Recent findings in physical and cultural weed control in Mediterranean Italy

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Summary Weed management is often perceived as the key problem to be solved in integrated and organic crop production systems. In this respect, a series of experiments has been conducted over the last ten years in Mediterranean environments in Central Italy, comparing different cultural and physical weed management methods (cover crops, mechanical weed control, soil solarisation, soil steaming) on a range of arable and vegetable crops. This paper reports the most significant results of these experiments, to outline the potential and drawbacks of the different methods.

Keywords Cover crops, cultural weed control, physical weed control, soil solarisation, soil steaming, spring-tine harrowing.

INTRODUCTION

One of the most critical technical problems to be faced in alternative (integrated or organic) production systems is weed management. In such systems, the best strategy to be followed is one that integrates cultural (i.e. preventative) and physical (i.e. curative) weed control (Bàrberi 2002).

Over the last ten years, a series of experiments has been conducted in Mediterranean environments at the Centre for Agri-environmental Research E. Avanzi of the University of Pisa and at the University of Tuscia, Viterbo (Central Italy), comparing different cultural and physical weed management methods on a range of arable and vegetable crops. These methods included cover crops, mechanical weed control (e.g. spring-tine harrowing), soil solarisation, and soil steaming. In particular, the last two methods have been tested as a possible alternative to use of methyl bromide after its phase out in 2005.

Some of these physical and cultural weed control methods have shown promising results: here, the most significant data are presented and discussed, and the potential and limits of the methods are outlined.

MATERIALS AND METHODS

Cover crops A long-term study, started at Pisa in 1993, is comparing the agronomic, economic, and environmental effects of inclusion of winter annual cover crops in a grain maize (*Zea mays* L.)-durum wheat (*Triticum durum* Desf.) two-year rotation carried out on a silty soil. Three cover crops, namely rye (*Secale cereale* L.), crimson clover (*Trifolium incarnatum* L.) and subterranean clover (*Trifolium subterraneum* L.), sown in the autumn following wheat, are destroyed immediately prior to maize sowing. A crop stubble control and four rates of synthetic N fertiliser (applied to the cash crops only: 0, 60, 120 and 180 kg N ha^{-1} to wheat and 0, 100, 200 and 300 kg N ha^{-1} to maize) are also included. In the spring, the cover crops are crushed and either used as a green manure (conventional system, CS) or left on the soil surface as a dead mulch after killing with glyphosate (low-input system, LIS).

After seven years of trials, a weed seedbank analysis was carried out by taking a total of 864 soil cores (diameter 3.5 cm, depth 0–15 cm), which were placed in tubs in a non heated glasshouse for a period of 12 months under optimum moisture conditions, except for a 1-month drought period imposed to stimulate seed dormancy breakage (Moonen and Bàrberi 2002). Weed seedlings that emerged were periodically identified, counted, and then removed.

Mechanical weed control In the study area, spring-tine harrowing has proven to be a viable option for mechanical weed control in a range of arable and vegetable crops (e.g. see Raffaelli *et al*. 2002).

In durum wheat, the effect of spring-tine harrowing on weed control and crop yield was studied in 1995–1996 under conventional tillage (CT) or no tillage (NT) conditions. Eight combinations between four tine adjustments (-30°, -15°, 0° and +15°; values refer to the angle between the upper part of the tine and the perpendicular to the soil surface) and two treatment intensities (one vs. two passes) were compared to post-emergence herbicide spraying and a weedy check.

Experimental measurements included soil moisture, soil dry bulk density, tine working depth, crop and weed density and/or biomass before and after the harrow passes, and crop and weed biomass at harvest.

Soil solarisation A soil solarisation trial was carried out at Viterbo in the summer of 1994 under tunnel glasshouse conditions. Two types of tunnel glasshouse cover [polyethylene (PE) AIF3 film and ethylenvynilacetate (EVA) film] were factorially combined with three soil cover types (solarisation with PE transparent film vs. black PE film vs. no cover). Soil solarisation effects were monitored in a lettuce (*Lactuca sativa* L. var. *longifolia* (Lam.) Janchen)–radish (*Raphanus sativus* L. var. *radicula* Pers.) + rocket salad (*Eruca* *sativa* Miller)–fresh marketable tomato (*Lycopersicon esculentum* Mill.) cropping sequence over the following 12 months.

Soil temperature was measured with thermocouples all over the duration of solarisation (27 July–31 August 1994). Weed density and biomass were periodically measured over the crop growing cycles. Total crop biomass and marketable yield was measured at harvest.

Soil steaming The Italian company Celli, in collaboration with the Agricultural Engineering Sector of the Department of Agronomy, University of Pisa, has developed a prototype machine (Alce Garden System©) for soil disinfection with hot steam and the concurrent use of compounds (CaO or KOH) that, by producing an exothermic reaction, increase the amount of heat generated in the soil. This machine (Figure 1) is able to heat the soil down to 20 cm depth. A dedicated experiment investigated the effect of this machine on field emergence of autumn-germinating weeds and on seedling emergence from the seedbank (in the 0–10 and 10–20 cm soil layers). The field experiment consisted in a factorial combination between two soil cover treatments (bare soil vs. black polyethylene film cover), two compounds (CaO vs. KOH) and five compound rates (0, 1000, 2000, 3000 and 4000 kg ha^{-1}). Soil temperature was measured with thermocouples in selected plots. Field weed emergence was monitored from 23 October 2000 (treatment date) to 15 March 2001. The weed seedbank analysis was carried out in a non heated glasshouse over the same period.

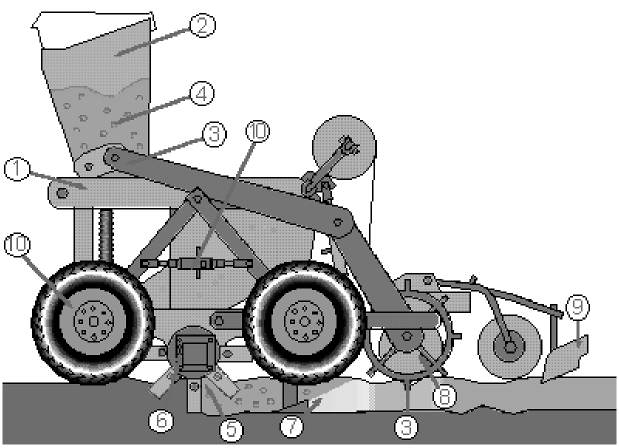

Figure 1. Scheme of the machine for soil disinfection by means of steam: (1) frame, (2) hopper of the compound, (3) mechanical drive to the dispenser, (4) compound, (5) blade rotor for compound incorporation in the soil, (6) hydraulic engine, (7) steam injection, (8) roller, (9) ridging-mulching machine, (10) wheel for adjustment of working depth.

Statistical analysis For all the trials, experimental data were statistically analysed by means of ANOVA. Regression analysis was used where appropriate. Prior to statistical analyses, data were checked for homogeneity of error variances (Bartlett test). Treatment means were compared by an LSD test (or a Duncan's Multiple Range Test, where appropriate) at $P \leq 0.05$.

RESULTS

Cover crops Results from the weed seedbank analysis revealed significant differences between the average weed seedling density in CS and LIS (5521 vs. 28,840 seedlings m^{-2} respectively). Significant differences were also detected between the four cover types (Table 1). Compared to the stubble control, in CS the highest reduction in seedling density was found in the rye plots (24%), while in LIS it was found in the subterranean clover plots (26%).

The crop management system was also the factor that exerted the most distinctive effect on weed seedbank composition. *Veronica persica* Poiret was stimulated by high N fertilisation levels and suppressed by the rye cover crop, independent of crop management system. Presence of *Amaranthus* spp., *Anagallis arvensis* L., *Centaurium erythraea* Rafn., *Cuscuta* spp. and *Verbena officinalis* L. was positively correlated with CS, while presence of *Cardamine hirsuta* L., *Cerastium* spp., *Digitaria sanguinalis* (L.) Scop., *Picris echioides* L., *Plantago* spp., *Poa* spp. and *Polygonum aviculare* L. was positively correlated with LIS (Moonen and Bàrberi 2002).

Mechanical weed control Tine working depth was higher in CT than in NT due to lower soil dry bulk density, and increased with the theoretical aggressiveness of tine adjustments (from -30° to +15°), but its correlation with short- and long-term effects on crop and weeds was generally poor, suggesting that tine adjustment was not a major factor involved (Bàrberi *et al*. 2000). Spring-tine harrowing did not work well in 1995, when weed pressure was higher. In 1996, lower weed pressure resulted in grain yield (3982 kg ha^{-1} in CT and 2809 kg ha^{-1} in NT, average of mechanical weed control treatments) comparable with that obtained with herbicides (Figure 2). In general, durum wheat grain yield and weed biomass were much more affected by

Table 1. Total seedbank density (seedlings m^{-2}) for the four cover types in the conventional (CS) and low-input (LIS) systems (in parentheses: % reduction with respect to crop stubble). Means with the same letter are not significantly different at P≤0.05 (LSD test). After Moonen and Bàrberi (2002), modified.

Cover type	CS	LIS	Mean
Crimson clover	5809 (9%)	29,806 (6%)	13,152 ab (7%)
Rye	4835 (24%)	31,089 (2%)	12,274 ab (14%)
Subterranean clover	5208 (18%)	23,605 (26%)	11,092 a (22%)
Crop stubble	6365	31,688	14,191 b

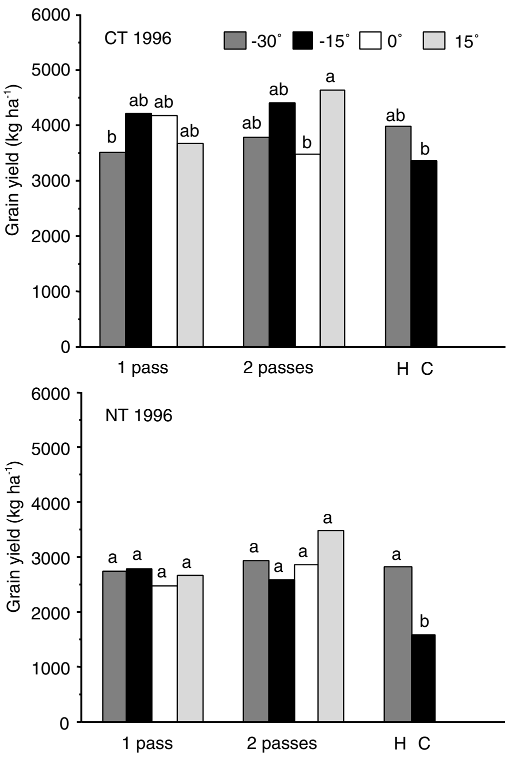

Figure 2. Durum wheat grain yield in 1996 in conventional tillage (CT) and no tillage (NT) following spring-tine harrowing (one or two passes) with four tine adjustments (shown in the legend). H = herbicide spraying, C = weedy check. Mean bars labelled with the same letter are not significantly different at P≤0.05 (Duncan's Multiple Range Test). After Bàrberi *et al.* (2000), modified.

tillage system than by tine adjustment or harrowing intensity, and seemed mostly dependent on the lower crop competitive ability in NT, caused by reduced crop emergence, higher weed abundance and presence of more aggressive species (e.g. *Lolium* spp.).

Soil solarisation Soil solarisation increased daily persistence of temperatures >45°C (an effect threshold suggested by Horowitz *et al*. 1983) in the upper soil layer (0–5 cm), particularly in the EVA-covered glasshouse. In this respect, colour of the polyethylene (PE) mulch film had little effect. Soil solarisation reduced weed density and biomass in almost all crops (Table 2), which likely concurred to increased radish and rocket salad yield on the treated soil. *Amaranthus retroflexus* L., *Oxalis* spp., *Portulaca oleracea* L. and *Stellaria media* (L.) Vill. were well controlled by solarisation, while *Chenopodium album* L. was not (Temperini *et al*. 1998).

Soil steaming Maximum soil temperature reached in the soil varied between 75 and 85°C. Compared to steam alone, application of CaO or KOH increased temperature duration above 45°C (Moonen *et al*. 2002). Treatment effects in the field were poor and limited to the first sampling date. This may be partly due to serious soil disturbance posed by the unexpectedly heavy rainfall occurred during the experimental period (858.2 mm). In the field, >50 total plants m^{-2} always survived the treatment, a density likely to require supplemental weed control if occurring in a production situation.

In contrast, the effect of steaming on the weed seedbank was very clear. In the 0–10 cm layer, a significant negative relationship between KOH and CaO application rate and total seedling emergence was found (Figure 3). Compared to steam alone, use

Table 2. Effect of soil cover type on total weed biomass (g m^{-2} d.m.) at crop harvest following soil solarisation (mean of two tunnel glasshouse cover types). In each row, means followed by the same letter are not significantly different at P≤0.05 (LSD test), WAS: Weeks After Solarisation.

Crop	Soil cover type		
	Transparent PE film	Black PE film	No cover
Lettuce (13 WAS)	0.1 b	0.1 b	2.7 a
Radish (24 WAS)	0.3 b	0.4 b	21.5 a
Rocket (25 WAS)	0.4 b	2.0 b	46.9 a
Tomato (46 WAS)	82.7 b	72.2 b	146.0 a

of KOH and CaO decreased weed emergence of 76% and 20% respectively. Compared to CaO, use of KOH reduced weed emergence by 58 seedlings m^{-2} for any additional 100 kg ha^{-1} of compound applied. Increasing rates of KOH reduced seedling emergence also in the 10–20 cm layer (maximum reduction: 55%), while CaO application rate had not such a clear effect (Figure 3).

DISCUSSION

Results from the above-mentioned experiments on physical and cultural weed control have shown some pros and cons of these methods.

Long-term data on cover crop effect on weeds showed that after seven years the weed seedbank in the low-input system was 5-fold more abundant than in the conventional system, but in both cases the use of cover crops can reduce weed seedbank size with respect to bare soil.

Spring-tine harrowing can be a valuable tool for mechanical weed control in durum wheat but in case of high weed abundance and presence of problem weeds (e.g. grasses) it cannot possibly provide adequate weed control if not coupled with other weed control tactics.

Soil solarisation can reduce weed abundance for nearly the following 12 months and, as such, is highly recommended in areas with enough solar radiation to get the desired control effect.

Although additional on-field data are needed, steaming looks a promising soil disinfection method to substitute for both methyl bromide and solarisation in high-value cash crops, especially in areas with reduced summer solar heating or in case of winter cropping.

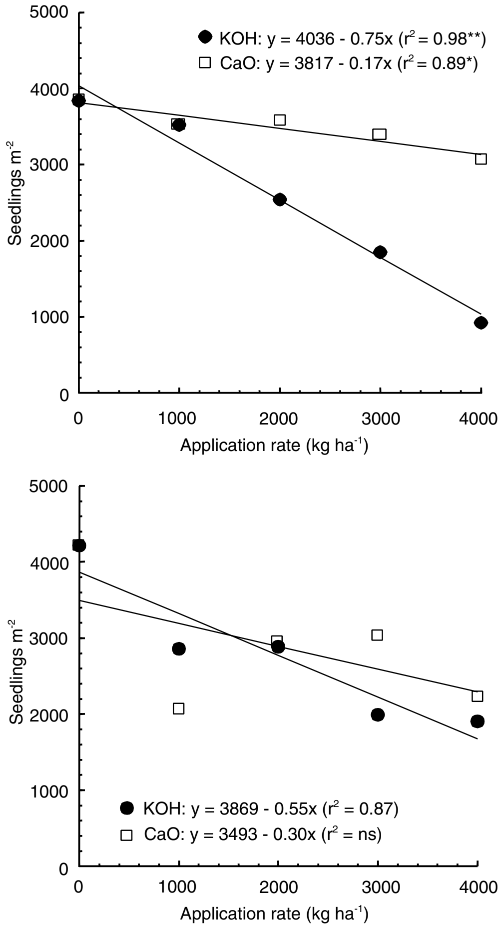

Figure 3. Regression of weed seedling density on application rate of KOH and CaO in the 0–10 (top) and 10–20 (bottom) cm soil layers. **, *, ns = significant at P≤0.01, P≤0.05 and not significant respectively.

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