in July and August 2010 when the air temperatures (i.e. both maximum and minimum) were considerably lower than historical trend (Fig. 3).

Cover crop biomass production and its characteristics

In both years, all cover crops emerged uniformly approximately about two weeks after sowing. Nevertheless, at cover crop suppression, the amount of aboveground biomass and its characteristics differed among the winter cover crops (Table 1). In 2009/2010 growing season, all cover crops grew regularly throughout the wettest and coldest period of the year, but produced a higher aboveground biomass than in the 2010/2011 growing season (on average 605.2 vs. 511.7 g m^{-2} of DM, respectively). These differences could be attributed to the large variability of climatic conditions, particularly air temperature (Fig. 3), between the growing seasons of cover crops. Generally, hairy vetch produced more aboveground biomass than oat and oilseed rape (on average 717.8, 514.2 and 443.4 g m^{-2} of DM, respectively), which was also characterized by a high nitrogen content (2.49%) and low C:N ratio (13.4, Table 1), thus proving to be suitable a cover crop for the Mediterranean environment of central Italy. Since the C:N ratio affects the nitrogen release rate from cover crop residues, it is one of the most important indices to consider when choosing a cover crop (Cabrera et al., 2005). In fact, the ratio between carbon to nitrogen (C:N) in decomposing biomass is an important indicator of the overall breakdown process and possible release of nutrients, particularly nitrogen. If the amount of nitrogen accumulated in organic residues is greater than that required by the microbial biomass, there is a net mineralization with the release of inorganic nitrogen (Cabrera et al., 2005). Accordingly, oat residues (4.3 g m^{-2} of N) associated with a high C:N ratio can cause nitrogen immobilization and consequently compete with the subsequent crop for the available nitrogen in the soil (Döring et al., 2005), while oilseed rape (7.7 g m^{-2} of N) and hairy vetch residues (17.9 g m^{-2} of N) that have a low C:N ratio mineralize rapidly and release mineral nitrogen into the soil which is available for the eggplant crop (Jensen and Hauggaard-Nielsen, 2003).

Eggplant yield, fruit weight and size

The eggplant yield was significantly affected by year × cover crop × harvesting data (Table 2) and cover crop × soil tillage × harvesting data (Table 3) ($P \leq 0.05$), while the percentage of unmarketable yield was not influenced by the treatments (data not shown). Generally, eggplant performed better in 2011 than 2010 (on average 412.5 vs. 316.4 g $plant^{-1}$ of FM, respectively, Table 2), probably due to different climatic condition between the years, particularly air temperature (Adamczewska-Sowinska and Krygier, 2013). In fact, optimum temperature for eggplant growth is within the range of 22 – 30 °C, while the mean air temperature observed in the period from July to August 2010 was lower than 22 °C (Fig. 3). Eggplant yield in hairy vetch was generally much higher than oilseed rape, oat, and bare soil (on average 622.4, 328.7, 268.8, and 258.2 g $plant^{-1}$ of FM, respectively, Table 2). Generally, tilled treatments proved to have a positive effect on the eggplant yield in oilseed rape (on average 378.4 vs. 270.0 g $plant^{-1}$ of FM in tillage and no-tillage treatments, respectively, Table 3), while there was a negative effect on eggplant yield in oat compared to the no-tillage treatment (on average 199.4 vs. 338.1 g $plant^{-1}$ of FM in tillage and no-tillage treatments, respectively), while a similar fruit yield was observed in the eggplant cultivated in hairy vetch residues regardless of the soil tillage management (Table 3). It is possible to explain the effect on the eggplant yield by hypothesizing that cover crops and soil tillage affected nitrogen mineralization from cover crop residues and therefore nitrogen translocation from cover crop residues to the eggplant crop, as also confirmed by the SPAD readings of the eggplant leafs. In fact, the SPAD values were generally similar in hairy vetch regardless the soil tillage (on average 51.9, Table 3), in oilseed rape the SPAD readings were higher in tillage than no-tillage treatments (on average 48.8 vs. 45.4, respectively), while in oat was observed an opposite trend (on average 44.5 vs. 48.5 in tillage and no-tillage treatments, respectively, Table 3). Since nitrogen is one of the main factors influencing the formation of chlorophyll (Evans, 1989), these results indicated that there were various levels of nitrogen availability among the treatments. Although the mineralization rate is related to different variables, such as air temperatures and rainfall (Cabrera et al., 2005), the cover crop species and their residue management seemed to play on the level of nitrogen availability for the following summer vegetable (Thomsen and Christensen, 1998). Hairy vetch residues characterized by high nitrogen concentration and low C:N ratio probably mineralized faster compared to oilseed rape and oat residues which are characterized by a high C:N ratio. Moreover, according to Rosecrance et al. (2000), the rate of mineralization in hairy vetch is almost constant in all tillage practices including no-tillage, while the high C:N ratio of the oat residues probably determined the immobilization of the available nitrogen, particularly when incorporated into the soil in tillage treatments than when the residues were left on the soil surface in no-tillage strategy (Rosecrance et al., 2000). In oilseed rape residues with intermediate C:N ratio, the nitrogen availability was probably higher in tillage than no-tillage treatment probably due to the high contact between soil microorganisms and residues (Campiglia et al., 2011a).

Regarding harvest time, the marketable eggplant yield tended to increase gradually reaching the highest values at the 3rd harvest time (on average 644.0 g plant^{-1} and 2.9 fruits plant^{-1}, respectively, Table 3). The eggplant generally yielded more fruits in tillage than no-tillage treatments on the 1st harvest date (HT1), except for the oat treatment, while in the following HTs the eggplant yield tend to show an opposite trend (Table 3). Probably cover crop mulches delayed the maturity of vegetable fruits due to a high soil moisture and soil nitrogen content which delay and cause differences in fruit maturity times as reported by Thomas et al. (2001) in tomato crops.

In general, fruit size gradually decreased over the harvest time. On average, fruit size metrics (length, diameter and volume) were significantly affected by winter soil management showing higher values in hairy vetch and oilseed rape treatments (Table 4), while fruit length was also affected by soil tillage resulting in lower values when mulching (no-tillage) was adopted. The results showed an inverse relationship between fruit length and crop yield in terms of fruit weight per plant as well as the number of marketable fruits per plant (r = -0.45** and -0.47**, respectively, Table 5), which may be due to inter-fruit competition for mineral nutrients (Zegbe et al., 2014). Furthermore, the soil tillage × harvest time interaction highlighted the effect of mulching on fruit diameter with an average increase of 0.44 cm per fruit at HT1, while fruit diameter at other HTs was not significantly influenced by soil tillage (data not shown). Finally, size metrics showed significant correlations with pH, dry matter, seed index, total phenols and color of both pericarp and endocarp (Table 5). In particular, a weak positive relationship between total phenols and size metrics (i.e. diameter and volume) was observed. However, fruit length was the most representative parameter, showing positive correlations with h of pericarp, and L^* and C^* of endocarp as well as negative relationships with pH, browning index, L^* and C^* of pericarp, firmness, dry matter and seed index.

Firmness and fruit dry matter

The firmness and dry matter of the eggplant fruits were both affected by the winter soil management showing higher values for hairy vetch (Table 4). The results might be due to the differences in nitrogen availability of the winter soil management treatments. In fact nitrogen availability depends on the release of both NO_3^- and NH_4^+ from cover crop residues. Moreover, nitrogen availability regulates dry matter production and water loss per dry matter unit in dicotyledonous crops, as well as the dry matter partitioning between shoot and root of vascular plants (Andrews et al., 2013). Regarding the HT an increase in the firmness, was only observed at the HT4, while fruit dry matter tended to gradually increase during the entire harvest period. Firmness and fruit dry matter were positively correlated (r = 0.58**, Table 5). They showed positive relationships with crop yield, number of marketable fruits per plant and the browning index. Firmness also showed a positive relationship with the seed index (r = 0.49*). On the other hand, fruit dry matter was negatively related to fruit diameter, fruit length and total phenols content. Moreover, firmness and fruit dry matter showed weak correlations with the browning index (r = 0.34*) and total phenols (r = -0.37*), respectively.

Number of seeds

The results of the computer-vision-based SI estimation are summarized in Table 4, while significant correlations between fruit seeds and size metrics are reported in Table 5. It can be clearly seen that fruit length, diameter, volume and weight had negative relationships with the SI. More specifically, fruit size showed significant effect on the seed index: the small berry had highest SI, while the least was determined from the big fruit. Consequently, although the image analysis was restricted to a slice per fruit, it is clear that the spatial domain could have an added value only to improve the qualitative evaluation of eggplant fruit, especially concerning the effect of the main factors: soil management, soil tillage and harvest time. In fact, SI showed lower values (i.e. smaller slice surface identified as seeds) for those samples in which factors were responsible for higher nitrogen availability (e.g. hairy vetch, tillage and HT1). However, it is important to consider that SI values could be affected by seed size, which is negatively related to the nitrogen level as well as affected by the nitrogen source (Akanbi et al., 2007).

Color measurements

The color variation of the fruit pericarp of the eggplant may depend on the proportion of chlorophyll and anthocyanins. Therefore, the darkest purple berry is expected to have high concentrations of anthocyanins and chlorophyll (Nothmann et al., 1976). In fact, Concellón et al.,

(2007) observed a positive relationship between the surface chroma and anthocyanin content before the occurrence of degradative processes against the surface layer of the cuticle. This is affected by color change to a duller shade of purple and then to a grey-brown color in dark-purple eggplants. Moreover, Lancaster et al. (1997) found a linear correlation between anthocyanin content and hue angle and a logarithmic relationship between increasing chlorophyll and tissue darkness. However, the authors suggest using caution when interpreting color in terms of pigment composition, because similar CIELab coordinates may be measured on tissues with significantly different levels of pigments.

Our experimental results showed an interesting pattern in pericarp color development during the whole harvest period. Both winter soil management and soil tillage factors affected the color profile at each harvest time, thus proving to have a significant effect on luminance ($L*$), hue angle (h) and chroma ($C*$) at different levels. In particular, the winter soil management × harvest time interactions had significant effects on $L*$ and $C*$ (Fig. 4a and 4c), while the soil tillage × harvest time interaction significantly influenced h (Fig. 4b). Moreover, differences in $C*$ were also observed with regard to the soil tillage system. In fact, starting from HT3, oat and oilseed-rape cover crops developed fruit with pericarp with less luminance and color saturation, while an opposite trend was observed in both hairy vetch and bare soil treatments which had higher $L*$ and $C*$ values. These differences among winter soil management techniques were especially noticeable at HT4, when higher values of both luminance ($L* = 24.05$a) and chroma ($C* = 5.08$a) were observed for hairy vetch, followed by bare soil ($L* = 22.94$b; $C* = 3.86$b), oilseed rape ($L* = 22.08$c; $C* = 2.63$cd) and oat ($L* = 21.58$cd; $C* = 2.62$cd). Moreover, soil tillage showed lower chroma values in no-tillage (Table 6). Regarding the hue angle development of the pericarp, no-tillage showed lower h values than conventional tillage starting from HT3.

Increased nitrogen availability may increase chlorophyll concentration and may decrease the anthocyanin content. Consequently, nitrogen nutrition potentially affected pericarp color development, which is an indirect result of an effect on plant vigor (Ferguson and Boyd, 2002). In our experiment, the factors showed effects on nitrogen translocation, as confirmed by the various SPAD readings taken from the eggplant crop at each harvest time (Table 3). It was generally observed that color differences among treatments occurred when the crop life cycle was coming to an end. This is particularly evident for both hairy vetch and bare soil treatments, which produced fruits with a duller shade of purple. Furthermore, a slight positive relationship was observed between the hue angle and the SPAD readings (r = 0.32*), highlighting that the purple color was duller at higher nitrogen availability. Nitrogen deficiency may result in the delay of the vegetative and reproductive growth of eggplant, thus requiring more time for flowering and fruit setting. However, optimal nitrogen availability may lead to early fruit maturation (Hossein Aminifard et al., 2010) and this may explain our results.

Regarding the endocarp color, a progressive change from a greenish to a brownish color was observed throughout the HTs which was measured as a decrease in both luminance and chroma, and an increase in hue angle. It is important to note that both L^* and C^* were negatively correlated to the browning index (BI) of tegument (r = -0.37* and r = -0.53**, respectively). Therefore, due to the decrease in TP with maturity, the increase in BI should coincide with major polyphenol oxidase activity (Mennella et al., 2012). However, this finding is strictly related to eggplant genotype and may be affected by environmental factors (Raigón et al., 2010). Finally, fewer differences in flesh color were observed between treatments due to winter soil management, but there was no significant effect on BI.

BI was not affected by winter soil management and soil tillage. Nevertheless, major changes in ΔE^* 10 min after slicing were observed in both oat and bare soil in combination with no-tillage and conventional tillage respectively (Fig. 5a). This means that a^* and b^* coordinates considerably contributed to color change on slice surface. Furthermore, both BI and ΔE^* indices gradually increased during the harvest period (Table 6), although the rising trend concerning change of color was more evident in BI, which is exclusively related to the variance of luminance.

Both BI and ΔE^* were negatively correlated to fruit size, *h* of pericarp as well as L^* and C^* of endocarp. They also showed positive relationships with fruit dry matter, seed index, pH, and L^* and C^* of the pericarp (Table 5), while no significant correlation with the total phenols content was observed (data not shown).

Total phenols content

TP content was significant for both winter soil management × soil tillage interaction (Fig. 5b) and harvest time factor (Table 4). In oat, the low availability of nitrogen due to immobilization was probably responsible for the significantly higher TP content. This effect was particularly evident in oat in combination with conventional tillage where soil nitrogen availability was lower than the other treatments. This effect was also confirmed by the correlation between the TP content and SPAD readings (r = -0.89**). Several authors have observed that lower nitrogen nutrition could lead to a negative relationship between yield and TP (Raigón et al., 2010). Due to slow nitrogen mineralization, a behavior similar to the oat treatment was observed for bare soil in combination with no-tillage. However, the TP content may be strongly affected by plant-to-plant biological variations, response to environmental factors and maturity stage (Ferguson and Boyd, 2002; Hanson et al., 2006; Luthria et al., 2010). In eggplant, TP content decreases with fruit maturity (Mennella et al., 2012) and this probably explains why the TP content trend decreased slightly yet significantly from HT1 to HT4. In fact, TP was negatively correlated with peel luminance and chroma (r = -0.46** and r = -0.37*, respectively) as well as SSC, seed index and dry matter (r = -0.57**, r = -0.57** and r = -0.37*, respectively). These results confirm an association between low TP and fruit maturity.

Soluble solids content, Titratable acidity and pH

SSC showed significant differences for winter soil management and soil tillage as main factors. Eggplant fruits grown in oat residues showed the lowest SSC value equal to 3.57b °Brix, while no significant differences were observed among the other cover crops (on average 3.91a, Table

4). This is probably due to a lower accumulation of the photosynthesis products because of less chlorophyll-foliage caused by less nitrogen availability (Zhang et al., 2014). Regarding the TA, Table 4 showed that there were no significant differences between treatments. The average content of malic acid was 0.14%. Table 4 reports the pH values which increased throughout the harvest time and was slightly higher for tilled treatments.

Synthetic view using the Principal Component Analysis

The impact of winter soil management, soil tillage and harvesting time on eggplant fruit quality was determined by means of a principal component analysis (PCA) (Fig. 6). First and second components (PC1 and PC2) of the PCA accounted for 59.39% and 24.82% of total variance, respectively. PC1 mostly separated the harvest time, while PC2 mainly contributed to separating the winter soil management starting from HT3. Both PC1 and PC2 also minimally separated the soil tillage.

PC1 had negative loadings for pH, dry matter, seed index, firmness, luminance and chroma of pericarp as well as hue angle of endocarp, while weight, size metrics, total phenols, hue angle of pericarp and luminance and chroma of endocarp had positive loadings. Regarding PC2, luminance of endocarp, length and seed index had positive loadings, whereas negative loadings were assigned to the other features.

CONCLUSIONS

Within the framework of changing agricultural practices towards a sustainable vegetable cropping system, this experiment, which was carried out in field conditions adopting sustainable practices, confirmed that cover crops could be successfully used for reducing external inputs without creating negative changes in the commercial yield. In particular, the results show that legume cover crops such as hairy vetch, should be considered preferable to other no-legume cover crops to enhance the marketable fruit yield of the following summer eggplant crop due to their ability to supply large amounts of nitrogen after their suppression. Moreover, the quality components measured on the eggplant fruits from the hairy vetch treatments were equal to, and at times exceeded, those obtained with conventional production practices. Furthermore, using mulching practices in no-tillage systems appears to be a suitable approach for improving marketable yield and reducing agronomical inputs, even if a delay on fruit yield than green manured residues was observed. However, mulching with legume cover crops can be considered an important step toward low input vegetable cropping system, especially in organic production where the use of chemical inputs, such as herbicide and mineral fertilizers, is forbidden. Further research on the effects of cover crops and their residue management is required in order to obtain a better understanding of fruit quality (e.g. sensorial analysis, phenols characterization through HPLC, antioxidant activity as well as mineral and vitamin contents).

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TABLE CAPTIONS

Table 1. The effects of interaction of the winter soil management × year on total cover crop above ground biomass and its nitrogen content, nitrogen accumulation, and C:N ratio of cover crops at their suppression. Mean values belonging to the same factor without common letters are statistically different according to LSD ($P \leq 0.05$). D.M. = Dry Matter.

Table 2. The effects of interaction of the winter soil management × harvest time × year on marketable eggplant yield and number of marketable eggplant fruit. Mean values followed by the same lower case letters in columns are not different according to LDS ($P \leq 0.05$). Mean values followed by the same upper case letters in rows [within HT] are not different according to LSD ($P \leq 0.05$). F.M. = Fresh Matter; HT = Harvest Time.

Table 3. The effects of interaction of the winter soil management × soil tillage × harvest time on marketable eggplant yield, number of marketable eggplant fruit and SPAD readings. Mean values followed by the same lower case letters in columns are not different according to LDS ($P \leq 0.05$). Mean values followed by the same upper case letters in rows [within HT] are not different according to LSD ($P \leq 0.05$). F.M. = Fresh Matter; HT = Harvest Time.

Table 4. The main effects of winter soil management, soil tillage, and harvest time on the physical and chemical quality parameters of the marketable eggplant fruits. Mean values belonging to the same factor without common letters are statistically different according to LSD ($P \leq 0.05$). NS = no significant differences. HT = Harvest Time; SSC = Soluble Solid Content; TA = Titratable Acidity.

Table 5. Pearson's product-moment correlation coefficients (*r*) between features measured on the marketable eggplant fruits.

(*), *, ** Significant correlations at $P \leq 0.1$, $P \leq 0.05$, $P \leq 0.01$ respectively (two-tailed). SSC = Soluble Solid Content.

Table 6. The main effects of winter soil management, soil tillage, and harvest time on pericap and endocarp color of the marketable eggplant fruits. Mean values belonging to the same factor without common letters are statistically different according to LSD ($P \leq 0.05$). BI = Browning Index; NS = no significant differences.

TABLE 1

Cover crops	Aboveground biomass ($g\ m^{-2}$ of D.M.)		Nitrogen content	Nitrogen accumulation	C:N ratio
	2010	2011	(%)	($g\ m^{-2}$)	
Hairy vetch	708.80 aA	726.80 aA	2.49 a	17.90 a	13.40 c
Oilseed rape	535.30 bA	351.50 bB	1.79 b	7.70 b	26.70 b
Oat	571.60 bA	456.70 bB	0.86 c	4.30 b	46.60 a
P value	0.04		< 0.001	< 0.001	< 0.001

TABLE 2

Factors	HT1		HT2		HT3		HT4	
	2010	2011	2010	2011	2010	2011	2010	2011
	Marketable eggplant yield (g plant^{-1} of F.M.)							
Soil management								
Hairy vetch	449.50 aA	478.90 aA	471.50 aB	647.30 aA	981.20 aB	1080.00 aA	345.50 aA	365.10 aA
Oilseed rape	190.70 bA	203.10 bA	232.20 cB	424.30 bA	423.40 bB	786.90 bA	143.30 bB	225.60 bA
Oat	137.90 bA	168.90 bA	197.70 cB	332.00 cA	360.70 bB	667.40 cA	130.10 bA	155.30 cA
Bare Soil	188.20 bA	111.40 cA	303.40 bA	275.40 cA	372.50 bB	480.30 dA	135.80 bA	198.80 bcA
P value = 0.03								
	Number of marketable eggplant fruits (n plant^{-1})							
Soil management								
Hairy vetch	2.00 aA	2.10 aA	2.20 aB	3.30 aA	4.90 aA	5.00 aA	1.40 aB	2.00 aA
Oilseed rape	1.00 bcA	0.70 bA	1.10 bB	2.10 bA	2.30 bA	2.40 bA	0.70 bB	1.30 bA
Oat	0.70 cA	0.70 bA	1.20 bB	1.60 cA	1.80 cB	2.20 bA	0.70 bA	1.00 bA
Bare soil	1.10 bA	0.70 bA	1.30 bA	1.50 cA	2.10 bcA	2.40 bA	0.60 bB	1.10 bA
P value < 0.001								

TABLE 3

Factors	HT1 Tillage	HT1 No-Tillage	HT2 Tillage	HT2 No-Tillage	HT3 Tillage	HT3 No-Tillage	HT4 Tillage	HT4 No-Tillage
	Marketable eggplant yield (g plant^{-1} of F.M.)							
Soil management								
Hairy vetch	527.70 aA	400.60 aB	605.20 aA	513.60 aB	944.10 aB	1117.10 aA	319.50 aB	391.10 aA
Oilseed rape	243.70 bA	150.20 bcB	387.40 bA	269.10 bB	679.50 bA	530.80 cB	238.80 bA	130.00 bB
Oat	133.80 cA	173.00 bA	226.20 cB	303.50 bA	340.00 dB	688.10 bA	97.70 cB	187.70 bA
Bare Soil	199.80 bcA	99.80 cB	324.00 bA	254.80 bA	484.80 cA	367.90 dB	215.40 bA	119.20 bB
P value = 0.01								
	Number of marketable eggplant fruits (n plant^{-1})							
Soil management								
Hairy vetch	2.30 aA	1.70 aB	3.00 aA	2.50 aB	4.70 aB	5.20 aA	1.50 aA	1.90 aA
Oilseed rape	1.00 bcA	0.70 bA	1.80 bA	1.30 bB	2.50 bA	2.20 bcA	1.30 aA	0.80 bB
Oat	0.60 cA	0.80 bA	1.30 cA	1.50 bA	1.40 cB	2.50 bA	0.60 bB	1.10 bA
Bare soil	1.20 bA	0.60 bB	1.60 bcA	1.20 bA	2.50 bA	1.90 cB	0.70 bA	1.00 bA
P value < 0.001								
	SPAD readings							
Soil management								
Hairy vetch	55.60 aA	51.80 aB	54.00 aA	51.70 aA	53.10 aA	55.10 aA	45.70 aB	48.40 aA
Oilseed rape	49.50 bA	44.10 cB	51.80 bA	48.70 bB	49.30 bA	48.90 cA	44.50 bA	39.80 dB
Oat	43.90 dB	48.10 bA	46.10 cB	49.40 bA	48.20 bB	51.00 bA	41.00 cB	45.50 bA
Bare soil	46.80 cA	42.70 cB	48.30 cA	46.30 cB	47.80 bA	47.00 cA	45.50 bA	42.70 cB
P value = 0.04								

TABLE 4

Factors	Length (cm)	Diameter (cm)	Volume (cm³)	Seed index (%)	Firmness (N)	Dry matter (%)	Total phenols (mg GAE gDW⁻¹)	SSC (° Brix)	TA (%)	pH
Soil management (SM)										
Hairy vetch	18.00 ab	5.53	446.41 a	8.08 b	8.42 a	8.71 a	1.98	3.83 a	0.14	5.03
Oilseed rape	18.65 a	5.41	443.54 a	8.78 a	7.58 b	7.96 c	2.10	3.93 a	0.14	5.00
Oat	17.40 b	5.42	413.26 b	9.03 a	7.78 b	8.16 bc	2.35	3.57 b	0.13	5.00
Bare soil	17.51 b	5.43	412.71 b	8.92 a	8.75 a	8.53 ab	1.99	3.97 a	0.14	5.04
P value	< 0.05	NS	< 0.001	< 0.05	< 0.001	< 0.05	NS	< 0.001	NS	NS
Soil tillage (ST)										
No-Tillage	17.51 b	5.50	428.31	8.38 a	8.14	8.18	2.13	3.96 a	0.14	5.04 a
Tillage	18.27 a	5.40	429.65	8.14 b	8.13	8.73	2.08	3.69 b	0.14	5.00 b
P value	0.02	NS	NS	< 0.05	NS	NS	NS	< 0.001	NS	< 0.05
Harvest time (HT)										
HT1	20.83 a	5.92	579.69 a	7.25 c	7.80 b	8.18 b	2.24 a	3.78	0.13	4.98 b
HT2	17.67 b	5.42	415.94 b	8.61 ab	8.15 b	8.68 a	2.15 b	3.82	0.14	5.00 b
HT3	17.28 b	5.16	365.83 c	8.33 b	7.70 b	7.63 c	2.05 b	3.73	0.14	5.03 ab
HT4	15.78 c	5.30	354.47 c	8.97 a	8.90 a	8.87 a	1.98 c	3.97	0.13	5.07 a
P value	< 0.001	NS	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	NS	NS	< 0.05
SM x ST										
P value	NS	NS	NS	NS	NS	NS	< 0.001 *	NS	NS	NS
SM x HT										
P value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
ST x HT										
P value	NS	< 0.05 *	NS	NS	NS	NS	NS	NS	NS	NS
SM x ST x HT										
P value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

TABLE 5

Pearson's r	Ripened fruits	Yield	Length	Diameter	Volume	Weight	Firmness	Browning Index	Total Phenols	Dry Matter
Ripened fruits	-	0.9498 **	-0.4677 **	-0.2275	-0.3691 *	-0.2179	0.5375 **	0.5383 **	-0.3295 (*)	0.5346 **
Yield	0.9498 **	-	-0.4530 **	-0.1772	-0.3330 (*)	-0.1392	0.4842 **	0.4993 **	-0.2836	0.5753 **
SPAD	0.6721 **	0.7063 **	0.0990	0.3378 (*)	0.2682	0.3184 (*)	0.2619	0.1466	-0.8921 **	0.0891
Length	-0.4677 **	-0.4530 **	-	0.6380 **	0.8865 **	0.8115 **	-0.3961 *	-0.7763 **	0.2767	-0.6541 **
Diameter	-0.2275	-0.1772	0.6380 **	-	0.9139 **	0.8643 **	-0.2050	-0.4987 **	0.3193 (*)	-0.4462 *
Volume	-0.3691 *	-0.3330 (*)	0.8865 **	0.9139 **	-	0.9364 **	-0.3464 (*)	-0.6757 **	0.3093 (*)	-0.6145 **
Weight	-0.2179	-0.1392	0.8115 **	0.8643 **	0.9364 **	-	-0.2149	-0.6064 **	0.1935	-0.4295 *
Seed index	0.6596 **	0.6251 **	-0.7415 **	-0.7063 **	-0.7668 **	-0.7546 **	0.4882 *	0.6722 **	-0.5718 **	0.2280
Firmness	0.5375 **	0.4842 **	-0.3961 *	-0.2050	-0.3464 (*)	-0.2149	-	0.3422 (*)	-0.2040	0.5752 **
L (pericarp)*	0.6278 **	0.6059 **	-0.8218 **	-0.6004 **	-0.7671 **	-0.5598 **	0.5440 **	0.6376 **	-0.4641 **	0.7489 **
h (pericarp)	-0.1577	-0.1626	0.7547 **	0.7513 **	0.8364 **	0.8176 **	-0.1313	-0.6070 **	0.2497	-0.4566 **
C (pericarp)*	0.6551 **	0.6417 **	-0.5031 **	-0.2255	-0.3838 *	-0.1241	0.6188 **	0.4009 *	-0.3673 *	0.6181 **
L (endocarp)*	-0.3967 *	-0.5259 **	0.5636 **	0.2066	0.4148 *	0.2718	-0.5455 **	-0.3656 *	0.1698	-0.6061 **
h (endocarp)	0.0703	0.1663	-0.0440	-0.0814	-0.0553	0.2136	0.1028	0.0281	-0.1791	0.2482
C (endocarp)*	-0.3758 *	-0.2898	0.4705 **	0.4623 **	0.5094 **	0.4063 *	-0.2601	-0.5282 **	0.2255	-0.2600
SSC	0.1776	0.1996	-0.1812	0.0964	-0.0239	0.0320	0.1813	0.0286	-0.5674 **	0.1783
pH	0.4485 *	0.4517 **	-0.6710 **	-0.2647	-0.5031 **	-0.3657 *	0.5636 **	0.4759 **	-0.3101 (*)	0.5278 **
Dry Matter	0.5346 **	0.5753 **	-0.6541 **	-0.4462 *	-0.6145 **	-0.4295 *	0.5752 **	0.4666 **	-0.3736 *	-

TABLE 6

Factors	Color (Pericarp)			Color (Endocarp)				
	*L**	*h*	*C**	*L**	*h*	*C**	*ΔE*	*BI*
Soil management (SM)								
Hairy vetch	21.21	-0.51	2.77	82.66 a	95.74	28.54 b	7.40	3.70
Oilseed rape	20.25	-1.49	1.99	82.62 a	96.49	29.57 a	7.14	2.64
Oat	20.46	-5.27	1.87	82.13 ab	95.86	30.13 a	8.12	3.18
Bare soil	20.93	-3.68	2.27	81.87 b	95.40	29.99 a	7.70	3.10
P value	NS	NS	< 0.001	< 0.05	NS	< 0.01	NS	NS
Soil tillage (ST)								
No-Tillage	20.67	-4.19	2.07 b	82.44	95.51	29.81	7.60	3.14
Tillage	20.76	-1.28	2.38 a	82.20	96.20	29.31	7.58	3.17
P value	NS	NS	< 0.05	NS	NS	NS	NS	NS
Harvest time (HT)								
HT1	18.91	10.46	1.69	83.21 a	96.54 b	31.01 a	6.01 c	1.32 c
HT2	19.93	-1.56	1.54	82.11 b	92.93 c	30.36 a	8.79 a	3.48 b
HT3	21.35	-7.11	2.13	83.43 a	96.54 b	28.41 b	7.90 b	3.34 b
HT4	22.66	-9.72	3.55	80.83 c	97.80 a	28.93 b	7.66 b	4.47 a
P value	NS	NS	< 0.001	< 0.001	< 0.01	< 0.001	< 0.001	< 0.001
SM x ST								
P value	NS	NS	NS	NS	NS	NS	< 0.01 *	NS
SM x HT								
P value	< 0.001 *	NS	< 0.001 *	NS	NS	NS	NS	NS
ST x HT								
P value	NS	< 0.05 *	NS	NS	NS	NS	NS	NS
SM x ST x HT								
P value	NS	NS	NS	NS	NS	NS	NS	NS

FIGURE CAPTIONS

Figure 1. Plan of the eggplant seedlings transplanted in conventional tillage treatments (A) and in no-tillage mulched soil (B).

Figure 2. Selection steps of the seed index. (a) represents the binary image of the berry slice; (b) shows the seed areas as the resulting region of interest (ROI) mask (light-blue color area).

Figure 3. Weather data at 10-day intervals (minimum and maximum temperatures and monthly total amount of rainfall) over the 2-yera study period (2009/2010 and 2010/2011) and long-term mean values for the experimental site (30-year mean values).

Figure 4. The interaction effect of winter soil management × harvest time on luminance (*a*) and chroma (*c*) and the interaction effect of 'soil tillage × harvest time' on the hue angle (*b*).

Figure 5. The interaction effect of winter soil management × soil tillage on both CIELab color difference (ΔE^*) (*a*) and total phenols (mg gallic acid equivalents gDW^{-1}) (*b*). Mean values with no common letters are statistically different according to LSD ($P \leq 0.05$).

Figure 6. Principal Component Analysis of the physical and chemical traits of eggplant fruit harvested on plant subjecting four cover crops and two different soil management levels, respectively. Score (*a*) and loading (*b*) plots in the PC1 (first principal component) versus PC2 (second principal component) plan. Hv = Hairy vetch, Oa = Oat, Or = Oilseed rape, Bs = Bare soil, and HT = Harvest time.

Figure 1

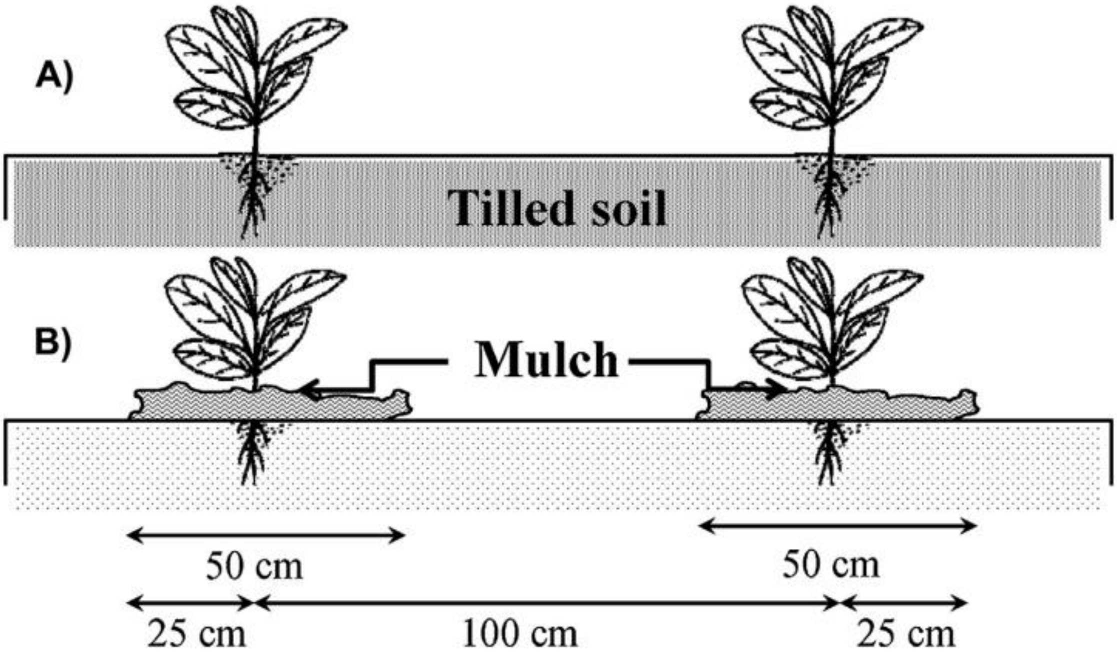


Figure 2

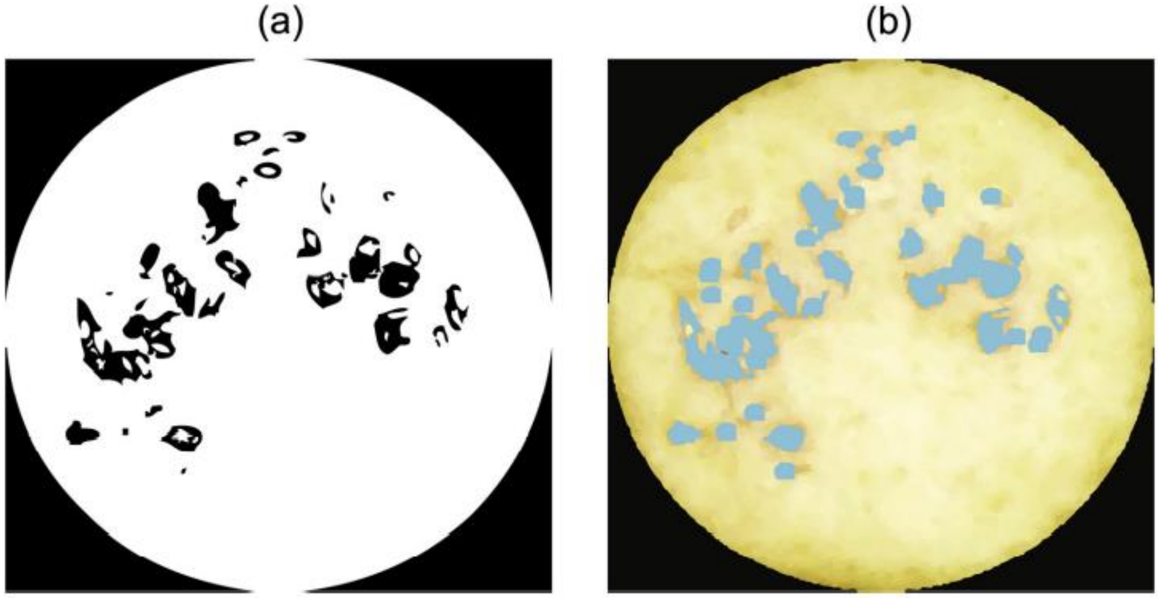


Figure 3

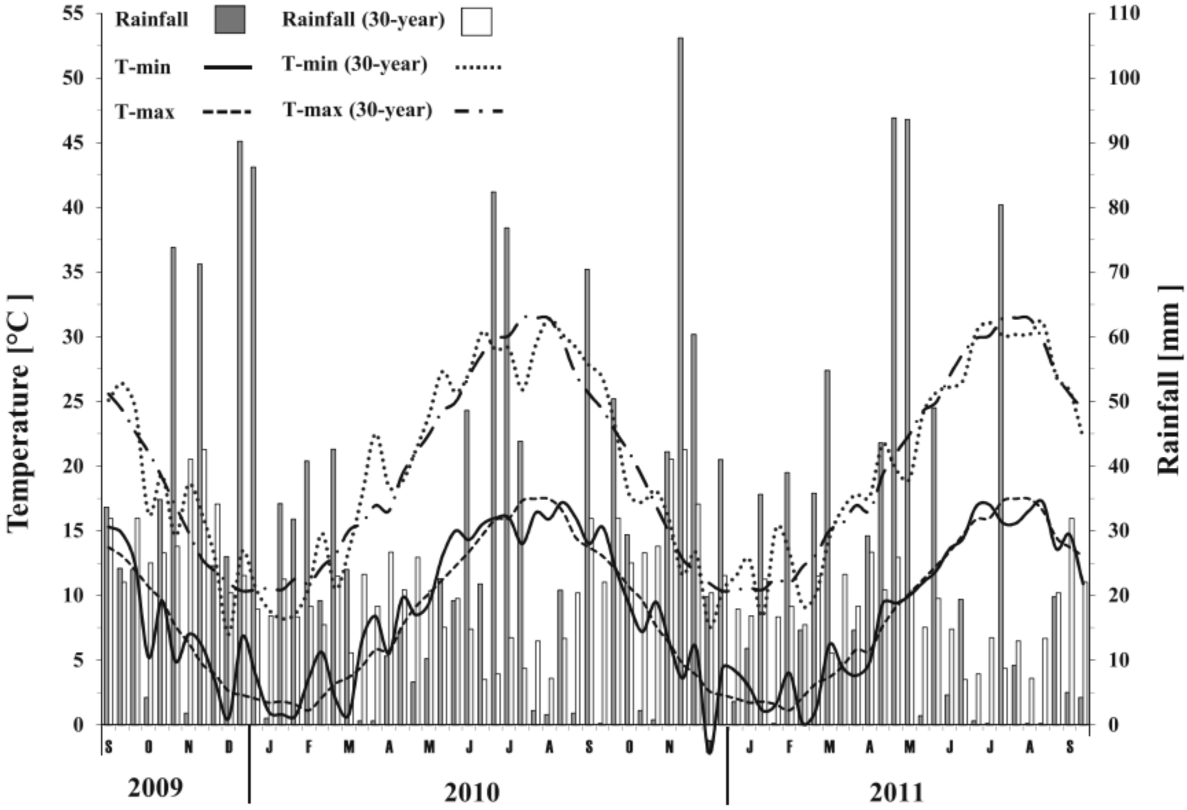

Rainfall
Rainfall (30-year)
T-min
T-min (30-year)
T-max
T-max (30-year)
Temperature [°C]
Rainfall [mm]
0
5
10
15
20
25
30
35
40
45
50
55
0
10
20
30
40
50
60
70
80
90
100
110
S O N D J F M A M J J A S O N D J F M A M J J A S
2009
2010
2011

Figure 4

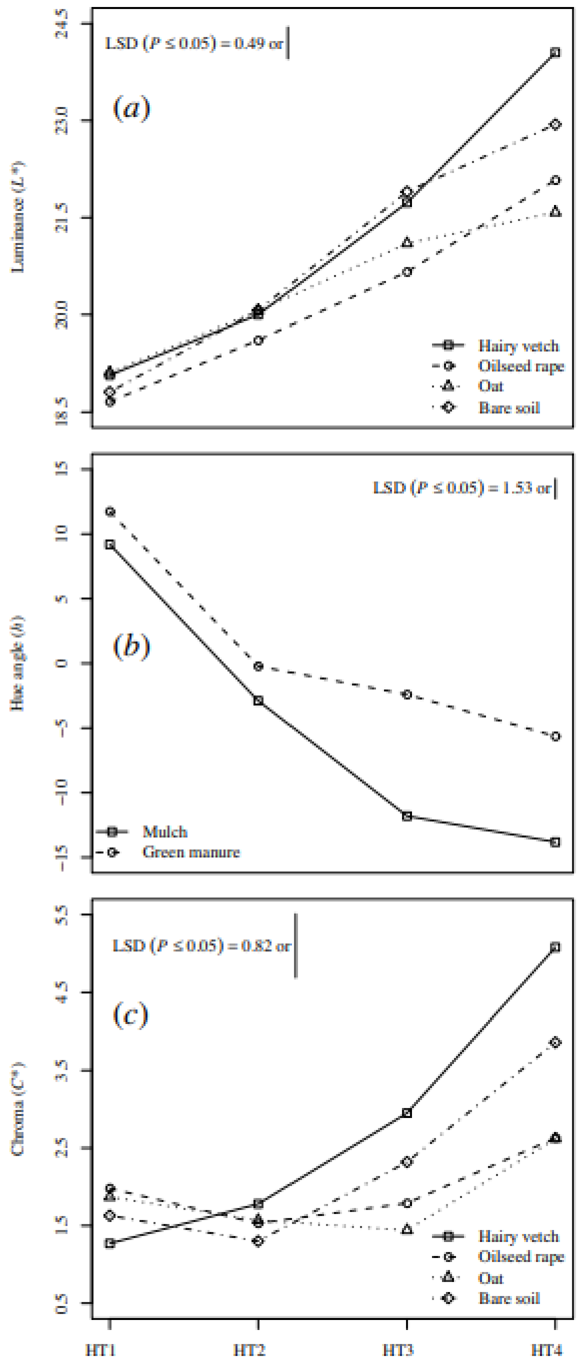

LSD (P ≤ 0.05) = 0.49 or
(a)
Luminance (L*)
24.5
23.0
21.5
20.0
18.5
Hairy vetch
Oilseed rape
Oat
Bare soil
LSD (P ≤ 0.05) = 1.53 or
(b)
Hue angle (h)
15
10
5
0
−5
−10
−15
Mulch
Green manure
LSD (P ≤ 0.05) = 0.82 or
(c)
Chroma (C*)
5.5
4.5
3.5
2.5
1.5
0.5
Hairy vetch
Oilseed rape
Oat
Bare soil
HT1
HT2
HT3
HT4

Figure 5

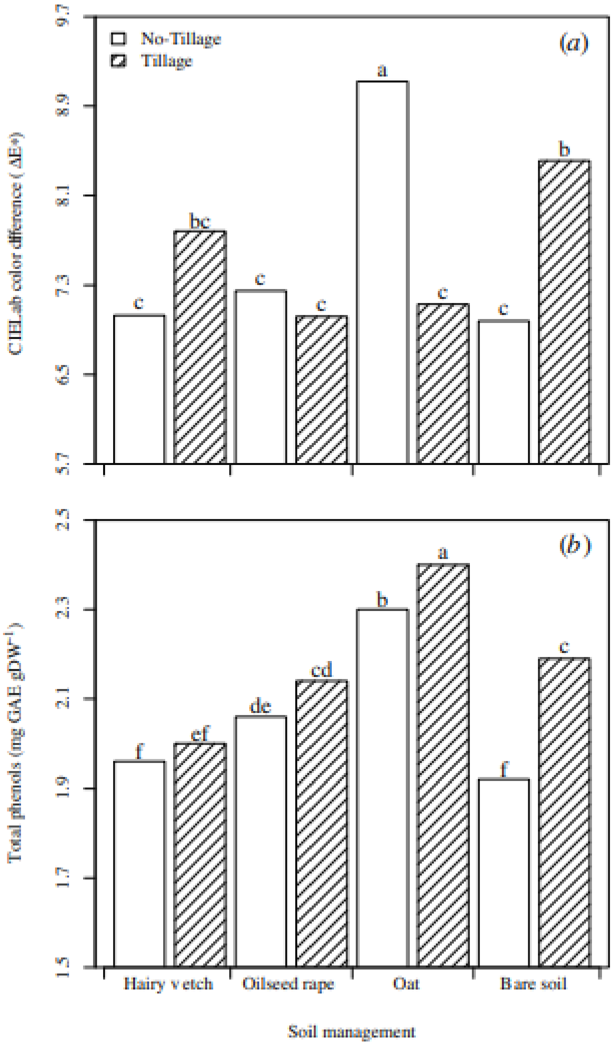
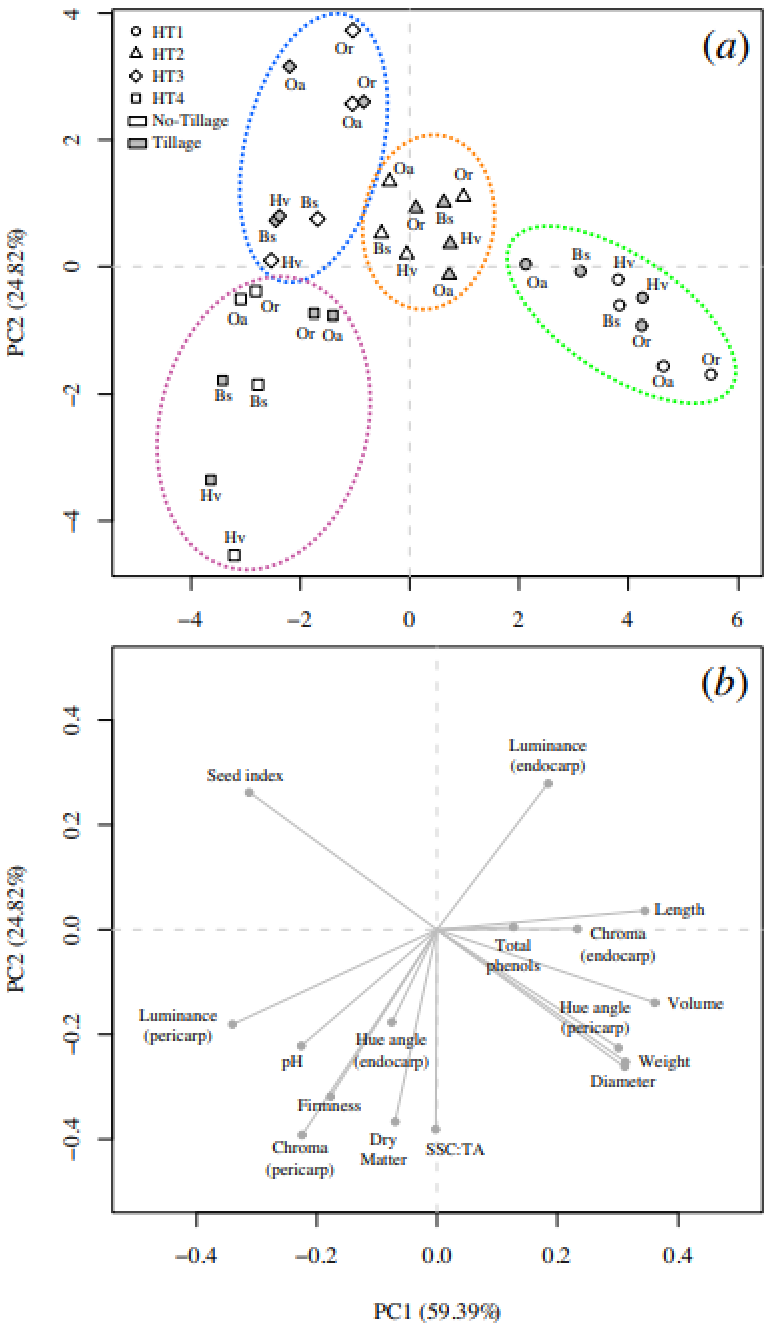

No-Tillage
Tillage
(a)
CIELab color difference (ΔE*)
5.7
6.5
7.3
8.1
8.9
9.7
c
bc
c
c
a
c
c
b
(b)
Total phenols (mg GAE gDW⁻¹)
1.5
1.7
1.9
2.1
2.3
2.5
f
ef
de
cd
b
a
f
c
Hairy vetch
Oilseed rape
Oat
Bare soil
Soil management

Figure 6


HT1
HT2
HT3
HT4
No-Tillage
Tillage
(a)
(b)
PC2 (24.82%)
PC1 (59.39%)
Seed index
Luminance (endocarp)
Length
Chroma (endocarp)
Total phenols
Volume
Hue angle (pericarp)
Weight
Diameter
Luminance (pericarp)
pH
Hue angle (endocarp)
Firmness
Chroma (pericarp)
Dry Matter
SSC:TA