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Evaluation of mechanical weed control in legume crops

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ABSTRACT

Two three-year field experiments with soya bean (*Glycine max* (L.) Merr.) and faba bean (V*icia faba* L., var. *minor* Beck.) were carried out in central Italy in order to evaluate the effects of different mechanical methods (spring-tine harrowing, hoeing, hoeing-ridging, split-hoeing, finger-weeding) on weed control and crop yield. Split-hoeing + finger-weeding was the best mechanical weed control option, both in soya bean and faba bean, showing an excellent control of both inter- and intra-row weeds with efficacy values ranging from 73% to 97%. Split-hoeing and hoeing gave a good inter-row weed control, showing an effective action against both broad-leaves and grasses also in relatively advanced developmental stages, although they did not effectively control weeds along the row. Harrowing and finger-weeding gave the worst weed control due to low efficacy against grasses and weeds bigger than 12–14 BBCH-scale. Yield crop showed not significant differences among the untreated control and all the other treatments, confirming the high competitive ability of legume crops. All the treatments gave crops yield values around the overall mean of trials with contained inter-annual variation, showing as the mechanical weed control can be a sustainable method to manage weeds in this legume crops without considerable losses in yield. Furthermore, the adoption of legume crops thanks to their good competitive ability against weeds and other important characteristics, offers the potential of enhancing the productivity and sustainability of the cropping system, especially in the organic farming.

1. Introduction

The increasing interest in organic and low-input farming systems has renewed attention toward alternative methods of weed management, such as the development of innovative mechanical solutions (Avola et al., 2008; Pannacci and Tei, 2014; Melander et al., 2015). Organic and low-input farming systems mainly relied for its crop nutrients on legume crops (De Ponti et al., 2012). In general, increasing legume cultivation could bring benefits for the environment and resource use at a range of scales, from the field to the global; their pre-crop effect, nitrogen provision, and potential to improve nutrient conservation and soil structure add to the sustainability of farm productivity while saving resources and reducing emissions (Covarelli et al., 2010; Reckling et al., 2014). Among the grain legume crops, soya bean and faba bean are considered very important, although due to different reasons.

In fact, soybean (*Glycine max* (L.) Merr.) is one of the most important grain legume and oilseed crops in the world, accounting for more than 50% of the global oilseed production (Datta et al., 2017). Faba bean (*Vicia faba* L.) is grown world-wide as a protein source for food and feed, offering ecosystem services such as renewable inputs of nitrogen (N) into crops and soil via biological N_2 fixation, and a diversification of cropping systems (Jensen et al., 2010).

It is well known that prolonged weed interference not only causes heavy crops yield losses, but increases production costs and reduces the quality of produce, thus requiring early-season weed management to achieve economically acceptable yields (Knezevic et al., 2003; Sardana et al., 2017). In particular, the presence of weeds up to beginning of seed stage of soya bean (R5) may cause 8–55% reduction in yield (Van Acker et al., 1993). Weeds are managed in soya bean primarily by herbicides (Niekamp and Johnson, 2001; Datta et al., 2017), although mechanical and cultural weed control methods showed to be effective (Chauhan and Opeña, 2013; Pannacci and Tei, 2014). Faba bean is known to compete weakly against weeds in the early growth phase (Lee and Lopez-Ridaura, 2002); so the pre-emergence herbicides are commonly used in order to control weeds until the crop is big enough to suppress any additional emerging weeds (Köpke and Nemecek, 2010). However, over the last twenty years, environmental and human health impact of herbicides use, increasing of herbicide resistance, the scarce availability of herbicides for minor crops and the increased of organic farming were the main factors that stimulated the interest to develop alternative methods to chemical weed control, such as mechanical weed control (Melander et al., 2005; Pannacci et al., 2017). Soya bean and faba bean are very often inserted in the organic farming systems, now

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even more than in the past, due to their ecosystem services and increased demand for organic grains as food products (Place et al., 2009; Jensen et al., 2010). In this context, organic soybean and faba bean weed management can rely on mechanical weed control, due to large space between the rows. However, although weeds between the rows (inter-row weeds) can normally be controlled by ordinary inter-row cultivation, such as hoeing, weeds that grow within the line of row crop plants (intra-row weeds) have a great impact on yield and constitute a major problem for selective control, especially for organic farmers (Melander et al., 2012; Pannacci and Tei, 2014). For intra-row weed control, most mechanical methods are based on old principles, but new implements and improved versions have emerged lately, such as finger-weeder, torsion-weeder and intelligent weeders (Van der Weide et al., 2008; Rasmussen et al., 2012; Melander et al., 2015; Pannacci et al., 2017). Over the last fifteen years new mechanical weed control methods such as split-hoeing, finger-weeding and harrowing were introduced in order to give farmers more flexibility and options. However, there is a low availability of data on the performance of mechanical weed control methods obtained from field experiments in legume crops. For these reasons, the aim of this study was to evaluate the effects of mechanical methods on weed control, crop selectivity and crop yield in soya bean and faba bean in central Italy. The mechanical treatments involved in this study were chosen with the aim to compare weed control methods traditionally used (i.e. hoeing and hoeing-ridging) with weed control methods relatively new such as split-hoeing, finger-weeding and harrowing. Several initial studies have supported this choice, showing that these mechanical methods may have application in soya bean and faba bean (Gunsolus, 1990; Avola et al., 2008; Pannacci and Tei, 2014).

2. Materials and methods

From 2005 to 2008, two three-year field experiments with faba bean and soyabean were carried out in central Italy (Tiber valley, Perugia, 42°57′ N - 12°22′ E, 165 m a.s.l.) on a clay-loam soil (24.8% sand, 30.4% clay and 0.9% organic matter). The trials were carried out according to good ordinary practices, as concerns soil tillage and seedbed preparation (Bonciarelli and Bonciarelli, 2001). Experimental design was always a randomized block with four replicates and plot size of 24 and 30 m^2 (3 m width) in soya bean and faba bean, respectively. In each crop, different mechanical weed control methods were compared (Table 1) and untreated and manual weeding plots were added as checks.

Harrowing, a full surface mechanical control, was carried out with a 3 m-wide spring-tine harrow (Type SF-30, Faza, Italy, http://www.fazasrl.com/en/project/spring-tine-weeder-hackstriegel/, equipped with 7 mm-diameter flexible tines) at a cultivation depth of 10–20 mm and a driving speed of 7 km h^{-1}. Harrowing was applied only in soya bean and earlier with respect to the other mechanical treatments because its effectiveness is maximum especially against small weeds (Table 1). Hoeing, an inter-row mechanical control, was carried out with a 3 m-wide powered rotary hoe (Model CERES, Badalini, Italy, http://www.badalini.it/home_en.php?azione=scheda_prodotto_en&id=50) at a cultivation depth of 50–60 mm, a driving speed of 4 km h^{-1} and leaving 120-mm untilled strip in the crop rows. Hoeing-ridging was applied only in faba bean and was carried out with the same rotary hoe as mentioned above, but equipped with ridging implements to bury weeds along the row. Split-hoeing was performed with a 1.5 m-wide Asperg Gartnereibedarf split-hoe (Asperg, Germany, for more details see Tei et al., 2002) at a cultivation depth of 30–40 mm, a driving speed of 3 km h^{-1} and leaving a 100-mm untilled strip in the crop rows. Split-hoe is an inter-row mechanical machine for weed control equipped with shanks provided with sweep tools in front and rotors with steel tine in rear moved by hydraulic power. The sweep tools penetrate and lift the earth, the rotors, turning in the direction of travel between the rows, intercept and crumble the soil and separate (split) earth and weeds. The weeds remain on the soil surface and die quickly. Metal crop shields (100 mm wide) protect crops from moving soil.

Table 1
Treatments in the field experiments with faba bean and soya bean.

Treatments (codes)	Soya bean			Faba bean		
	2006	2007	2008	2005–06	2006–07	2007–08
Untreated control (UC)	X	X	X	X	X	X
Manual weeding (MW)	X	X	X	X	X	X
Harrowing (HA)	X	X	X	–	–	–
Hoeing (HO)	X	X	X	X	X	X
Hoeing-ridging (HOR)	–	–	–	X	X	X
Split-hoeing (SH)	X	X	X	X	X	X
Finger-weeding (FW)	X	X	X	X	X	X
Split-hoeing + finger-weeding (SH + FW)	X	X	X	X	X	X

Finger-weeding, an intra-row mechanical control, was carried out with a 1.5 m-wide Kress finger-weeder (Kress Umweltschonende Landtechnik GmbH, Germany, http://neu.kress-landtechnik.de/wEnglisch/produkte/gemuesebau/hacktechnik/fingerhacke_start.shtml?navid=12) at a cultivation depth of 10–30 mm and a driving speed of 5 km h^{-1}. Kress finger-weeder equipments were mounted on Kress Argus System (http://neu.kress-landtechnik.de/wEnglisch/produkte/gemuesebau/hacktechnik/argus_start.shtml?navid=19) equipped with special-flat share type “Holland” (340 mm wide, http://neu.kress-landtechnik.de/wEnglisch/produkte/gemuesebau/hacktechnik/hackwerkzeug/hackwerkzeuge_start.shtml?navid=31) that works between the rows. Rubber fingers grip from the side around the plant and there they hoe the weeds. In this way, the area which no other mechanical hoe usually reaches will be weeded as well. Special-flat share cuts the weeds between the rows that remain on the soil surface and die.

Preliminary tests were carried out in order to set the implements with the aim to obtain a level of cultivation intensity able to guarantee the highest efficacy against the weeds with the lowest crops damage.

2.1. Soya bean

Soya bean, cv. Nikko (Asgrow®, maturity group 1-), was sown on 04 May 2006, 09 May 2007 and 2008 in 0.5 m-spaced rows to obtain a final density of 30 plants m^{-2}. Soft winter wheat was always the preceding crop. A low-irrigation regime was adopted, with one irrigation in June and two irrigations in July (30 mm each). All mechanical treatments, except harrowing, were performed with the crop at the growth stage of 12–13 BBCH-scale (Meier, 2001), broadleaved weeds at 12–14 BBCH-scale and grasses at the growth stage of 14–15 BBCH-scale. Harrowing was performed earlier than the other treatments with the crop at the growth stage of 11–12 BBCH-scale, broadleaved weeds at 10–12 BBCH-scale and grasses at the growth stage of 13 BBCH-scale.

Soya bean was harvested on 03 October 2006, 21 September 2007 and 30 September 2008.

2.2. Faba bean

Faba bean, cvs. Vesuvio (2005-06 and 2006-07) and Scuro di Torrelama (2007-08) was sown on 09 November 2005, 07 November 2006 and 06 November 2007 in 0.5 m-spaced rows, at a seeding rate of 56 seeds m^{-2}. Oilseed rape, sunflower and soft winter wheat were the preceding crops, respectively. Mechanical treatments were performed with the crop at the growth stage of 150–200 mm height, broadleaved weeds from 12–14 BBCH-scale to 16–18 BBCH-scale and grasses at the growth stage from 13 BBCH-scale to 21–22 BBCH-scale.

Faba bean was harvested on 28 June 2006, 14 June 2007 and 24 June 2008.

2.3. Data collection and analysis

Four weeks after mechanical treatments (WAT), weeds on four squares (0.5 × 0.5 m each one) per plot were collected, counted, weighed, dried in oven at 105 °C to evaluate weed density and weed dry weight; these data were evaluated again at the harvest of soya bean only in 2006 and 2007. The squares were posed on four rows (one on each row) of the central part of the plot: the square position was random along the row but centred on the row, such as reported by Kurstjens and Bleeker (2000). Data on weed density and weed dry weight were used to calculate the efficacy (E) of different treatments relative to the untreated control, according to Chinnusamy et al. (2013):

$$E(\%) = \frac{W_U - W_T}{W_U} \times 100$$

where,

W_U: weed density or weed dry weight in untreated plots.

W_T: weed density or dry weight in treated plots.

At harvesting time, crop density, grain yield and weight of 1000 seeds were determined by hand-harvesting the central part of each plot. Crop density was used as indicator of treatments selectivity on the basis of uprooted crop plants, such as showed by Kurstjens (2000).

Prior to ANOVA, data on weed density were square root transformed and dry weight were log-transformed (Box and Cox, 1964). Means were separated by Fisher's protected LSD test at $p = 0.05$. Analysis of variance was performed with the EXCEL® Add-in macro DSAASTAT (Onofri and Pannacci, 2014).

Meteorological data (daily maximum and minimum temperature and rainfall) were collected from a nearby station. Decade averages were calculated and compared with multiannual averages (Fig. 1).

3. Results and discussion

3.1. Soya bean

Total weed flora was quite different in the three years. A combined analysis of data showed that the interactions "*years x treatments*" were significant ($P < 0.001$); therefore, the results were shown and discussed separately for each year.

In 2006, total weed flora was scarce due to the low rainfalls during May, June and July associated with a reduction of average temperature that have not favoured weeds emergence and their growth (Fig. 1a). In particular, 4 WAT, weed density and weed dry weight in the untreated control were 12.5 plants m^{-2} and 53.1 g m^{-2}, respectively (Table 2).

The main weed species were: *Solanum nigrum* L., *Vicia sativa* L., *Portulaca oleracea* L., *Polygonum aviculare* L., *Picris echioides* L., *Echinochloa crus-galli* L. and *Lolium multiflorum* Lam. Other sporadic species were: *Amaranthus retroflexus* L., *Chenopodium album* L., *Stachys annua* (L.) L., *Anagallis arvensis* L. and *Medicago lupolina* L. Against this weed flora, all the treatments, except harrowing and finger-weeding alone, showed a good efficacy at 4 WAT (Table 2). However, the highest levels of weed control were obtained by manual weeding, hoeing and split-hoeing + finger-weeding; this latter treatment showed not significant different with respect to split-hoeing alone (Table 2). Weeds data, at the crop harvest, confirm the results obtained at 4 WAT (Table 2). In fact, the above mentioned weather condition, characterized by low rainfall during the first half part of the soya bean cycle (Fig. 1a), not has allowed new weeds emergence from 4 WAT to harvest, both in the untreated control and in treated plots, limiting also the growth of the uncontrolled weeds (Table 2).

In 2007, total weed flora was scarce, although higher than in the previous year in terms of density. This is due to the abundant rainfall at the end of May and first decade of June that have favoured weeds emergence just before the treatments (Fig. 1b). In particular, 4 WAT, weed density and weed dry weight, in the untreated control, were 34.7 plants m^{-2} and 48.2 g m^{-2}, respectively (Table 3).

The main weed species were: *A. retroflexus*, *C. album*, *P. oleracea*, *S. nigrum*, *P echioides*, *E. crus-galli* and *Digitaria sanguinalis* (L.) Scop. Other sporadic species were: *L. multiflorum*, *Setaria viridis* (L.) Beauv., *Polygonum lapathifolium* L., *Veronica hederifolia* L., *Fallopia convolvulus* (L.) Holub. At 4 WAT, harrowing showed the worst weed control, as in 2006, while the other mechanical treatments provided good control of weeds without significant differences among them (Table 3). In particular, at the crop harvest, split-hoeing + finger-weeding maintained the highest weed control level in terms of weed dry weight control and comparable to manual weeding (Table 3). On the other hand, at the crop harvest, the highest weed dry weight levels were observed in the untreated control, as well as, in harrowing and finger-weeding (Table 3). These results on the weeds dry weight at the soya bean harvest were due especially to the uncontrolled weeds by the treatments and secondarily to the new weed emergence. These weeds were *A. retroflexus*, *C. album* and *E. crus-galli*, that thanks to their high growth capacity and helped to the rainfall in August (Fig. 1b), have increased their biomass until to the crop's harvest (Table 3).

In 2008, total weed flora was very abundant due to the high rainfalls during May, June and July associated with a good average temperature that have favoured weeds emergence and their growth (Fig. 1c). In particular, 4 WAT, weed density and weed dry weight in the untreated control were 166.6 plants m^{-2} and 178.9 g m^{-2}, respectively (Table 4).

The main weed species were: *P. oleracea*, *A. retroflexus*, *C. album, S. nigrum* and *E. crus-galli*. Other sporadic species were: *S. viridis, L. multiflorum and P. lapathifolium*. The high infestation level allowed to put in evidence significant statistically differences among the treatments, especially in terms of weed density (Table 4). In particular, a weed efficacy higher than 90% was obtained by hoeing and split-hoeing + finger-weeding. In this latter treatment the combination of split-hoeing + finger-weeding improved significantly the results obtained with the same treatments alone (Table 4), confirming as in the cases of high weed infestation, these two methods may be successfully combined to obtain a satisfactory inter- and intra-row weed control (Pannacci and Tei, 2014). Hoeing, as a traditional inter-row cultivation is most effective on weeds also in relatively advanced developmental stages, although did not effectively control weeds along the row (Gunsolus, 1990). Harrowing and finger-weeding gave the worst weed control, as in the previous years, due to low efficacy against grasses (*E. crus-galli*, *D. sanguinalis and L. multiflorum*) and weeds bigger than 12–14 BBCH-scale, confirming the results obtained by Raffaelli et al. (2002) and Pannacci and Tei (2014).

In all years, weed control methods didn't show significant differences in crop density, without uprooted crop plants after treatments (Table 5).

In general, crop yield was lower than the potential production for this area with higher yield in 2008 than in 2006 and 2007 (Table 5). This was due to low irrigation regime (only 90 mm in total for each year) and the unfavourable weather conditions (low rainfall) in the first two years (Fig. 1). In particular, in each year the lowest yield values were always observed in the untreated control, although these values were significantly different to the yield values of the weed control methods, only in 2008 (Table 5). These results could be explained by the lower weed density in 2006 and 2007 than in 2008, combined with the above mentioned weather conditions, that reduced the differences of yield losses among untreated and treated plots, while increased these differences in 2008, due to the high competition of uncontrolled weeds against the crop. Furthermore, the crop yield indices, expressed as average of the three years, confirm these results, showing as, except the untreated control, all the treatments gave soya bean yield values around the overall mean of trials with contained inter-annual variation (Fig. 2). These results seem to suggest that, in presence of low infestation level, weed control could be avoided, accepting low yield loss. However, the seed rain of uncontrolled weeds can increase substantially

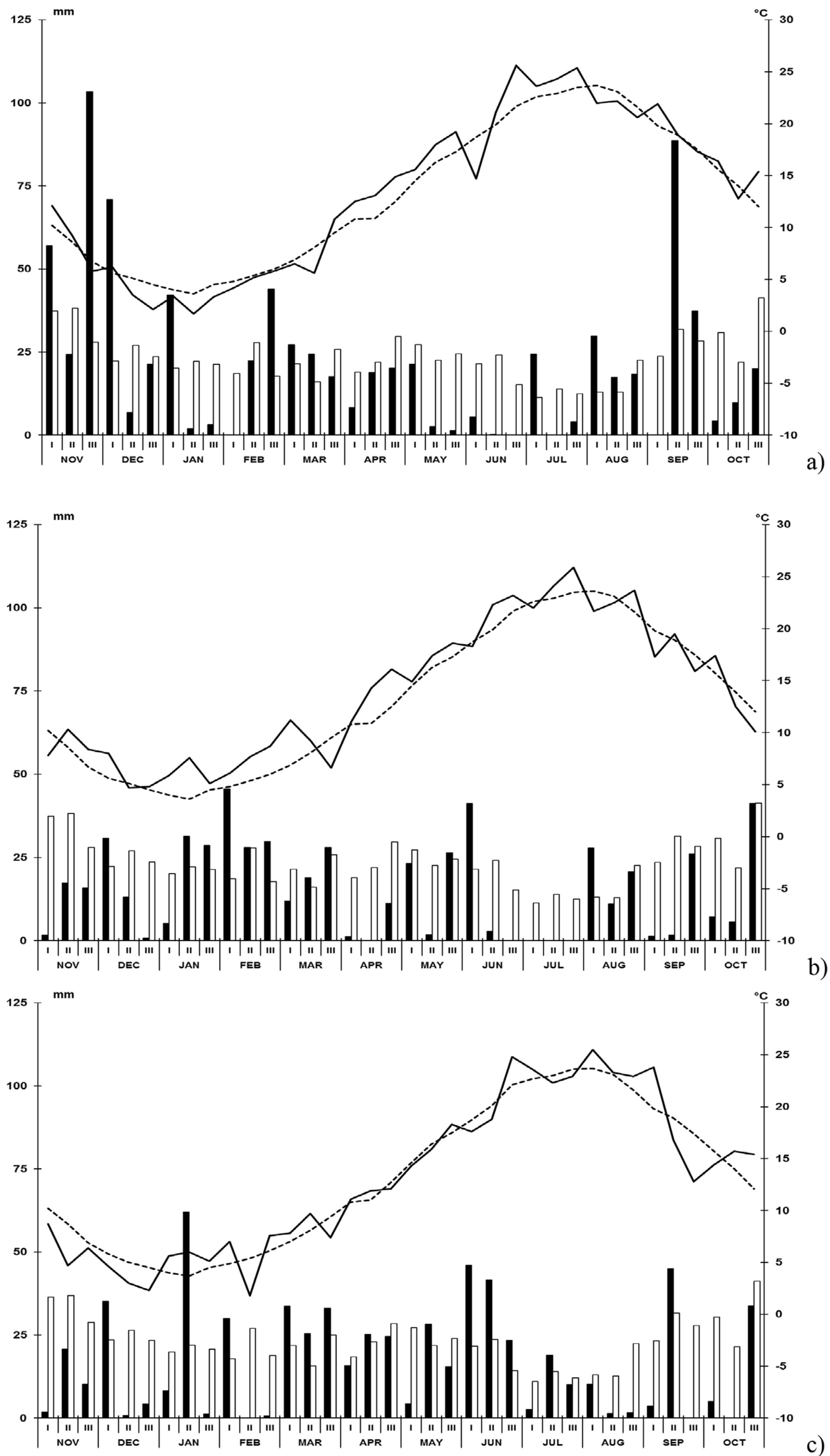

Fig. 1. Average decade values of rainfall (mm; bold bar) and temperature (°C; solid line) recorded during the experimental trials in 2005–2006 a), 2006–2007 b), 2007–2008 c), compared to multi-annual (from 1921) averages (rainfall: mm, empty bar; temperature: °C, sketched line).

the weeds seed bank, as showed in the previous studies in the same area (Graziani et al., 2012; Pannacci and Tei, 2014). For these reasons, the knowledge of the most efficacy mechanical weed control methods and their adoption is crucial to manage weeds in an integrated weed management system, especially for crops growth in organic and low-input farming systems (Harker and O'Donovan, 2013; Chauhan et al., 2015).

Table 2
Soya bean (2006): effect of different weed control methods on density and dry weight of total weeds.

Treatments	Weeds (4 weeks after treatments)								Weeds (at the crop harvest)							
	No. m^{-2}			Efficacy (%)	Dry weight ($g\ m^{-2}$)			Efficacy (%)	No. m^{-2}			Efficacy (%)	Dry weight ($g\ m^{-2}$)			Efficacy (%)
	$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.		$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.	
Untreated control (Uc)	3.7	a	12.5	–	1.7	a	53.1	–	2.3	a	4.4	–	1.8	ab	71.0	–
Manual weeding	1.0	d	0.0	100.0	0.0	c	0.0	100.0	1.1	d	0.3	92.4	0.6	e	4.5	93.7
Harrowing	2.5	b	5.5	56.0	1.1	b	12.2	77.0	2.0	b	3.0	32.2	1.4	bc	40.0	43.7
Hoeing	1.7	c	2.0	84.0	0.7	b	5.6	89.5	1.3	cd	0.7	83.9	1.0	de	9.9	86.1
Split-hoeing	1.6	c	1.8	86.0	0.9	b	10.3	80.6	1.5	c	1.1	74.4	1.1	cd	13.5	81.0
Finger-weeding	4.2	a	16.5	0.0	1.8	a	58.7	0.0	2.4	a	5.0	0.0	1.9	a	78.0	0.0
Split-h. + Finger-w.	1.6	cd	1.5	88.0	0.8	b	8.5	83.9	1.4	cd	0.9	79.1	0.9	de	10.3	85.5
SED	*0.28*		–	–	*0.27*		–		*0.13*		–	–	*0.22*		–	

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05).

Table 3
Soya bean (2007): effect of different weed control methods on density and dry weight of total weeds.

Treatments	Weeds (4 weeks after treatments)								Weeds (at the crop harvest)							
	No. m^{-2}			Efficacy (%)	Dry weight ($g\ m^{-2}$)			Efficacy (%)	No. m^{-2}			Efficacy (%)	Dry weight ($g\ m^{-2}$)			Efficacy (%)
	$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.		$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.	
Untreated control (Uc)	5.9	a	34.7	–	1.6	a	48.2	–	7.6	a	59.3	–	2.8	a	662.1	–
Manual weeding	1.0	d	0.0	100.0	0.0	d	0.0	100.0	3.2	b	10.7	82.0	1.4	cd	35.7	94.6
Harrowing	4.3	b	19.7	43.3	0.8	bc	8.0	83.4	5.7	a	36.3	38.8	2.2	ab	208.5	68.5
Hoeing	2.7	c	6.7	80.8	0.6	bc	4.3	91.1	3.7	b	14.7	75.3	1.9	bc	75.2	88.6
Split-hoeing	2.3	cd	4.7	86.5	0.5	bc	3.7	92.3	2.7	b	7.7	87.1	1.9	bc	89.1	86.5
Finger-weeding	2.4	cd	5.3	84.6	0.9	b	12.7	73.6	3.1	b	10.3	82.6	2.4	ab	325.3	50.9
Split-h. + Finger-w.	2.9	bc	8.7	75.0	0.3	cd	1.4	97.0	2.5	b	7.0	88.2	1.1	d	21.7	96.7
SED	*0.73*		–	–	*0.25*		–		*0.93*		–	–	*0.26*		–	

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05).

3.2. Faba bean

Total weed flora was quite different in the three years. As in soya bean, a combined analysis of data showed that the interactions "*years x treatments*" were significant ($P < 0.01$); therefore, the results were shown and discussed separately for each year.

In 2005–2006, total weed flora was characterized by a weak number of small weeds. Indeed, 4 WAT, weed density in the untreated control were 50 plants m^{-2} with a low weed dry weight of 3.2 g m^{-2} (Table 6).

The main weed species were: *P. aviculare, F. convolvulus, L. multiflorum*. Other sporadic species were: *S. nigrum, S. annua, Sinapis arvensis* L., *A. arvensis* and *Papaver rhoeas* L. Against this weed flora, all the treatments showed a comparable efficacy at 4 WAT (Table 6), although the highest levels of weed control were obtained by manual weeding and split-hoeing + finger-weeding (Table 6). The absence of significant differences among the mechanical treatments was due to the small weeds that allowed to be easily controlled by all the mechanical tools, as already mentioned in other studies (Rasmussen et al., 2010; Melander et al., 2015).

In 2006–2007, total weed flora was very scarce: 4 WAT, weed density and weed dry weight, in the untreated control, were 3.7 plants m^{-2} and 15.9 g m^{-2}, respectively (Table 7).

The main weed species were: *P. rhoeas* and *S. arvensis*. Other sporadic species were: *L. multiflorum, Galium aparine* L. and *Lactuca serriola* L. Against this weed flora, the highest levels of weed control were obtained by manual weeding, hoeing and split-hoeing + finger-weeding, while split-hoeing and finger-weeding alone gave the worst weed control (Table 7).

Table 4
Soya bean (2008): effect of different weed control methods on density and dry weight of total weeds.

Treatments	Weeds (4 weeks after treatments)							
	No. m^{-2}			Efficacy (%)	Dry weight ($g\ m^{-2}$)			Efficacy (%)
	$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.	
Untreated control (Uc)	12.9	a	166.6	–	13.0	a	178.9	–
Manual weeding	1.6	e	2.6	98.5	5.9	bc	36.5	79.6
Harrowing	8.2	b	67.5	59.5	8.9	b	81.6	54.4
Hoeing	3.1	d	9.8	94.1	5.5	c	30.9	82.7
Split-hoeing	4.7	c	23.2	86.1	4.4	c	25.1	86.0
Finger-weeding	5.1	c	26.6	84.0	6.9	bc	48.3	73.0
Split-h. + Finger-w.	2.3	de	5.7	96.6	4.4	c	24.3	86.4
SED	*0.54*		–	–	*1.58*		–	

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05).

Table 5
Soya bean: effects of different weed control methods on crop density, grain yield and weight of 1000 seeds.

Treatments	2006				2007			2008			
	Density (n. m^{-2})	Yield (t ha^{-1})	1000 seeds (g)		Density (n. m-2)	Yield (t ha^{-1})	1000 seeds (g)	Density (n. m^{-2})	Yield (t ha^{-1})		1000 seeds (g)
Untreated control (Uc)	28.0	3.13	152.2	a	28.8	2.73	158.9	31.8	3.18	b	179.0
Manual weeding	29.3	3.14	146.8	b	33.5	3.14	153.5	30.0	4.13	a	174.2
Harrowing	27.8	3.17	146.5	b	27.5	3.06	158.3	26.8	3.80	a	172.8
Hoeing	29.3	3.26	148.3	b	27.5	3.37	158.5	28.5	4.15	a	174.7
Split-hoeing	32.3	3.39	146.3	b	26.8	3.37	158.6	33.5	4.01	a	173.5
Finger-weeding	26.3	3.21	146.8	b	29.0	3.30	160.3	25.5	4.18	a	178.2
Split-h. + Finger-w.	32.0	3.45	148.3	b	30.5	3.24	154.2	30.3	4.04	a	172.9
SED	*3.1*	*0.12*	*1.7*		*3.6*	*0.31*	*6.4*	*2.9*	*0.28*		*4.5*

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05), while values without letter are not statistically significant.

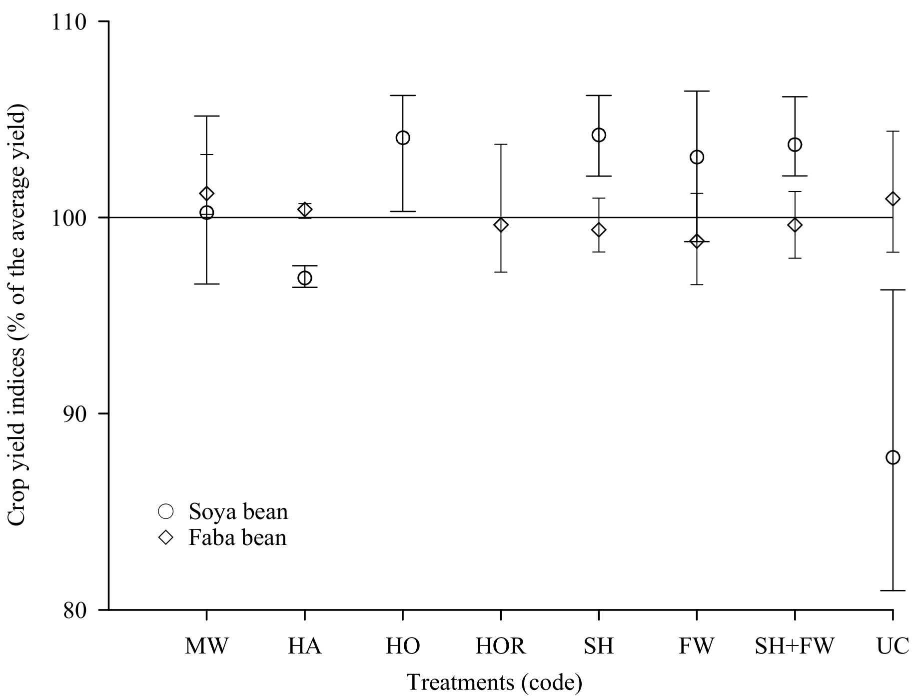

Fig. 2. Crop yield indices (overall mean of trials carried out for each crop = 100) of treatments (see Table 1 for corresponding treatments code).

Table 6
Faba bean (2005-06): effect of different weed control methods on density and dry weight of total weeds.

Treatments	Weeds (4 weeks after treatments)							
	No. m^{-2}			Efficacy (%)	Dry weight (g m^{-2})			Efficacy (%)
	$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.	
Untreated control (Uc)	7.1	a	50.0	–	0.62	a	3.2	–
Manual weeding	1.0	d	0.0	100.0	0.0	d	0.0	100.0
Hoeing	3.8	bc	13.5	73.0	0.17	cd	0.5	83.7
Hoeing-ridging	3.7	bc	13.0	74.0	0.21	bc	0.7	79.1
Split-hoeing	3.4	bc	12.0	76.0	0.24	bc	0.9	72.0
Finger-weeding	4.1	b	16.0	68.0	0.41	ab	2.0	36.3
Split-h. + Finger-w.	2.7	c	7.0	86.0	0.22	bc	0.7	76.8
SED	*0.53*		–	–	*0.09*		–	

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05).

In 2007–2008, as in 2005–2006, total weed flora was characterized by a weak number of small weeds: 4 WAT, weed density in the untreated control, were 64.4 plants m^{-2} (Table 8).

The main weed species were: *L. multiflorum*, *P. rhoeas*, *Hordeum vulgare* L. (volunteer crop), *P. aviculare*. Other sporadic species were: *F. convolvulus*, *Veronica hederifolia* L. Against these weeds, all the treatments showed a weed control efficacy higher than 70%; however, manual weeding, hoeing-ridging and split-hoeing + finger-weeding were able to control more than 90% of weeds (Table 8).

It could be point out as the weed flora in faba bean was always characterized by high density of small weeds with a low presence of grass weeds, as it could be observed from data of weeds in the three

Table 7
Faba bean (2006-07): effect of different weed control methods on density and dry weight of total weeds.

Treatments	Weeds (4 weeks after treatments)							
	No. m^{-2}			Efficacy (%)	Dry weight (g m^{-2})			Efficacy (%)
	$y^{0.5}$-trf.		Back-trf.		Log-trf.		Back-trf.	
Untreated control (Uc)	2.0	a	3.7	–	0.8	ab	15.9	–
Manual weeding	1.0	c	0.0	100.0	0.0	c	0.0	100.0
Hoeing	1.0	c	0.0	100.0	0.0	c	0.0	100.0
Hoeing-ridging	1.4	abc	1.7	54.5	0.3	abc	4.1	74.6
Split-hoeing	1.9	ab	3.3	9.1	1.0	a	42.2	0.0
Finger-weeding	1.9	ab	3.0	18.2	1.0	a	28.1	0.0
Split-h. + Finger-w.	1.3	bc	1.0	72.7	0.2	bc	1.5	90.7
SED	*0.33*		–	–	*0.36*		–	

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05).

Table 8
Faba bean (2007-08): effect of different weed control methods on density of total weeds.

Treatments	Weeds (4 weeks after treatments)			
	No. m^{-2}			Efficacy (%)
	$y^{0.5}$-trf.		Back-trf.	
Untreated control (Uc)	8.0	a	64.4	–
Manual weeding	1.0	e	0.0	100.0
Hoeing	3.4	bc	10.8	83.3
Hoeing-ridging	1.8	de	3.8	94.2
Split-hoeing	2.9	cd	7.8	87.9
Finger-weeding	4.3	b	17.6	72.2
Split-h. + Finger-w.	2.3	cd	4.6	92.9
SED	*0.59*		–	–

In each column, values followed by the same letter are not significantly different according to the Fisher's protected LSD test (P = 0.05).

field experiments. This was due to the high competitive ability of faba bean that although has allowed the emergence of weeds in the first part of growth cycle, then it was be able to contain their growth, reducing in the incidence of grass weeds, as already observed by Jensen et al. (2010).

Concerning faba bean parameters recorded at harvesting time, in all years, not significant differences were observed among treatments for each one of the three parameters (Table 9). In particular, faba bean plants density was always not significantly affected by treatments, confirming also in faba bean the good selectivity of mechanical treatments. Yield crop values have not differed so much among the years, with average values very close to the overall mean of trials and small inter-annual variation (Fig. 2). Furthermore, the average yield crop values (3.0 t ha^{-1} in 2005–2006, 2.9 t ha^{-1} in 2006–2007 and 3.6 t ha^{-1} in 2007–2008) were in line with those reported by other authors in review articles and research papers (Duc, 1997; Avola et al., 2008; Link et al., 2010). Yield crop with not significant differences among the untreated control and all the other treatments, confirm the high competitive ability of faba bean that can allow high yield levels also without weed control. However, especially in the cases of high infestation levels, a weed control treatment has to be applied in order to avoid the risk to increase the weed seed bank. The high competitive ability of faba bean, together with other characteristics, offers the potential of enhancing the productivity and sustainability of the cropping system, especially in the organic farming (Köpke and Nemecek, 2010).

4. Conclusion

Mechanical weed control in legume crops showed a high weed control efficacy, reducing losses in crop yield also thanks to their good selectivity against the crop plants.

In soya bean, the best mechanical treatments were manual weeding and split-hoeing + finger-weeding, that gave an excellent control of both inter- and intra-row weeds. Split-hoeing and hoeing gave a good inter-row weed control, showing an effective action against both broadleaves and grasses also in relatively advanced developmental stages. However, these mechanical methods did not effectively control weeds along the row. Harrowing and finger-weeding gave the worst weed control due to their low efficacy against weeds with more than 12–14 BBCH-scale. All the treatments gave soya bean yield values around the overall mean of trials with contained inter-annual variation, showing as the mechanical weed control can be a sustainable method to manage weeds in this legume crop without considerable losses in yield.

In faba bean, manual weeding and split-hoeing + finger-weeding showed to be the best mechanical weed control methods, followed by hoeing-ridging, hoeing, split-hoeing and finger-weeding. The high competitive ability of faba bean reduced weed emergence allowing high yield levels also without weed control. However, the control of weeds

Table 9
Faba bean: effects of different weed control methods on crop density, grain yield and weight of 1000 seeds.

Treatments	2005–06			2006–07			2007–08		
	Density (n. m^{-2})	Yield (t ha^{-1})	1000 seeds (g)	Density (n. m-2)	Yield (t ha^{-1})	1000 seeds (g)	Density (n. m^{-2})	Yield (t ha^{-1})	1000 seeds (g)
Untreated control (Uc)	46.0	3.03	316.1	44.3	3.05	297.7	49.6	3.57	343.9
Manual weeding	51.5	3.12	323.4	47.0	2.93	299.3	49.9	3.64	354.0
Hoeing	49.3	3.04	320.5	42.7	2.92	298.9	44.4	3.66	349.8
Hoeing-ridging	45.5	2.96	320.2	44.7	2.84	301.1	49.8	3.77	357.9
Split-hoeing	47.8	2.99	323.9	43.3	2.87	289.1	46.1	3.67	346.9
Finger-weeding	44.3	3.06	321.9	41.3	2.88	298.7	47.9	3.51	338.3
Split-h. + Finger-w.	43.3	2.96	323.6	42.0	2.96	292.1	47.5	3.62	350.2
SED	*3.7*	*0.13*	*6.5*	*6.7*	*0.08*	*5.4*	*3.1*	*0.08*	*6.6*

In each column, values are not statistically significant.

can not to be omitted in order to avoid the risk to increase the weed seed bank due to the dissemination of uncontrolled weeds.

For these reasons the knowledge of the most efficacy mechanical weed control methods and their adoption is crucial to manage weeds in an integrated weed management system, especially for crops growth in organic and low-input farming systems. The adoption of legume crops thanks to their good competitive ability against weeds and other important characteristics, offers the potential of enhancing the productivity and sustainability of the cropping system, especially in the organic farming.

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