INNOVATIVE STRATEGIES AND MACHINES FOR PHYSICAL WEED CONTROL IN VEGETABLE CROPS IN CENTRAL AND SOUTHERN ITALY

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ABSTRACT Weed control is one of the most serious problems in vegetable crops limiting yields. Therefore, the aim of this work was to set up and improve innovative strategies and machines for physical weed control in organic or “integrated” vegetable crops cultivated in five important areas of Central and Southern Italy. Experimental on-farm trials were carried out on fresh marketable spinach, processing and fresh market tomato, cauliflower, savoy cabbage, potato, greenhouse cultivated leaf beet, garlic, chicory, fennel and carrot. The traditional farm weed management system was always compared to an innovative system. The innovative strategy was the combination among preventive methods (false or stale seed-bed technique), cultural methods (crop spatial arrangement adjusted in order to improve machinery effectiveness) and direct control methods (flaming, hoeing, etc.). Different kinds of flex tine and rolling harrows (patented by the University of Pisa) and flamers were used for false or stale seed-bed technique. Precision hoes and hoe-conformed rolling harrows, equipped with elastic tines for selective in-row weed control, were used for post emergence interventions. The innovative weed management systems always resulted in significant weed abundance reductions (from 70 to 100%), relevant yield increases (from 10 to 100%) and high contractions of manpower requirement (from 20 to 80%) compared to the standard systems. The results of these on-farm experimental trials emphasise that physical weed control can be effectively performed using the innovative machines built at the University of Pisa. These machines can also be easily adjusted for use in other crops and agricultural contexts.

Keywords: physical weed control, operative machine for weed control, stale-seedbed technique.

INTRODUCTION Weed management is one the most serious problems in agriculture. In particular, weed control is very difficult in organic horticulture (because of the lack of herbicide) and in general for vegetable crops (because of theirs low competitive ability) (Bärberi, 2002). The production valorisation (for example by organic cultivation) could be a good strategy in order to follow the new policy trends and to guarantee an appropriate income to
farmers. This aim could be reached by means of farming systems that allow environment and consumer health safety.

Furthermore for organic and conventional vegetable farming are not available effective specific machines (Fogelberg, 2007; Peruzzi et al., 2006; Raffaelli et al., 2010; van der Wide et al., 2008). Moreover, vegetable crop are generally classified as “minor crop”, so that there are not enough registered and effective a.i. because of the high cost of labelling (Fennimore, 2008; Fennimore & Doohan, 2008). For this reason, at the moment, the development of new operative machines for physical weed control is one of the most important research topics for weed science (Fennimore and Doohan, 2008; van der Weide et al., 2008).

In this work, the result of long-term (2000-2009) “on-farm” open field researches, carried out by MAMA division of DAGA and CIRAA “E. Avanzi” of the University of Pisa, are reported. On farm trials have been carried out in Central and Southern Italy on carrot, spinach, tomato and cabbage, with the aim to test innovative strategies and operative machines for weed control in vegetable crop, in order to reduce chemical distribution and to preserve environmental, citizen and consumer’s health.

**MATERIALS AND METHODS** In the trials, innovative and versatile operative machines able to properly work in the environment and crop conditions of the different horticultural areas were projected, realized, tested and optimized. In particular the strategy adopted for physical weed control was always characterized by the use of false or stale seedbed technique and by some post-emergence or post-transplanting hoeing interventions. False seedbed technique was performed with two or more passes with on purpose made operative machines for shallow soil tillage (spring tine harrow or rolling harrow) aiming to stimulate weed emergence and to control actual weed. In stale seedbed technique is included a flaming treatment. Both the techniques aim to deplete superficial weed seedbank. The spring-tine harrow (figure 1) consists of more frames having identical working width bearing he working tools: six lines of 6 mm diameter J-shaped special steel spring tines. The spring tines are made up of two parts: a 25 cm long vertical segment and second shorter, 11 cm long segment (sloping at an angle of 135° with respect to the vertical segment). A lever regulates this machine than can modify the slope of the tines and consequently the aggressiveness of treatment. In these trials the spring tine harrow was set to the most aggressive regulation and was used for non-selective pre-sowing treatment, at a driving speed up to 8 km h⁻¹.

![Diagram of the spring-tine harrow](image1)

Figures 1: (a) Diagram of the spring-tine harrow: (A) main frame; (B) supporting wheel; (C) U-shaped support; (D) modular secondary frame; (E) tine slope regulation lever; (F) chains; (G) spring tines. Detail: (d) working direction; (a) = 25 cm (b) 11 cm; Ø = 6 mm; α = 135°; β = 45°; γ = 15°; (b) spring-tine harrow at work before spinach sowing.

The rolling harrow was projected, built, tested and patented by Pisa University. It was set up both for pre-sowing (or pre-transplanting) and post-emergence hoeing (for inter-row
and intra-row selective weed control) interventions (figure 2). Working tools are spike disks (placed in the front) and cage rolls (placed at the rear), respectively mounted on two different parallel axles. An overdrive connects the axles. Spike discs till the soil very shallowly while cage rolls (rotating with a high peripheral speed) allow to separate weed seedling roots from soil. Working speed ranged from 5 to 8 km h\(^{-1}\) and working depth was about 4 cm.

Figure 2: First version of rolling harrow during a full-width intervention before spinach sowing (a) and second version, equipped with guidance system and elastic tines for in-row weed control, during an hoeing treatment on cabbage (b).

The flaming machine was equipped with open rod burners 25 or 50 cm wide (figure 3). The machine was equipped with 4 ordinary 25 kg weight LPG tanks placed into an on purpose made hopper that is part of an innovative heat exchange system. The flaming treatment has the advantage of eliminating weeds without stimulating new emergence because the soil remains undisturbed. The treatments were performed just in pre-sowing, pre-transplanting or pre-emergence phases with a working speed ranging from 3 to 7 km h\(^{-1}\). This machine can be used also for post emergence selective flaming treatments on tolerant crops as tomato and cabbage.

Figure 3: (a) Scheme of the 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) electronic led panel; g) flexible pipe collecting exhaust emissions to heat exchanger h) heat exchanger i) pressure regulator and manometer; (b) flaming machine at work before spinach emergence.

Concerning with post-emergence interventions, a 6-element precision hoe (figure 4a) was utilized for spinach while an operative machine for wider inter-row spaces was used for tomato and cabbage. The first one was equipped with rigid elements bearing a 9 cm wide horizontal blade, pairs of concave discs, and two alternative kinds of elastic tines (torsion weeders and vibrating tines, not used in 2001) designed to perform selective weed control in the crop row. The second machine was equipped with rigid elements for inter-row cultivation (a central “foot-goose” tool and two side “L” shaped sweeps) and elastic elements for intra-row selective weed control (torsion weeders) (figure 4b).
Figure 4: (a) Precision hoeing for narrow inter-row spaces during a post-emergence intervention on spinach; (b) precision hoeing for wide inter-row spaces during a post-transplanting intervention on processing tomato.

An 11-element precision hoe (figure 5) was utilized for post emergence inter- and intra-row weed control in the innovative, single row system on organic carrot. This machine, in the final optimized version used in 2002 and 2003, was equipped with rigid elements bearing a 9 cm wide horizontal blade (replacing the goose-foot push rod characterizing the first version), pairs of concave discs, and two alternative kinds of elastic tines (torsion weeders and vibrating tines, not used in 2001) designed to perform selective weed control in the crop row. The vibrating tines, which work in vertical position, have their longer segment bent at several points in order to till very close to the crop row. The torsion weeders, on the other hand, work in horizontal position; a torsion spring enables the tines to flex when they meet a fairly developed plant (generally a crop plant but it could also be a large weed) that opposes resistance to the implement. The position of both tools can be modified according to the treatment aggressiveness required. Treatment becomes more intense when the tines are positioned close to the row crop. The working speed of the hoe was in the different trials approximately 2 km h⁻¹.

Figure 5: Illustration of the 2002 version of the precision hoe: (A) seat; (B) steering handle; (C) directional wheel; (D) articulated parallelogram; (E) tine with blade tool; (F) side discs; (G) support wheel; (H) tools for intra-row weeding (in the right-hand side picture, vibrating tines (V) and torsion weeders (T) are shown in detail).

The on-farm trials Trials were aimed to define, test and improve innovative physical weed control strategies and to compare them with the ordinary technique carried out by farmers within organic, integrated and conventional agricultural contexts.

Trials involving physical weed control in an organic carrot crop were conducted over 4 years, from 2000 to 2003, on two organic farms located in the municipally of Avezzano (Province of L’Aquila, Region Abruzzo). A conventional cropping system was compared with an organic system.

Experiments on spinach were carried out from 2002 to 2005 in organic or integrated farms (ordinary manual vs physical and chemical vs physical weed management) and it
was cultivated on 1.4 m wide raised beds. In this case, crop space arrangement of innovative system was modified in order to improve the weeding effectiveness of the machines, passing from ordinary drilling to precision planting.

Processing tomato was cultivated on paired-rows in conventional farms (ordinary chemical vs physical weed management) while fresh market tomato was transplanted on single rows in integrated farms (ordinary biodegradable plastic film use vs physical weed management on bare soil or plus alternative straw mulch), and trials were in this case carried out from 2006 to 2008.

Trials on two different botanical varieties of cabbage were also carried out from 2006 to 2009 in conventional or integrated cultivation contexts (ordinary chemical or mechanical weed control vs physical weed management).

The experimental design was a randomized block. Operative machine performances, weed density and biomass and crop yield were assessed. Data were analyzed by ANOVA (with the exception of operative values) while LSD test was adopted for mean comparisons.

RESULTS Main results concerning on-farm experimental trials are shown in table 1, where all the most important parameters means are reported.

On carrot, physical weed control permitted a sensibly reduction of manpower requirement for weed control (-13.8 h ha⁻¹) and higher gross margin with respect to ordinary system (20516 € ha⁻¹).

Significant differences were obtained on yield and weed biomass at harvest on spinach: innovative system allowed to sensibly reduce weed competitive pressure (about -50% of weed dry biomass at harvest) and increase crop yield (about +100%). Good results were also reached concerning manpower and economical parameters, thanks to a considerable increase of gross margin, considering that spinach is probably the most value crop among the ones analyzed.

Physical weed control also allowed a significant yield increase on processing tomato (about +15%), but in this case weed dry biomass at harvest, manpower requirement and variable costs were higher for the innovative system with respect to the conventional. Anyway, gross margin was considerably higher for innovative weed control system (about + 500 € ha⁻¹).

Regarding to fresh market tomato, physical weed control plus the application of straw dead mulch guaranteed slightly but not significantly higher yields with respect to ordinary farming system. In this trial, weed biomass at harvest and manpower requirement were similar but higher variable costs were registered for ordinary farming system (due to the high cost of biodegradable plastic mulching film). Gross margin was over than 2400 € higher for innovative system with respect to the other technique in comparison.

Concerning with cabbage, the same results were obtained in terms of yield and weed control between the two different farming systems involved, while manpower
requirement was slightly higher in the physical weed management, so that gross margin was about 200 € ha\(^{-1}\) higher for the ordinary technique with respect to the innovative.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Weed management system</th>
<th>Fresh Yield (Mg ha(^{-1}))</th>
<th>Weed dry biomass at harvest (g m(^{-2}))</th>
<th>Manpower for weed control (h ha(^{-1}))</th>
<th>Gross margin (€ ha(^{-1}))</th>
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<tr>
<td>Carrot</td>
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<td>23.0 a</td>
<td>332.0</td>
<td>20516</td>
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<td></td>
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<td>83.1 a</td>
<td>13.2 b</td>
<td>240.0</td>
<td>26500</td>
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<tr>
<td>Spinach</td>
<td>Ordinary</td>
<td>5.4 b</td>
<td>91.2 a</td>
<td>26.7</td>
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<td></td>
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<td>38.9 b</td>
<td>19.6</td>
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<tr>
<td>Processing tomato</td>
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<td>55.1 b</td>
<td>36.7 ns</td>
<td>25.4</td>
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<tr>
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<td>68.0 ns</td>
<td>46.4</td>
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<td>Fresh market tomato</td>
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<td>52.4 ns</td>
<td>31.0</td>
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<td></td>
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<td>39.0 ns</td>
<td>27.6</td>
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<tr>
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<td>0.0 ns</td>
<td>19.6</td>
<td>5119.0</td>
</tr>
</tbody>
</table>

Table 1. Fresh yield, weed dry biomass at harvest, manpower required for weed control and gross margin determined in the trials. For the same crop and parameter, values labelled with different letters are significantly different at P<0.05. (Manpower and gross income were not analyzed).

**CONCLUSION** Results achieved during many years of experiments carried out on farm show that physical weed control can be considered an effective solution for low environmental impact weed control on vegetable crops (organic, integrated and also conventional). In our experimental trials, physical weed control strategies, whose effectiveness was improved year after year through increasingly optimized techniques and machines, consistently allowed good weed control, even on crops very sensitive to weed competition. The best investment for farmers is on the knowledge (weed biology and ecology, crop/weed interaction, technical innovations) that they need to build up a strategy fine-tuned to their specific cropping situation. On the economic side, considering the very high market value of organic products, use of innovative physical weed management system can turn into a good gross margin for the farmer.

**REFERENCES**


