Renewable Agriculture and Food Systems: 25(1); 8–15 doi:10.1017/S1742170509990287

Physical weed control in protected leaf-beet in central Italy

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Accepted 16 November 2009; First published online 15 January 2010 **Preliminary Report**

Abstract

Leaf-beet is a typical and very important protected cultivation crop in central Italy. In leaf-beet protected cultivation, weed control is one of the most important problems because of its fairly long crop cycle (approximately 4–5 months). The aim of this research was to set up an efficient non chemical weed control strategy performed with innovative machines built and set up by the University of Pisa. A two-year (2006–2007) 'on-farm' experimental trial was carried out in Crespina (PI). A conventional weed management technique (consisting of one pre-transplanting chemical treatment) was compared with an innovative physical weed control strategy in an organic production system (consisting of using a stale seedbed technique, in several post-emergence precision hoeing and in-row hand-weeding treatments). In the conventional technique, leaf-beet was manually transplanted, while it was sown with a precision pneumatic planter in the organic system. All innovative machines for physical weed control were adjusted and set up for the protected cultivation. Similar yields were recorded for the two systems in this two-year trial. Total labor time (for weed management and crop planting) was appreciably lower in the conventional system in the first year of the experiment (−67%), while in the second year, some improvement in the physical weed control techniques decreased labor needs with respect to the conventional technique (−40%). Weed dry biomass at harvest was significantly lower in the organic cropping system (on average −50%).

Key words: organic farming system, machines for physical weed control, rolling harrow, precision hoe, flaming machine

Introduction

Integrated pest management and organic vegetable production systems have gained a great deal of attention in agreement with EU agricultural policy reorientations[1,2]; furthermore, this is in line with mounting public concern over environmental issues, work safety and the growing consumer demand for high-quality food products. One of the major technical problems that arise in vegetable production when decreasing the use of agrochemicals is weed control[3,4]. This is a very important problem in protected cultivation in which an inevitable intensification of cultivation leads to even more difficulties. Protected cultivation has many commercial advantages but it has many agronomic and crop protection problems, including weed control. This problem, which is very important for horticultural crops, can be tackled and solved in a sustainable way by using and optimizing physical weed control.

Recently, a series of techniques and purpose-designed operative machines have been devised to perform efficient and economically viable non chemical weed control in open fields. Numerous interesting trials have been carried out with promising results on spring–summer crops[5–12], on winter cereals[13–16] and on horticultural crops[17–35].

In contrast, research on physical weed control in protected cultivations has not been conducted to the same extent. For this reason, technical and scientific knowledge available on this topic is lacking. Moreover, field techniques and machinery cannot be directly applied to different crops and operative conditions. Therefore, to develop a sustainable weed control in protected cultivation, it is necessary to develop or adapt machines to be used under different operative conditions and to determine the interactions among operative parameters (crop typology and management practices, as well as weed density, developmental stage and competitiveness, soil conditions, protection typology, etc.)[3,12,22,29,36–41].

An experiment was carried out on leaf-beet [*Beta vulgaris* L. var. *cycla* (L.) Ulrich] in order to develop and assess strategies to decrease or eliminate herbicide use in

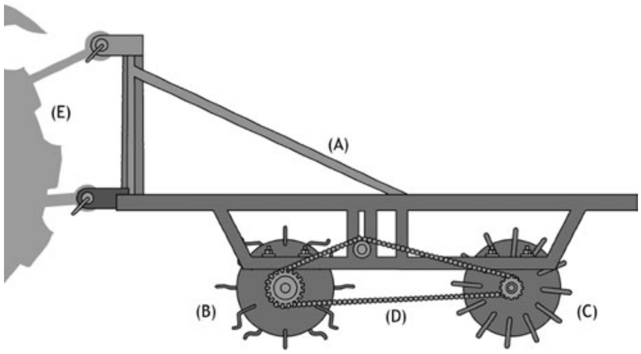

Figure 1. Schematic drawing of the rolling harrow: (A) frame; (B) front axle with spike discs; (C) rear axle with cage rolls; (D) chain drive and (E) three-point hitch.

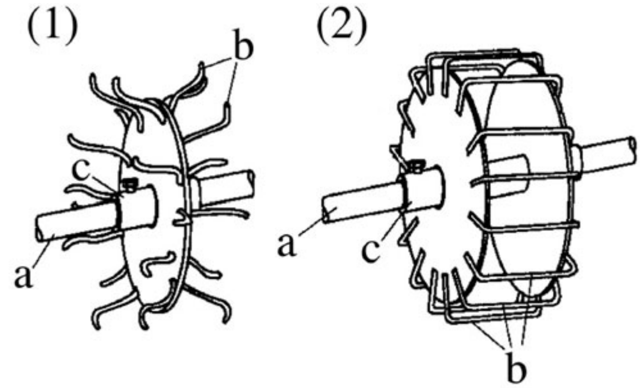

Figure 2. Schematic drawing of the working tools of the rolling harrow: (1) spike disc; (2) cage roll: (a) rotating axle; (b) spikes and cages and (c) sliding locking device of the units.

protected cultivation. In Central Italy, leaf-beet is a major crop under protected cultivation. It has a long crop cycle (between 4 and 5 months) and consequently weed control is one of its most important problems. In the experimental trials, a conventional weed management technique was compared with innovative physical weed control strategies.

Materials and Methods

A two-year (2006–2007) 'on-farm' experiment was carried out in Crespina (PI). The experiment was carried out on farms close to each other, conventional and organic, with similar sandy soil (sand 67%, silt 26%, clay 7% and organic matter 2%) and climatic conditions. Trials were performed in two 100 m × 7 m non heated greenhouses (2.25 m high).

On the organic farm, sowing was performed with a precision planter in August. The seeding rate was 30 seeds m^{-2} (20 × 12 cm) on ridges 1.4 m wide (with 5 rows $ridge^{-1}$). On the conventional farm, leaf-beet was first seeded in seedbeds in August and manually transplanted in the greenhouse or tunnel at the end of September at a rate of 12 plants m^{-2} on ridges 1 m wide (with 3 rows $ridge^{-1}$).

First year

The non chemical weed control strategy was carried out by using the false seedbed technique (with the rolling harrow), three post-emergence precision hoeing and two in-row hand-weeding treatments performed between hoeing treatments.

The conventional weed control strategy was carried out by transplanting and using one pre-planting chemical treatment (8 kg ha^{-1} Kerb, a.i. propizamide).

The physical weed control machines were studied, built and set up in this experiment by the Research Unit to perform effective and efficient treatments.

The rolling harrow was developed to perform a very shallow tillage and to provide effective weed control both in 'false seedbed' technique and in precision hoeing treatments after crop emergence. The machine is modular, so it can be built with different working widths adapted to row spacing (Fig. 1). Furthermore, the rolling harrow is structured on a square frame bearing working tools and three-point linkage. The tools are spike discs with a diameter of 30–35 cm (placed in the front) and gage rolls with a diameter of 27–33 cm (placed in the rear), which are inserted on two axles, connected by means of a chain drive with an easily adjustable ratio (Fig. 2). Discs and rolls of different sizes can be interchanged with a very simple blocking system. The discs and the rolls can be placed differently on the axles (Fig. 3): close together in order to perform a very shallow tillage (3–4 cm) of the whole area for seedbed preparation and non selective mechanical weed control (stale seedbed technique) and with spaced arrangement to perform selective mechanical weed control treatments post-emergence precision inter row weeding. In precision weeding, it is possible to work on a range of inter row widths from a minimum value of 15 cm. The action of the rotating rolls harrow is characterized by the passage of the spike discs that till the soil at a depth of 3–4 cm followed by the passage of the gage rolls that work at high peripheral speed as the rear axle is powered by the front axle by means of an overdrive, tilling and crumbling the soil to a depth of 1–2 cm. The rolling harrow can be equipped with couples of elastic tines (working as both vibrating teeth and torsion weeders) in order to also perform a mechanical weed control in the rows (Fig. 4). For precision weeding, a version of the rolling harrow with a steering handle system was set up. In these trials, a machine 1.4 m wide was used.

The precision hoe used in this experiment is a 2 m wide machine (Fig. 5), designed to perform selective weed control in the row crop with very narrow inter-row distances (in this trial 20 cm). The precision hoe is structured on a square tool bar bearing working tools and attached to the three points. There can be up to 11 working tools and each is placed on an articulated parallelogram equipped with a small wheel for adjusting working width. The machine was equipped with rigid elements bearing a 9 cm wide triangular horizontal blade and two kinds of flexible tines (torsion weeders and vibrating tines). The tines

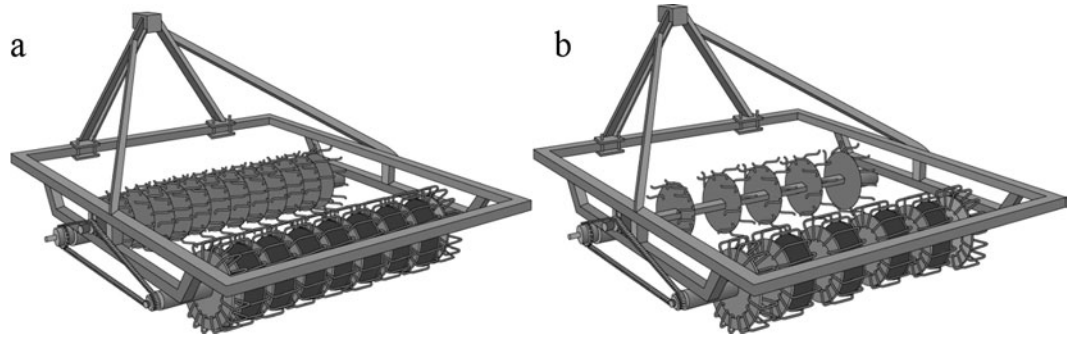

Figure 3. Arrangement of the rolling harrow to carry out treatments on whole surface (a) and of hoeing (b).

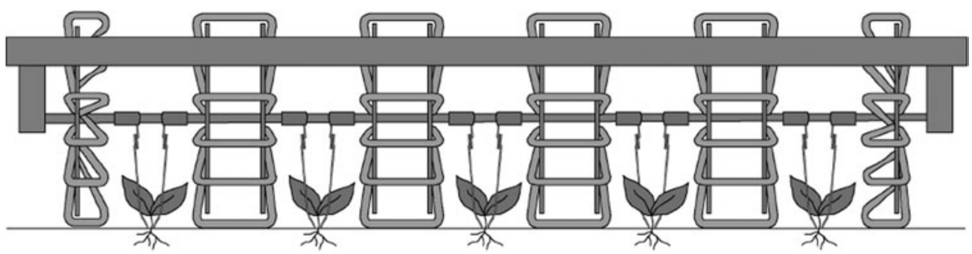

Figure 4. Schematic drawing of the combination of the rolling harrow with flexible tines, in order to carry out selective treatments both between and in the rows.

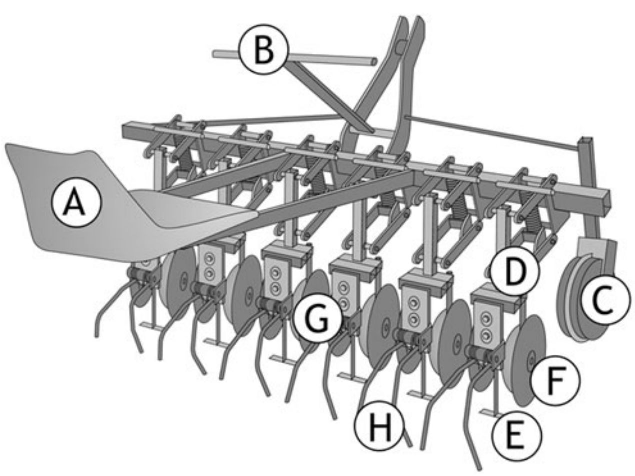

Figure 5. (A) Hoe operator seat; (B) steering handle; (C) steering wheel; (D) articulated parallelogram; (E) working tool; (F) lateral disc; (G) support wheel and (H) elastic tines.

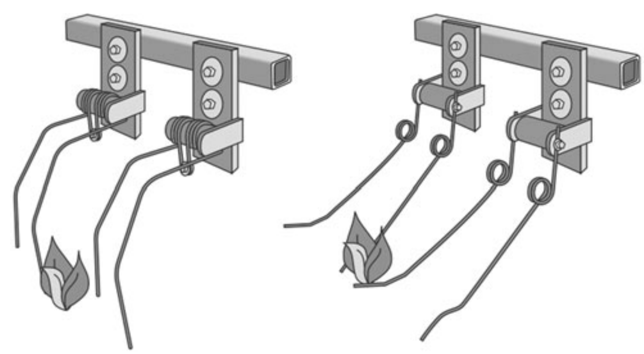

Figure 6. Vibrating tines (left) and torsion weeders (right).

perform selective weed control on the row crop (Fig. 6). A back-seated operator can adjust the actual position of the working tools with a steering handle. This precision hoe is a very interesting innovation for farms because it is able to work on five rows on a 'standard' ridge 1.4 m wide.

On the conventional farm, a Project srl sprayer was used for chemical weed control, with a tank capacity of 300 dm^3. The treatments were performed with a hand lance equipped with a turbulence full cone spray nozzle and with a manual valve for flow adjustment. The hand lance was equipped with a 100 m long hose (Fig. 7).

Second year

On the conventional farm, the crop was transplanted and weed control consisted of applying an herbicide prior to transplanting (3.5 kg ha^{-1} Betanal, a.i. phenmediphan). The application was done with the same machine as the one that was used the previous year.

On the organic farm, in light of the first year results, weed control was carried out with a modified strategy performed using the false seedbed technique (by a rolling harrow), one flaming pre-emergence of the crop, two post-emergence hoeing (the first with the rolling harrow, the second with the precision hoe) and one final in-row hand-weeding treatment. For physical weed control, besides the machines used in the first year, a flaming weeder constructed by the research team was used.

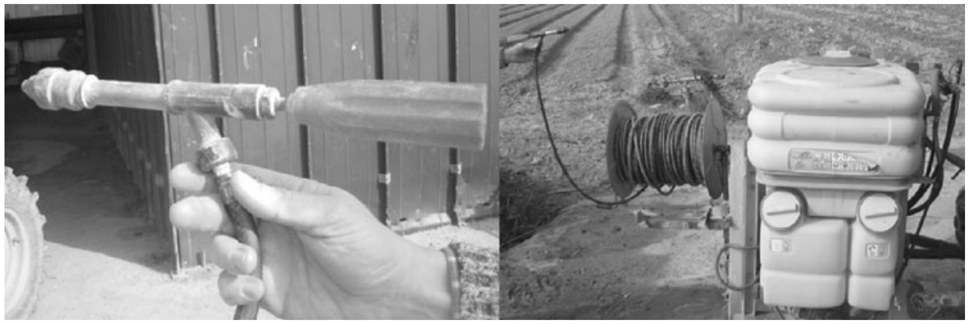

Figure 7. Sprayer utilized for chemical treatments.

The flame weeding implement can be used both pre-emergence (nonselective) and post-emergence (selective) (Figs. 8 and 9). The flaming machine can be equipped with up to eight rod burners that are 25 cm wide with a good flame shape and with four LPG tanks. Pairs of burners are placed on a control board and connected to a 25 kg LPG tank on which a pressure regulator and a manometer are placed. The LPG tanks are placed inside a hopper, which contains warm water, thus allowing a good exchange of heat. The exhaust gas of the tractor engine is used to heat the water through a hose connected to both the exhaust head and a copper tube placed inside the hopper. Pairs of burners are connected to an articulated parallelogram in order to maintain the set out adjustments (height and inclination with respect to soil surface) when the flamer is working. Each burner is also equipped with one valve, one safety tap and an electronic control system that allows the tractor driver to adjust the LPG feed (high or low levels) and to control the functioning of the burners directly from his seat.

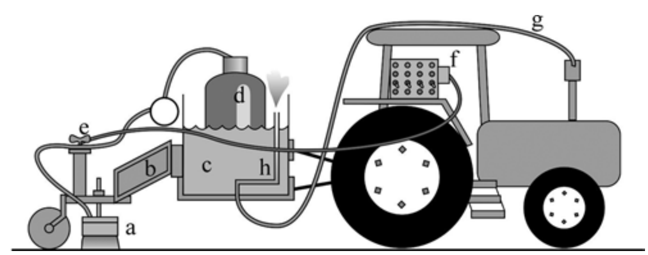

Figure 8. Schematic drawing of the new flaming machine: (a) burner; (b) articulated parallelogram; (c) hopper containing water; (d) LPG tank; (e) shelf on which the inflow LPG control system is located; (f) control panel; (g) flexible pipe that pipes the exhausted gas of the tractor engine to the heat exchanger in the hopper and (h) heat exchanger.

Experimental assessments

Trials were carried out on the entire surface of greenhouses, each of them was split into three different 30 m × 7 m plots (replications), along the longest side.

During the trials, data concerning machine and yard operative characteristics, weeds and crop yield were measured or calculated.

Machine and yard operative characteristics. During the experiment, all the main operative characteristics concerning weed management for both farming systems were registered and computed: working depth, working speed, working productivity, working time, fuel and LPG consumption for all the machinery used for weed control; manpower requirements for all manual weeding interventions.

Weeds. Weed density was recorded before and after each physical weed control treatment performed within the organic farming system and before the herbicide treatment in the conventional system. In this regard, a species-specific weed count assessment was performed on three 0.25 m × 0.30 m sampling areas $plot^{-1}$. At harvest, for both weed control strategies, weed samples were collected from two 1.5 m^2 areas $plot^{-1}$. Samples were then oven dried until constant weight in order to assess dry biomass of weeds. During the second year, an additional weed sampling was carried out at harvest by means of the Braun–Blanquet ordinal scale in order to assess weed canopy, biodiversity and aggressiveness.

Crop yield. Crop yield was sampled from the end of November to the end of February, at 10–15 day intervals, from two 1.5 m^2 areas $plot^{-1}$ in order to evaluate total fresh leaf production.

Statistical analysis. Weed and yield data were analyzed statistically. Each strategy was tested in one greenhouse, without randomization, because it was not possible and not experimentally correct to perform chemical treatments on organic farms and to grow organic leaf-beet on conventional farms. Thus, the two different farming systems were compared using a two-tailed *t*-test. The statistical analysis was carried out using Systat version 11[42].

Results and Discussion

Operation characteristics

The characteristics of the machines used in the first year trial are presented in Table 1.

The rolling harrow, utilized only for pre-sowing treatment, was used at a high speed (approximately 6 km h^{-1})

https://doi.org/10.1017/S1742170509990287 Published online by Cambridge University Press

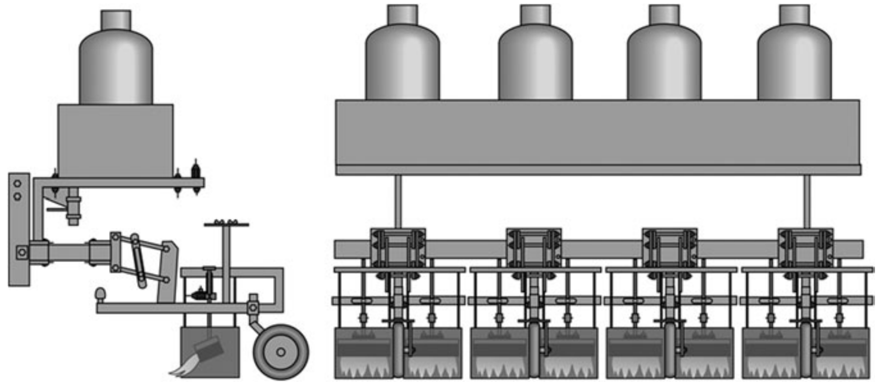

Figure 9. Side and rear view of the flaming machine in configuration for pre-emergence treatments.

Table 1. Performance of the machines used for physical weed control in the organic production system in the first year.

Characteristics	Har	Hoe 1	Hoe 2	Hoe 3
Working width (m)	1.35	1.35	1.35	1.35
Working depth (cm)	3.6	2.6	2.7	2.8
Working speed (km h^{-1})	5.9	1.2	1.1	1.2
Working productivity (ha h^{-1})	0.68	0.16	0.15	0.16
Working time (h ha^{-1})	1.47	6.21	6.87	6.36
Operators	1	2	2	2
Tractor engine capacity (kW)	37	37	37	37
Fuel consumption (kg ha^{-1})	2.9	12.4	13.7	12.7

Har, harrowing; hoe, hoeing (1, 2, 3, first, second or third pass).

Table 2. Working time for physical weed control in the organic production system in the first year.

Working time	
Physical weed control (h ha^{-1})	21
Sowing (h ha^{-1})	4
Hand weeding (h ha^{-1})	259
Total (h ha^{-1})	284

and therefore its working time was low (1.47 h ha^{-1}). The precision hoe was used with a working speed of 1.2 km h^{-1} and consequently the working time for each treatment was approximately 6 h ha^{-1}. The working depth was lower than 0.04 m for all treatments. Fuel consumption was approximately 3 kg ha^{-1} for the false seedbed treatment and 13 kg ha^{-1} for each hoeing.

Total working time for physical weed control (Table 2) was roughly 280 h ha^{-1}. Most of this time was due to the two hand weeding operations, over 80 and 170 h ha^{-1} for the first and second weeding, respectively.

In a conventional strategy for weed control (Table 3), the time for manual transplanting (a technique that facilitates the crop rather than the weeds) was approximately 85 h ha^{-1}, while working time for chemical treatment was roughly 8 h ha^{-1}.

Table 3. Characteristics and working time in the conventional production system in the first year.

Characteristics	
Transplanting time (h ha^{-1})	84
Spraying time (h ha^{-1})	8
Total (h ha^{-1})	92
Working productivity (ha h^{-1})	0.13
Sprayed mixture (l ha^{-1})	2817

Table 4. Performance of the machines used for physical weed control in the organic production system in the second year.

Characteristics	Har	Fla	Har	Hoe
Working width (m)	1.35	1.35	1.35	1.35
Working depth (cm)	3.5	–	2.7	2.8
Working speed (km h^{-1})	6.1	3.5	1.7	3.0
Working productivity (ha h^{-1})	0.73	0.42	0.22	0.37
Working time (h ha^{-1})	1.36	2.39	4.47	2.71
Operators	1	1	1	2
Tractor engine capacity (kW)	37	37	37	37
Fuel consumption (kg ha^{-1})	2.7	4.8	8.9	5.4

Har, harrowing; Fla, flaming; hoe, hoeing.

In the first year of the project, the physical weed control strategy required a total labor input higher than the conventional strategy (284 versus 92 h ha^{-1}, respectively).

The operation characteristics of the machines used for physical weed control in the second year trial are presented in Table 4.

For the false seedbed treatment, the rolling harrow worked at a very high speed and consequently its working time was short (1.36 h ha^{-1}). In the first hoeing treatment, when the weeds were small, the rolling harrow was used at a slow speed, consequently increasing its time (4.47 h ha^{-1}). This parameter, however, was lower than that recorded in the previous year for precision hoeing. This is probably because of the flaming treatment done in pre-emergence of the crop. The flaming treatment was performed at a

Table 5. Working time for physical weed control in the organic production system in the second year.

Working time	$h\,ha^{-1}$
Physical weed control	11
Sowing	4
Hand weeding	37
Total	52

Table 6. Characteristics and working time in the conventional production system in the second year.

Characteristics	
Transplanting time ($h\,ha^{-1}$)	84
Spraying time ($h\,ha^{-1}$)	6
Total ($h\,ha^{-1}$)	90
Working productivity ($ha\,ha^{-1}$)	0.16
Sprayed mixture ($l\,ha^{-1}$)	1408

Table 7. Yield and weed biomass at harvest determined in 2006. In each column, means followed by the same letter are not significantly different at $P \leq 0.05$ (*t*-test).

Weed management system	Yield ($Mg\,ha^{-1}$)	Weed dry biomass ($g\,m^{-2}$)
Conventional system	36.9 ns	12.8 a
Organic system	33.4 ns	5.9 b

Table 8. Yield, weed biomass and canopy at harvest determined in 2007. In each column, means followed by the same letter are not significantly different at $P \leq 0.05$ (*t*-test).

Weed management system	Yield ($Mg\,ha^{-1}$)	Weed dry biomass ($g\,m^{-2}$)	Weed canopy (%)
Conventional system	30.6 ns	7.8 a	12.9 a
Organic system	30.8 ns	3.5 b	4.4 b

speed of $3.5\,km\,h^{-1}$ ($2.39\,h\,ha^{-1}$) and working pressure of 0.25 MPa with an LPG consumption of roughly $40\,kg\,ha^{-1}$. The working time of the last hoeing, carried out with the precision hoe with static tools, was also lower than that recorded in the previous year. Along with working time, fuel consumption was also reduced, in fact, fuel consumption was approximately half that of the first year. The trend in time reduction was also reflected in the time for hand weeding ($37\,h\,ha^{-1}$); which was nearly seven times less than in the first year (Table 5).

In the conventional production system, the time for manual transplantation was nearly the same as in the previous year (Table 6), while the time for the herbicide application was slightly less ($6.30\,h\,ha^{-1}$).

In the second year, the physical weed control strategy reduced labor input, especially hand weeding time (Table 5).

For the physical weed control system in the second year, the total working time was $52\,h\,ha^{-1}$, while it was $90\,h\,ha^{-1}$ for the conventional farm.

Weed control and yield

In the first year experiment, physical weed control caused a progressive depletion of the seed bank in the first centimeters of soil layer. The weed flora was initially composed of *Picris echioides* L. (30% of relative density), *Veronica persica* Poiret (20%), *Rumex* spp. L. (20%) and winter annual and perennial grasses (17%). Weed density was $350\,plants\,m^{-2}$ before using the stale-seedbed, 250 plants m^{-2} before the first hoeing, $100\,plants\,m^{-2}$ before the second hoeing and $120\,plants\,m^{-2}$ before the third hoeing pass. Weed control efficiency was 100% with the rolling harrow and over 90% with hoeing (taking into account in-row and inter-row space). Weed dry biomass registered prior to the second hand-weeding was triple compared to the first one (12 versus $4\,g\,m^{-2}$).

Weed density at the conventional farm before chemical treatment was approximately $150\,plants\,m^{-2}$ with *Stellaria media* (L.) Vill. as the dominating species, 90% of density.

Weed dry biomass registered before the last crop leaf harvesting was 6 and $13\,g\,m^{-2}$ for the organic and the conventional farm, respectively (Table 7). The most abundant species observed were *Rumex* spp. (13% of relative density), *P. echioides* (39%), *Conyza canadiensis* (L.) Cronq. (19%), *V. persica* (7%), *Anagallis arvensis* L. (6%), *Cerastium holosteoides* Fries. ampl. Hylander (6%) for the organic farm and only *S. media* (almost 100% of relative density) on the conventional farm.

There were no significant differences in total fresh yield between the two cropping systems, at the end of the first year of the experiment, concerning with total fresh yield (Table 7). However, yield in the conventional system was slightly higher compared with the organic one (on average, 37 versus $33\,Mg\,ha^{-1}$).

In the second year of this project, the weed density observed before the stale-seedbed preparations was approximately $400\,plants\,m^{-2}$ in the organic cropping system. The weed flora density was mainly composed of *Solanum nigrum* L. (52% of relative density), *P. echioides* (22%), *C. canadiensis* (22%) and *Portulaca oleracea* L. (8%). However, the rolling harrow was 100% effective in controlling weeds prior to sowing. Furthermore, very few weeds re-grew after this treatment prior to crop emergence (about $10\,plants\,m^{-2}$). Pre-emergence flaming treatment was carried out to control the few weed species (for example *Cyperus* spp.) that were fairly developed (4–6 true leaves) to prevent their interference with crop emergence. Weed density was about $200\,plants\,m^{-2}$ before the first hoeing intervention carried out with the rolling hoe. This treatment controlled approximately 90% of the weeds in the inter-row space and 30% of the weeds in the in-row space. Similar levels of weed control characterized the second hoeing treatment, carried out by means of the precision hoe. Weed density before this intervention was approximately 100 plants m^{-2}. Moreover, one hand weeding intervention was carried out in order to reduce weed density in the intra-row space. Weed dry biomass was approximately 4 g m^{-2} and *Amaranthus retroflexus* and *Chenopodium album* were the most abundant and developed weeds.

In the conventional farm system, weed density before herbicide application was approximately 180 plants m^{-2}, and consisted almost exclusively of *S. media*.

Weed dry biomass and weed cover data collected before the last crop harvest showed significant differences between the two cropping systems. Organic plots were characterized by a significantly lower weed biomass (−50%) and weed canopy percentage (−65%) compared to the conventional ones (Table 8). The weed canopy assessments used the Braun–Blanquet ordinal scale and 16 different weed species were observed in the organic farm and only three in the conventional plots. This difference might be attributed to a weed selection action caused by the use of herbicides. However, a strictly selected weed flora could be very aggressive. In this case, the most widespread species was *S. media* for both cropping systems. Its canopy percentage value was approximately 87% for the conventional farm and 57% for the organic one. In addition, two other weed species reached relevant relative percentage values before the last harvest in the organic cropping system: *Conyza canadensis* and *C. album* (approximately 40% of relative density together).

The different results concerning weed flora composition should not be strictly related to the two cropping systems under comparison. Random factors and previous cultivation practices could also have made an important contribution. In fact, specialized 'flora' is a common feature of conventional farms, while organic systems are generally characterized by a more heterogeneous weed population.

Concerning the total crop fresh yield, there were also no significant differences in the second year. The observed value was approximately 31 Mg ha^{-1} for both the cropping systems and it was similar, even if slightly lower, compared with yields observed in 2006 (Table 8).

Conclusions

These experiments show that the use of physical weed control strategies can provide efficient weed control in leaf-beet produced under protected cultivation. In the first year of this project, the yield of the two cropping systems was very similar but the physical weed control strategy required much more labor than the conventional cropping system.

In the second year, the physical weed control strategy was improved and its labor requirements were reduced. Effectively, both cropping systems had similar yields with similar working times. In a global comparison of these two cropping systems, among the benefits of using physical weed control strategies is that a product of higher quality can be obtained along with a better price (on average in the two years, the prices on Central Italy market were 1.5 and 0.5 € kg^{-1} for organic and conventional leaf-beet, respectively).

Acknowledgements. The authors wish to express sincere thanks to Roberta Del Sarto and Calogero Plaia of DAGA and Paolo Gronchi and Alessandro Pannocchia of CIRAA 'E. Avanzi' (University of Pisa) for their valuable contribution to this research.

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