Integration of Cover Crop Management and Herbicide Rate on Weeds and Yield in Tomato in a Mediterranean Environment

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Abstract
A 2-year field experiments were carried out in North of Iran with the aim of assessing the effect of grass and legume cover crop residues managed under different soil tillage and herbicide rates on weed control, weed community, and on yield of tomato crop. The treatments consisted in: (a) two winter cover crops: annual alfalfa and barley and no covered soil; (b) two tillage system: no-tillage, and conventional tillage; (c) three pre-emergence herbicide rates: no-herbicide application, half rate recommended, and full rate recommended. Cover crops were sown in early September and mechanically suppressed in March about two weeks before tomato transplanting. At cover crop suppression, alfalfa showed the highest aboveground biomass (569 g m^{-2} of dry matter), while barley showed the lowest weed content (32 g m^{-2} of dry matter). At tomato harvesting, weed density and aboveground biomass ranged from 13.8 to 62.3 plants m^{-2} and 61 and 1257 g m^{-2} of dry matter, respectively. At tomato harvesting, the tomato yield was higher in alfalfa than barley and no cover regardless of tillage management (on average 62.3, 51.8 and 50.1 t ha^{-1} of fresh matter, respectively) probably due to an abundant availability of soil nitrate throughout the tomato growing season. This was confirmed by high and constant values of chlorophyll leaf content of tomato plants grown in alfalfa. Cover crop residues placed in surface suppressed weeds more effectively than incorporated residues. Reducing the pre-emergence herbicide rate by half did not affect weed control or tomato fruit yield compared with the full rate. Therefore combining legume cover crops and conservation tillage, it is possible to maintain tomato yield while reducing both herbicide inputs (by 50%).
***Keywords*: Annual alfalfa, Barley, Integrated weed management, Mulch, tillage.**

Introduction
The use in agriculture of herbicides are becoming more limited, due to their expense and environmental impact which has recently caused much concern and there is also an increase of herbicide-resistant weed biotypes. Therefore, new control approaches to weeds are necessary both for assuring an adequate crop yield and for respecting the environment. Sustainable management practices, such as conservation tillage and cover cropping can improve crops, soil fertility and environmental conditions (Campiglia et al., 2010). Studies on tomato production systems have been limited to exploring effects of cover crops, conservation tillage, or herbicide rates. The integration of the three components into a unique cropping system has not been investigated. Thus, the objective of this work was to study tomato yield and weed population dynamics, in a system that integrates cover crops, conservation tillage, and reduced herbicide rates.

Materials and Methods
Each field experiment consisted in a cover crop – tomato sequence. The experimental treatments were: three winter soil management: two cover crop species [annual alfalfa (*Medicago scutellata* L., var. Robinson, hereafter called CC1) and barley (*Hordeum vulgar*L., var Sahra, hereafter called CC2)] and a no covered soil (hereafter called CC0); two soil tillage for preparing the transplanting bed of tomato crop: soil tilled conventionally at a depth of 30 cm (hereafter called CT) and no-tilled soil (hereafter called NT); three pre-plant herbicide rates, [no (H1), half rate recommended (H2), or full rate recommended (H3) of pre-emergence herbicides]. The experimental design was a split-split plot, where the winter soil management was the main factor, the soil tillage was the split factor and the pre-plant herbicide rate was the split-split factor. The treatments were replicated four times for a total of 72 basic plots. The analysis of variance (ANOVA) was carried out for all the data of 2-years

period using the JMP statistical software package 4.0 (SAS Institute, 1996). Fisher's protected least significant differences (LSD) were used for comparing the main and interaction effects.

Results

The weed density and weed aboveground biomass at tomato harvesting followed a similar trend both at cover crop, even if there were smaller differences between annual alfalfa and barley (Table 1). Weed aboveground biomass were lower in barley, intermediate in annual alfalfa and higher in bared soil, regardless the tillage and herbicide treatments (Table 1). However, when weeds were controlled with herbicides, weed dry biomass was similar between full rate, and half rate of applications in barley and annual alfalfa cover crop systems. The NT treatment had the smallest weed density and biomass (Table 1). Weed density of CT was higher than NT. The application of pre-emergence herbicide significantly reduced weed density and biomass (Table 1). As expected half rate, H2, and full rate, H3, of herbicide resulted in lower weed density and lower weed biomass than no herbicide, H1. The half rate of herbicide gave similar weed control as the full rate in terms of weed density and weed biomass. There was also earlier weed emergence in the half-rate treatment compared with the full rate of the herbicide.

At tomato harvesting, a total of 12 broadleaf and grass species were found across the treatments (Table 2). Weed density of nitrophilous weeds such as *Solanum nigrum*, *Amaranthus retroflexus* and *Chenopodium album* was higher in annual alfalfa than in barley or no cover crop. Also, the density of annual photoblastic weed was higher in tilled uncovered soil such as *A. retroflexus*, *C. album*, *S. nigrum*, and *Portulaca oleracea*.

The results of the canonical discriminant analysis on the weed density observed for cover crop and tillage management treatments at tomato harvesting are reported in Fig. 1. The first two canonical variables explained 69% of the total variance. *Amaranthus retroflexus* L., *Chenopodium album* L., *Solanum nigrum* L., *Portulaca oleracea* L. and *Anagallis arvensis* L. vectors were generally in the same ordination space of bare soil and alfalfa in NT and CT regardless the herbicide treatments, while barley NT and CT appear to be associated with *Ammi majus*, *Verbena officinalis* L., *Malva sylvestris* L., and *Conyza canadensis* (L.) Cronq, (Fig. 1). Annual alfalfa increased marketable yield tomato compared with barley (Fig. 2). Tillage treatment had significant effects on tomato production (Fig. 2). Although NT had the highest all tomato values, CC0NTH1 had the lowest tomato production among the tillage treatments (Fig 2). Herbicide treatments significantly impacted fruit yield (Fig. 2). Applying half rate or full rate of the pre-emergence herbicides increased tomato fruit yield (on average among residue management treatment and cover crops by 42% and 48%, respectively, compared with no herbicide treatment). The half rate of the pre-emergence herbicide had equivalent tomato production in comparison with the full rate of the herbicide. The fitness of the tomato and the weeds (RRIt and RRIw) was showed in table 3. The relative response index of tomato (RRIt), In general it was lower in annual alfalfa than barley and in NT than CT treatments, (Table 3). The relative response index of weeds (RRIw), was always higher in NT than CT treatments, while it was higher in barley compared to annual alfalfa. The difference in plant biomass between tomato and weeds, expressed as response comparison index (RCI), was affected by an interaction cover crop × tillage management (Table 3). The RCI was always higher in NT compared to CT and in annual alfalfa compared to barley.

Table 1. The interaction effects of cover crop x soil tillage and cover crop x herbicide rate on weed density and weed aboveground biomass at tomato harvesting. Values belonging to the same characteristic and treatment with different letters in rows for soil tillage or herbicide rate (upper case letter), and in columns for cover crop (lower case letter) are statistically different according to LSD (0.05). CC_0 = no covered soil, CC_1 = annual medic, CC_2 = Barley, CT = Conventional tillage, NT = No-tillage, H1= Non herbicide, H2 = Half rate herbicide, H3 = Full rate herbicide.

	Weed density -------- plants m^{-2} --------									
Cover crop	Soil Tillage				Herbicide rate					
	CT		NT		H_1		H_2		H_3	
CC_0	43.1	aA	32.4	aA	61.5	aA	32.9	aB	18.8	aC
CC_1	24.3	bA	7.3	bB	25.7	bA	14.2	bB	7.5	bB
CC_2	22.7	bA	6.9	bB	23.9	bA	13.7	bB	6.9	bB
	Weed biomass -------- g m^{-2} of DM --------									
	CT		NT		H_1		H_2		H_3	
CC_0	490.3	aA	440.7	aA	1157.0	aA	177.9	aB	61.7	aC
CC_1	149.2	bA	58.1	bB	181.4	bA	91.1	bB	38.6	bC
CC_2	83.6	cA	36.4	bB	96.7	cA	49.7	cB	33.6	bB

Table 2. Weed characteristics and density per species at tomato harvesting in annual medic, barley and in bare soil. Data were combined for two years. CC_0 = no covered soil, CC_1 = annual medic, CC_2 = Barley, A = Annual weed specie; B = Biennial weed specie; and P = Perennial weed specie, SED = Standard error of differences.

Name	Taxonomic Group	Life Cycle	Weed code	CC_0	CC_1	CC_2
					Plant m^{-2}	
Amaranthus retroflexus L.	*Amaranthaceae*	A	W_1	11.2	3.3	0.3
Ammi majus L.	*Umbelliferae*	A	W_9	0.3	1.1	3.1
Anagallis arvensis L.	*Primulaceae*	A	W_5	4.3	0.6	0.1
Chenopodium album L.	*Chenopodiaceae*	A	W_3	8.3	3.3	0.0
Conyza Canadensis(L.) Cronq.	*Asteraceae*	A	W_7	0.0	0.3	4.4
Lolium spp.	*Poaceae*	A	W_{10}	0.0	0.3	0.3
Malva sylvestris L.	*Malvaceae*	P	W_{11}	0.0	0.6	2.1
Polygonum aviculare L.	*Polygonaceae*	A	W_{12}	1.5	2.9	0.4
Portulaca oleracea L.	*Portulacaceae*	A	W_4	5.6	0.3	0.0
Rumex crispus L.	*Polygonaceae*	P	W_6	0.0	0.0	1.5
Solanum nigrum L.	*Solanaceae*	A/B	W_2	4.5	2.8	0.0
Verbena officinalis L.	*Verbenaceae*	A/B	W_8	0.1	0.3	3.6
SED				*0.7*	*0.5*	*1.1*

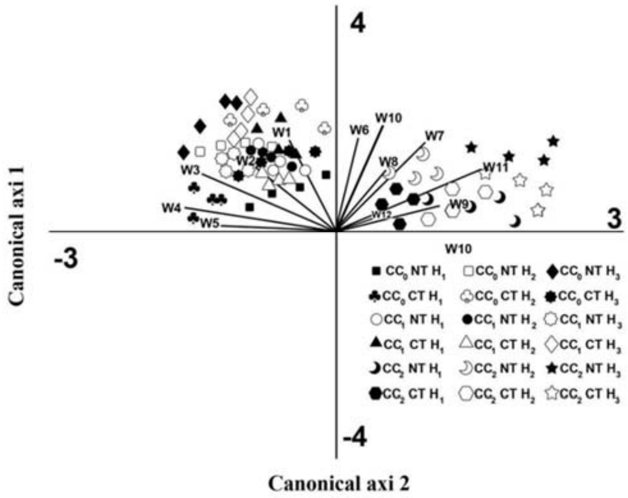

Figure 1. Biplot from canonical discriminant analysis (CDA) of the weed species in the tomato crop at tomato harvesting. Data were combined for two growing seasons. CC_0 = no covered soil, CC_1 = Annual medic, CC_2 = barley, NT = No-tillage, CT = Conventional tillage, H_1 = non herbicide, H_2 = half rate herbicide and H_3 = full rate herbicide. See Table 3 for a description of symbols for weed species.

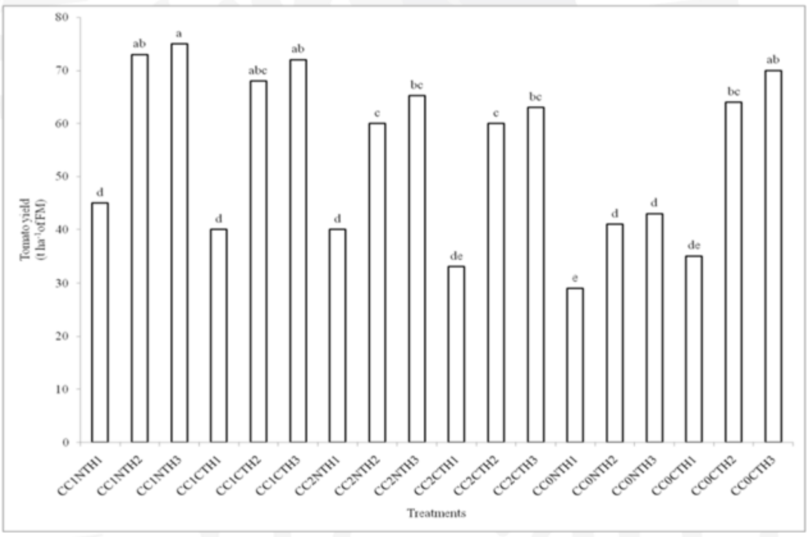

Figure 2. The effect of interaction of the cover crop × tillage management × herbicide rate on the yield of tomato. CC_0 = no covered, soil CC_1 = annual medic, CC_2 = Barley, CT = Conventional tillage, NT = No-tillage, H_1 = Non herbicide, H_2 = Half rate herbicide and H_3 = Full rate herbicide. The same letters in columns are not different according to LSD (0.05). FM = fresh matter.

Table 3. The effect of interaction of the winter soil management × soil tillage management on the relative response index of tomato (RRIt), the relative response index of weeds (RRIw), and on response comparison index (RCI) at tomato harvesting in the full rate of herbicide treatment (H3). Values belonging to the same characteristic without common letters are statistically different according to LSD (0.05) in columns for each cover crop (lower case letter) and in rows for each residue management (upper case letter) of each weed management. CC_1 = Annual medic, CC_2 = Barley, CT = Conventional tillage, NT = No-tillage.

	Relative response index of tomato (RRIt)				Relative response index of weed (RRIw)				Response comparison index (RCI)			
Cover crop	CT		NT		CT		NT		CT		NT	
CC_1	-0.27	bA	-0.44	bB	0.53	aB	0.77	aA	0.80	aB	1.21	aA
CC_2	-0.01	aA	-0.25	aB	0.71	bA	0.85	aA	0.72	aB	1.10	bA

References

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