Management of crop residues to improve quality traits of tomato (*Solanum lycopersicum* L.) fruits

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Abstract

Management of cover crops provides mulching and/or topsoil incorporation of plant residues, which can enhance soil organic matter content as well as supply important nutrients. An experiment was conducted to evaluate the effects on tomato quality and yield performance of different managements of plant residues from three cover crops compared with plastic cover (polyvinyl chloride) and bared soil (control). Management treatments consisted of: mulch with faba bean (MuF), rapeseed and barley and incorporated plants of faba bean (InF), rapeseed and barley. PVC and mulching with crop residues obtained higher yields; faba bean, due to its chemical composition, gave the highest fruit growth and yield, regardless of residues management. Residues improved tomato crop physiology as well as minerals concentration in fruits: the highest calcium values were observed for InF, while magnesium was significantly concentrated in fruits of MuF and InF treatments. Faba bean as previous crop seemed more effective in enhancing yield and quality tomato traits. Rapeseed did not confirm the expected results.

Introduction

Tomato (*Solanum lycopersicum* L.) is a one of the most popular vegetables worldwide, and it is rich source of fiber, minerals, sugars as well as vitamins and lycopene. Conventional tomato production typically includes deep tillage and bedded plastic mulch to minimise weed populations and water evapotranspiration. Nevertheless, conventional tillage increases soil erosion and nutrient loss, reduces organic carbon, and increases soil strength (Mahboubi *et al*., 1993). Plastic mulch is expensive and pose environmental issues if not removed from the field after harvest. In spite of tomato universal popularity, there has been little improvement in term of quality (Ratanachinakorn *et al*., 1997; Causse *et al*., 2002). Besides the role of breeding, quality traits as well as yield are determined by environmental factors and cultivation practices.

Within a general framework of sustainable approach to the agro-system, the application of agronomic practices which referers to conservation agriculture principles, could be very interesting also in those rotations which include tomato crops especially under Mediterranean conditions. The use of cover crops would give numerous benefits, *i.e*. prevent soil erosion, protect water quality, improve yields by enhancing soil health (soil structure and tilth), cut fertiliser costs by fixing the atmospheric N, conserve soil moisture, and reduce the need for herbicides and other pesticides (Hartwig and Ammon, 2002). Grass and legumes are frequently used as cover crops, because they satisfy the essential requirements, such as ruggedness, vigorous vegetative growth, and high shoot dry matter yield (Branco *et al*., 2013).

Management of cover crop provides for mulching and/or topsoil incorporation of plant residues improve soil organic matter content as well as supplies important nutrients (Stagnari and Pisante, 2010). When incorporated, the degradation processes are quick, while the application as mulch ensures a slower release of plant nutrients, likely improving the synchrony of nutrient release to the requirements of the next crop (Fischler, 1997). Few data on the management of cover crop residues as mulching in horticultural crops are available, and in particular study focusing on the relationships with the quality traits of tomato are lacking.

Therefore, the objective of this study was to evaluate the effects of different managements of plant residues, from three cover crops, on yield, physiology and quality traits of tomato, compared with plastic cover and bared soil.

Materials and methods

One field trial was carried out during 2010-2011 cropping season in a representative vegetable production area of central-south Italy (Martinsicuro, Italy, 42°86'N, 13°92'E, 0 m asl) with a typically Mediterranean climate. The means of maximum and minimum temperatures recorded during the experimental period were 27.7 and 19.4°C, respectively, while the amount of rainfall was of

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203.2 mm. The physical and chemical characteristics of the soil were as follows: sand, 48%; silt, 29%; clay, 23%; pH (H_2O), 7.2; CEC, 16.7 mequiv. 100 g^{-1}; total $CaCO_3$, 1.2%; total organic matter, 1.4%; total N, 1.0 g kg^{-1}; P, 43 mg kg^{-1}; K, 450 mg kg^{-1}.

The experiment was arranged on a randomised complete block design with three replicates, where 8 thesis, consisting in different managements of soil and plant residues, were compared as follows: i) harrowing soil between tomato rows plus hand weed control on the rows (control); ii) mulching with polyvinyl chloride (PVC) on the rows and harrowing between the rows; iii) whole plant residues of faba bean (*Vicia faba* L. var. *minor*), rapeseed (*Brassica napus* L. var. *oleifera*) and barley (*Hordeum vulgare* L.) distributed over all the soil surface, creating a layer of about 5 cm (MuF, MuR and MuB, respectively) as mulching; iv) whole plant residue of faba bean, rapeseed and barley chopped and incorporated into the first 5 cm of soil (InF, InR and InB, respectively). Faba bean, rapeseed and barley were previously sown in the plots (November 26th, 2010) at a rate of 60, 52 and 312 plants m^{-2}, respectively, and managed as previously reported on April 19th, 2011 at the phenological stage of flowering (faba bean and rapeseed) or at complete head emergence (barley). Plots receiving control and PVC were previously kept free from weeds by harrowing.

Tomato was transplanted on May 23th, 2011 at a density of 4.4 plants m^{-2} (with a distance of 0.75 m between the rows and 0.30 m on the row) and each plot consisted of four 4-m-long rows with a size of 12 m^2. During transplanting, a PVC (black polyethylene) film of caliper 130 (3.25 mm thick) was applied in the PVC treatment plots.

In all plots, the water loss by evapotranspiration was replaced through artificial irrigation with pressure compensating micro sprinklers. No herbicides were applied and, where needed, weeds were removed by hand-hoeing; fertilisers were not applied in order to better estimate the contribution, in term of nutrient release, from crop residues.

Tomato fruits were sampled from the first truss on July 26th [64 days after transplanting (DAT)], when approximately 80% of the total fruits were ripened. Six marketable ripe fruits were randomly selected from each plot, washed with distilled water and characterised for their fresh weights (FW, g) and equatorial diameters (cm). Sub-samples of 20 g were oven-dried at 80°C until constant weight, for dry matter (DM) content determinations. Tomato yield was estimated from July 26th (64 DAT) to the beginning of October on three randomly selected plants per plot.

The pH, titratable acidity (TA) and soluble solids (TSS) content were immediately determined. TSS were measured at 20°C with a digital refractometer (model Brix PR-1; Atago CO. Ltd., Tokyo, Japan), which provides values as °Brix. The pH was measured with a pH-meter (model 701 Al Digital Ioanalyzer; Orion-Research Inc., Cambridge, MA, USA). TA was quantified by titrating 50 g of tomato paste with 0.1 mol L^{-1} NaOH to pH 8.1. Acidity was expressed as grams of citric acid equivalent per 100 g fresh weight.

The concentrations of P, Ca, K and Mg of tomato fruits and leaves were determined by Atomic Absorption Spectrometry (AAnalyst 300; Perkin Elmer, Waltham, MA, USA) according to the Method 968.08 (AOAC, 1995), while P was determined by the colorimetric method with molybdo-vanadate reagent (Method 965.17) (AOAC, 1995).

On crop residues, the total N content was determined with the Kjeldahl method; the neutral detergent fibre (NDF) value was analysed following the procedure reported by van Soest *et al*. (1991), while the acid detergent fibre (ADF) analysis was carried out according to AOAC method 973.1834 (1997).

Plants physiological traits were recorded at 22, 29, 37 and 45 DAT. Chlorophyll content was estimated with SPAD (soil-plant analysis development) 502 plus portable chlorophyll meter (Konica Minolta Inc., Tokyo, Japan) on 10 same sun-oriented leaves from three plants per plot. Leaf temperature was measured with a portable infrared thermometer (Everest Interscience Inc., Tucson, AZ, USA) either around midday or in the early afternoon on 10 same leaves of three plants per experimental unit. Leaf stomatal conductance (mmol $m^{-2}s^{-1}$) was measured with a steady state diffusion porometer (Model SC-1; Decagon Devices, Pullman, WA, USA) in one fully expanded leaf of three randomly selected plants per plot.

Treatment and block effects for all the investigated variables were tested by analysis of variance (ANOVA). If the ANOVA detected significant differences, means separation was performed through Tukey's honestly significant difference (HSD) test (P≤0.05). Before ANOVA, data were analysed to test the normality and homoscedasticity assumptions. Statistical analysis was performed using the R software (R Development Core Team, 2013).

Table 1. Yield, fruit fresh weight, fruit diameter, dry matter content, total soluble solids content, pH, titratable acidity and mineral elements concentrations as observed in fruits of tomato plants subjected to eight different soil treatments.

Treatment	Yield (t ha^{-1})	Fruit FW (g)	Fruit diameter (cm)	DM (%)	TSS (°Brix)	pH	TA (%)	Ca (µg g^{-1} DM)	P (µg g^{-1} DM)	Mg (µg g^{-1} DM)	K (µg g^{-1} DM)
Control	36.9^{d}	119.7^{de}	20.5^{c}	5.47	4.00	4.34	0.32	265^{ab}	406^{b}	153^{bc}	3972
PVC	47.8^{ab}	173.6^{bc}	24.1^{ab}	5.39	4.17	4.38	0.32	212^{cd}	426^{ab}	146^{c}	3929
MuF	51.1^{a}	224.8^{a}	26.7^{a}	5.58	4.40	4.37	0.33	247^{bc}	405^{b}	171^{a}	4207
MuR	44.3^{b}	166.2^{bcd}	23.8^{b}	5.42	4.17	4.37	0.32	234^{bcd}	464^{a}	146^{c}	4564
MuB	45.7^{b}	143.5^{cde}	22.0^{bc}	5.41	3.93	4.40	0.30	197^{de}	406^{b}	143^{c}	3992
InF	48.6^{a}	199.5^{ab}	24.8^{ab}	5.05	4.33	4.46	0.29	287^{a}	438^{ab}	167^{ab}	4362
InR	40.2^{c}	113.9^{e}	20.1^{c}	5.70	4.17	4.37	0.35	188^{e}	412^{b}	153^{bc}	4264
InB	39.7^{c}	108.9^{e}	19.7^{c}	5.78	4.27	4.42	0.34	206^{de}	395^{b}	143^{c}	3981
SED	1.7	13.2	0.8	0.30	0.37	0.05	0.03	16.8	18.2	7.5	234
F-test	**	**	**	ns	ns	ns	ns	**	*	*	ns

FW, fresh weight; DM, dry matter; TSS, total soluble solids content; TA, titratable acidity; Ca, calcium; P, phosphorus; Mg, magnesium; K, potassium; control, un-mulched; PVC, black polyethylene film; MuF, mulched faba bean residues; MuR, mulched rape seed residues; MuB, mulched barley residues; InF, incorporated faba bean residues; InR, incorporated rape seed residues; InB, incorporated barley residues; SED, standard error of differences between means (degrees of freedom: blocks 2; treatments 7; residual 14). $^{a-e}$Means in the same column followed by different letters significantly differ (Tukey's HSD test, P<0.05). *P<0.05; **P<0.01; ns, not significant. Fruits were collected at 64 days after transplanting.

Results and Discussion

Soil management practices greatly influenced yield response of tomato plants, inducing significantly higher values than control (Table 1). In general, higher yields were observed in mulched soil with PVC and crop residues, principally due to moisture preservation as already reported (Samaila *et al*., 2011). However, faba bean gave the highest yield, regardless of residues management (51.1 and 48.6 t ha^{-1} for MuF and InF, respectively), probably due to the chemical composition of its residues. Leguminous cover crops usually have an higher N content and lower C:N ratios compared to non-leguminous ones, thus influencing the key factors of mineralisation process (Thorup-Kristensen *et al*., 2003). Similar results were observed in tomato following hairy vetch either incorporated into the soil (Sainju *et al*., 2001) or applied as mulch (Marinari *et al*., 2015).

Mulching with faba bean induced also the highest fruit weight and diameter (224.8 g and 26.7 cm, respectively) although not statistically different from InF (Table 1).

Soil management was also responsible for interesting changes in plant physiology, as measured in terms of POR and TIR responses (Table 2). Indeed, these traits can be considered as indirect methods of monitoring plant water status (Hsiao, 1990). In general, faba bean and rapeseed treatments performed better, especially nearly the reproductive stage, thanks to higher POR values (averaging over samplings: 46, 32, 27 and 20% more for MuF, MuR, InF and InR, respectively) and lower leaf temperature values than control (Siddique *et al*., 2001). Normally, crop residues reduce the water evaporation from soil through shading (van Donk *et al*., 2010), influencing soil moisture both during irrigation and dry spells (Montenegro *et al*., 2013). However, the nature of mulch material and the amount of crop residues could also influence the temperature at the top layer of soil and, consequently, the magnitude of water retention (Stagnari *et al*., 2014). As confirmed in our study (data not shown), plastic mulches tend to increase daily maximum soil temperatures while organic mulches to reduce them (Dabney *et al*., 2001).

Since sugars, acids, phenols and minerals are the main responsible of tomato taste (Kader, 2008), fruits were characterised for TSS, pH, TA and mineral elements concentrations (Table 1). Soil management practices did not significantly influence TSS, pH and TA, as well as TSS:TA ratio, which registered values ranged from 11.8 (InR) to 14.7 (InF) (data not shown). Our results did not confirm previously findings on tomato (Hong *et al*., 2000; Samaila *et al*., 2011) and melon (Stagnari and Pisante, 2010) crops, which indicate significant positively impacts of mulching with residues on fruit taste and quality. This is probably due to the harvest time, since only fruits from the first truss were considered. However, soil management significantly influenced Ca, P and Mg concentrations in fruits (Table 1). In particular, the highest Ca values were observed for InF and control (287 and 265 μg g^{-1} DM, respectively), while Mg significantly concentrated in fruits from plots with MuF and InF treatments (171 and 167 μg g^{-1} DM, respectively). The higher Ca and Mg concentration in leaves of tomato plants grown after faba bean (Ca: 8045 and 8337 μg g^{-1} DM for MuF and InF, respectively; Mg: 730 and 884 μg g^{-1} DM for MuF and InF, respectively; data not shown) support these findings. The effect of mulching whit crop residues is mostly attributable to nutrient release, following residues decomposition. The aerial parts of faba bean were characterised by high total N and low NDF and ADF values (data not shown), allowing a rapid decomposition and promptly release of minerals in soil solutions which were significantly correlated with their residue content (Ranjbar and Jalali, 2012). Conversely, barley did not induce any higher uptake of minerals from tomato plant, as shown by mineral concentration in fruits (Table 1) and leaves (data not shown). Rapeseed gave a positive response for P concentration in fruits, as well as InF and PVC. A great uptake of K, as demonstrated by leaf mineral concentration (data not shown), could have determined a subsequent release of H^+ in the rhizosphere, lowering pH values and increasing the P concentration in the soil solution (Barber, 1995).

Table 2. Soil-plant analysis development, stomatal conductance and canopy temperature as recorded in tomato plants subjected to eight different soil treatments.

DAT	Treatment	SPAD	TIR (°C)	POR (mmol m^2 s^{-1})
22	Control	45.9	24.9	243.2^{cd}
	PVC	47.1	24.8	217.0^{d}
	MuF	50.8	24.8	321.9^{a}
	MuR	46.9	24.6	312.8^{ab}
	MuB	43.1	24.6	260.9^{bcd}
	InF	47.4	24.6	264.6^{bcd}
	InR	49.8	24.9	272.3^{abc}
	InB	46.9	25.0	245.0^{cd}
	SED	2.9	0.3	15.3
	F-test	ns	ns	*
29	Control	51.1^{bc}	33.8^{a}	129.9^{cd}
	PVC	55.7^{abc}	33.5^{a}	168.9^{a}
	MuF	57.2^{ab}	30.7^{b}	173.8^{a}
	MuR	49.6^{c}	32.7^{ab}	148.0^{b}
	MuB	53.9^{abc}	34.0^{a}	111.4^{e}
	InF	57.9^{ab}	32.3^{ab}	174.7^{a}
	InR	58.9^{a}	32.6^{ab}	140.9^{bc}
	InB	55.5^{abc}	33.0^{a}	124.6^{de}
	SED	2.1	0.7	4.6
	F-test	**	**	**
37	Control	49.1^{b}	33.3^{bc}	114.3^{e}
	PVC	55.5^{ab}	33.6^{ab}	180.6^{b}
	MuF	56.0^{a}	31.5^{d}	210.3^{a}
	MuR	52.9^{ab}	32.7^{bc}	179.2^{b}
	MuB	53.6^{ab}	34.7^{a}	135.7^{d}
	InF	58.2^{a}	32.2^{cd}	154.7^{c}
	InR	56.2^{a}	33.0^{bc}	161.1^{c}
	InB	55.2^{ab}	33.0^{bc}	114.1^{e}
	SED	1.9	0.3	3.7
	F-test	*	**	**
45	Control	49.6	29.7^{b}	269.1^{d}
	PVC	53.0	30.0^{b}	314.6^{c}
	MuF	53.1	29.0^{b}	402.4^{a}
	MuR	50.0	29.4^{b}	363.4^{b}
	MuB	51.0	31.4^{a}	288.0^{d}
	InF	54.6	29.1^{b}	369.3^{b}
	InR	55.1	29.5^{b}	337.7^{c}
	InB	50.3	29.6^{b}	267.9^{d}
	SED	2.4	0.3	6.7
	F-test	ns	**	**

DAT, day after transplanting; SPAD, soil-plant analysis development; TIR, canopy temperature; POR, stomatal conductance; control, un-mulched; PVC, black polyethylene film; MuF, mulched faba bean residues; MuR, mulched rape seed residues; MuB, mulched barley residues; InF, incorporated faba bean residues; InR, incorporated rape seed residues; InB, incorporated barley residues; SED, standard error of differences between means (degrees of freedom: blocks 2; treatments 7; residual 14). $^{a-e}$Means in the same column followed by different letters significantly differ (Tukey's HSD test, P<0.05). *P<0.05; **P<0.01; ns, not significant. Measurements were taken at 22, 29, 37 and 45 days after transplanting.

Conclusions

In conclusion, mulching improves crop physiological status of tomato plants than un-mulched soil or treatments consisting in incorporation of plant residues in the soil. Plastic mulch favours higher soil temperatures, allowing obtaining higher and earlier yields. The effects of faba bean as previous crop, regardless of management, seem clear already at vegetative phases of tomato plants, inducing higher fruit weight and diameter and, consequently, crop yield. In general, barley does not induce any significant amelioration of tomato plants growth and fruits quality; anyway, mulching rather than straw incorporation seems to give better results. Rapeseed as previous crop does not confirm the expected results, despite clear differences emerge between MuR and InR treatments. We found a significant influence on fruit minerals concentration that finds an explication in the quality and composition of crop residues. Differently to gramineous, leguminous crops allow a rapid decomposition and promptly release of minerals in soil solutions, which in turn positively affect their uptake by plant roots system and translocation to the fruits.

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