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Efficacy and Profitability of Solarization for Weed Control in Strawberry

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Abstract: The efficacy and profitability of solarization for weed control in strawberry (Cv. Chandler and Camarosa) in Turkey was investigated. Two trial sites were selected and a Randomized Complete Block Design with four replicates was used. Prior to planting, fields were cultivated and irrigated and raised beds were prepared. Both the raised beds and the soil between them were covered with clear plastic sheets in order to increase soil temperature due to exposure to the sun. Mean soil temperature of solarized areas at 5 cm soil depth was 47.5°C, which was about 10°C higher than non-solarized areas. This increased temperature was maintained for 45-50 days before transplanting After transplanting, the beds were mulched with black polythene sheets. Weeds were counted before and after mulching (at 3-4 dates), both on the bed around the strawberry transplants and between the raised beds. Data were analyzed using the student t-test within each field. Results showed that solarization reduced the population of common weeds including common purslane, annual bluegrass, redroot pigweed, wild radish and wild chamomile more than 99% compared to untreated controls. Horseweed was not controlled by solarization. The costs of buying and laying clear plastic sheeting for solarization were significantly lower than the costs of labor for hand-weeding and for herbicides, which are normally used. Calculations indicated that profitability increased by $470/ha using solarization only for weed control in strawberry rather than other methods.

Key words: Solarization, weed control, profitability of solarization

INTRODUCTION

Strawberry production in Turkey is widespread due to favorable environmental conditions. Annually, 117000 tones of strawberries are produced in Turkey on 9700 ha. In 2001, 10675 tones of strawberries was produced in Aydın on 313 ha[1]. Strawberry is produced on raised beds under tunnels (2 m high) covered with clear polyethylene sheets. Soil is cultivated to a depth of 50-60 cm in June. The soil is irrigated and raised beds are prepared into which strawberries are transplanted, generally in August. In September (about 3-4 weeks after planting), the raised beds are mulched with black polyethylene sheets. Holes are made in the sheets through which the plants can grow. In January, high plastic tunnels (2 m height; about 5 m wide) are made containing four raised beds. Strawberry is harvested during the period between March and June in two subsequent years.

Weeds are one of the main problems in strawberry plantations. According to Pritts and Kelly[2], two months of weed competition in strawberry reduced the yield by 65%. There are two stages when weed competition in strawberry is particularly troublesome: a) from planting to mulching with black polyethylene sheets on raised beds (from late summer to autumn) and b) after mulching (from spring to early summer) between raised beds and around the strawberry plants. In addition to the loss of yield resulting from competition, weeds also cause secondary negative effects in strawberry by serving as host plants to diseases and insects, particularly mites[3], or by reducing harvesting efficiency.

Boz *et al.*[4] monitored weed species incidence before and after black mulching (especially during harvest time) in 40 fields in the strawberry growing areas of the Aydın province. This survey showed that summer weeds such as heliotrope (*Heliotropium* spp.), bermudagrass (*Cynodon dactylon* (L.) Pers.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), wild radish (*Raphanus raphanistrum* L.), foxtail species (*Setaria* spp.), barnyardgrass (*Echinochloa cruss-galli* L.), black nightshade (*Solanum nigrum* L.), johnsongrass (*Sorghum halepense* (L.) Pers.), sowthistle (*Sonchus* sp.) and puncture vine (*Tribulus terrestris* L.) were the most common weed species before black mulching on raised beds (from late summer to autumn). Winter weeds, such as horseweed (*Conyza canadensis* L.), wild chamomile (*Matricaria chamomilla* L.), annual bluegrass (*Poa annua* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) Medicus.), prostrate knotweed (*Polygonum aviculare* L.) and common chickweed (*Stellar media* (L.) Vill.) were the most common weed species in strawberry growing areas after mulching. In addition to these weeds, common purslane

(*Portulaca oleracea* L.), purple nutsedge (*Cyperus rotundus* L.), pigweed species (*Amaranthus* spp.) and common lambsquarter (*Chenopodium album* L.) were present both before and after mulching.

Weed control in strawberry is usually achieved by hand weeding, hoeing, application of methyl bromide or mulching with black polyethylene sheets. Glyphosate or paraquat may be used for weed control between raised beds These practices generally provide sufficient control of weeds in strawberry, but a cheaper, more effective and selective non-chemical method is needed.

Recently, there is interest in techniques, such as solarization for pest control as an alternative to traditional methods. Soil solarization is used to control weeds, soil borne diseases and nematodes, especially in regions with high summer temperatures. The basis of solarization is to increase soil temperature by covering the moistened soil with a clear polyethylene sheet and then to maintain this temperature for 4-6 weeks before planting[5-10]. Soil solarization is recommended by various researchers for weed control, however, its effects may vary according to weed species. For example, Kumar *et al.*[8] found good control of weed species reproduced by seed but not tubers of purple nutsedge by solarization. Ioannou[11] stated that most annual weeds such as mallow (*Malva*), pigweed, common chrysanthemum (*Chrysanthemum*), lambsquarters, field marigold (*Calendula arvensis*), wimmera rye grass (*Lolium rigidum*) and burning nettle (*Urtica urens*) were effectively controlled by solarization. In another study, it was found that solarization reduced annual bluegrass seed survival from 89 to 100% in the upper 5 cm of soil[9]. In Italy, good control of barnyardgrass, large crabgrass, lambsquarters and shepherd's purse was obtained by solarization while the control of common purslane was poor[12].

Although soil solarization is used in some vegetable growing areas and in greenhouses in the southern and western parts of Turkey, there are no reports of its efficacy for control of weeds in strawberry. Therefore, the objectives of this study were to investigate the effect of solarization on weed control in major strawberry producing areas in Aydın Province, Turkey and to evaluate the economic benefits of solarization in strawberry production.

MATERIALS AND METHODS

Solarization trials were conducted in two naturally weed-infested fields in Sultanhisar County of Aydin Province, Turkey (37° 51′ N, 27° 50′ E, altitude is about 57 m). Randomized Complete Block Design with four replicates was used. Treatments were solarized and non-solarized (control). Plots were 13x5 m in field 1 and 15x5 m in field 2.

Fields were prepared by deep cultivation (approx. 50-60 cm) followed by harrowing and light rolling. The soil was irrigated to field capacity and raised beds (35x55 cm) were prepared. Raised beds were covered manually with clear polyethylene sheets (110 μm) including the soil between the raised beds. Care was taken to avoid leaving air between the soil and the plastic cover. The soil was then solarized for 50 days (between June 19 and Aug 8) and 45 days (between June 28 and Aug 12) for experimental sites 1 and 2, respectively. At the end of the solarization periods, chilled (frigo) strawberry transplants (Cv. Chandler for site 1 and Camarosa for sites 2) were planted on the plots before black plastic was installed. Each raised bed contained two rows (row width 25 cm) with transplants spaced 30 cm apart. Drip irrigation was used to supply water throughout the growing season. Fertilizer was applied at (kg ha^{-1}) 110 N-40 P-130 K-67 Ca. Soil pH at the trial sites was c. 7.

Soil temperatures at 5 cm depth was recorded hourly in non-treated (control) and solarization plots using WatchDog data loggers (Spectrum Technologies, Inc) during the solarization.

Evaluation of efficacy of the solarization on weed species: The effect of solarization on weed emergence was evaluated by counting the weed seedlings: a) on the raised beds before mulching with black polyethylene sheets and b) on the raised beds around the strawberry transplants and between the raised beds after mulching. The weeds were counted in quadrat of 0.25 m^2 (0.5x0.5 m) on raised beds and of 0.15 m^2 (0.5x0.3 m) between raised beds. On the raised beds, weeds around each hole of four strawberry transplants were counted. Weeds were counted at 3-4 dates depending on the experimental field. At each counting date, 6-10 sites in each plot were depending on the plot size. Weeds were removed from all plots (including untreated) by hand after each counting date, regardless of experimental site. Yield was obtained in both fields. Data were analyzed using the student-t test within each field.

Evaluation of profitability of solarization for weed control: In order to estimate the profitability of solarization only for weed control, solarized plots are compared to the non-solarized plots in only one strawberry growing season over a six-year observation period. Some of the information for control plots, such as damage to strawberry transplants due to hand removal, was based on growers' experience of weed control.

RESULTS AND DISCUSSION

Control of weed species by solarization: Mean soil temperature of solarized areas at 5 cm soil depth was 47.5°C, which was about 10°C higher than non-solarized areas. Various weed species were observed during the growing season depending on experimental field and observation time (Table 1) and were similar to those recorded in a previous survey of Boz *et al*.[4]. Three weed species (common purslane, redroot pigweed and wild radish) were most commonly observed on raised beds before mulching. While common purslane and wild radish were observed on raised beds in both fields, redroot pigweed was observed only in fields 2. Around strawberry plants, common purslane and wild radish observed in both fields, whereas redroot pigweed only was found in field 2 and horseweed was found in field 1. Between raised beds, annual bluegrass was found in both fields whereas horseweed was only observed in fields 1 and wild chamomile in fields 2 (Table 1).

Table 1: Mean number of weed species in non-solarized and solarized plots (0.25 m²)

Weeds	Fields I	Fields II
On raised beds (0.25 m²)	Aug. 22, 2002	Sept. 02, 2002
Common purslane		
Non-solarized	134.7a	40.3a
Solarized	1.3b	0.0b
Redroot pigweed	-	6.0a
	-	0.0b
Wild radish	20.3a	0.0b
	13.4a	0.0b
On raised bed around strawberry	Oct. 02, 2002	Oct. 03, 2002
Common purslane	5.6a	3.0a
	0.0b	0.0b
Redroot pigweed	-	5.0a
	-	0.0b
Horseweed	3.3 NS	-
	2.3 NS	-
Wild radish	4.6 a	4.0a
	0.0 b	0.0b
Between raised beds (0.15 m²)	Feb. 20, 2003	Feb. 18, 2003
Annual bluegrass	22.8a	23.1a
	0.0b	0.0b
Horseweed	9.0NS	-
	8.3NS	-
		April 03, 2003
Wild chamomile	-	15.2a
	-	0.0b

-: Weed species not present at this location, NS: Non-significant

Effect on common purslane: Solarization reduced the emergence of common purslane by more than 99% in both fields (Table 1). This indicates that solarization was an effective method for control of this species in this study. In Greece, common purslane was controlled by solarization at 40°C for 50 h in 1988 and 45°C for 24 h in 1989[7]. Hartz *et al*.[13] stated that solarization controlled annual weeds such as *Conyza bonariensis*, common purslane and annual sowthistle by 56-72%. Defilippi *et al*.[14] concluded that solarization for two months at 45.7°C at a depth of 10 cm provided effective control of weed species such as common purslane, *Convolvulus arvensis*, *Veronica persica* and barnyardgrass. In a study reported by Tekin *et al*.[15], solarization for 61 days at 47°C at 5 cm did not control common purslane effectively. Vidotto *et al*.[12] stated that variable days of solarization did not provide acceptable control of common purslane.

Effect on annual bluegrass: The emergence of annual bluegrass was completely prevented by solarization in both fields (Table 1). Similar results were reported by Elmore[16] in the United States, Portugal and Israel. Peachey *et al*.[9] also showed that solarization for 53-59 days at temperatures of 52, 47 and 33°C at 5, 10 and 20 cm depths, respectively, reduced annual bluegrass seed survival from 89 to 100%.

Effect on redroot pigweed: Redroot pigweed was found to be quite sensitive to solarization. It was controlled by 100% (Table 1), which was significant compared to untreated plots. Ioannou[11] found that most annual weeds such as *Malva*, pigweed, *Chrysanthemum*, lambsquarters, *Calendula arvensis*, *Lolium rigidum* and *Urtica urens* were effectively controlled by solarization for 8 weeks at 43-45°C at 15-20 cm in Cyprus. In another study, populations of the annual summer weeds such as *Amaranthus hybridus* and *Galinsoga parviflora* and of the annual winter weeds such as *Medicago arabica*, *Stellaria media*, *Sonchus oleraceus* and *Coronopus didymus* were significantly reduce by 42 days of solarization in Argentina[17].

Effect on wild radish: Wild radish was not found in solarized plots in this study. In contrast, this species was present in non-solarized plots in fields 1 and 2 at 20.3 and 13.4 plants/0.25 m², respectively before mulching (Table 1). Solarization was an effective means of controlling wild radish in this study. Elmore[16] stated that this weed was susceptible to solarization.

Effect on wild chamomile: Wild chamomile was found during the last evaluation period at 15.2 plants/0.15 m² between raised beds in non-solarized plots in field 2 (Table 1). None were found in the solarized plots, indicating that this method is effective for control of this species.

Table 2: Profitability of solarization for weed control

Grower's practices	Solarized area/ha	Non-solarized area/ha
Plowing and harrowing	Same	Same
Fertilizer application		
before raised bed preparation	Same	Same
Raised bed preparation	Same	Same
Clear polyethylene sheet for solarization	900/3*=$300	-
Laborers for solarization	$130	-
(including irrigation and covering of sheets)		
Seedlings planting	Same	Same
Mulching on raised bed with black polyethylene sheet	Same	Same
Clear polyethylene sheets for tunnel	Same	Same
Fertilization	Same	Same
Irrigation systems and irrigation	Same	Same
Laborers for hoeing the weeds on raised bed	-	80 labors x $6/day=$480
Strawberry seedling lost due to weed removal	-	60 000 seedlings/ha total x 5% decrease=3 000 3 000 x $0.1/seedling= $300
Laborers for hoeing the weeds around strawberry seedlings	-	10 labors x $6/day=$60
Herbicide using between raised beds (twice)	-	$30 x 2 times application=$60
Total expenses for non-solarization	-	$900 (480+300+60+60)
Total expenses for solarization	$430 ($300+$130)	-
Profit for weed control due to solarization	$900-$430=$470 per ha	

*: Polyethylene sheets could be used three times for solarization, or could be used for tunnel

Effect on horseweed: In this study, solarization was not effective on horseweed (Table 1).

Yield: The yield was obtained 72830 kg ha^{-1} in solarized plot and 30670 kg ha^{-1} in non-solarized plot in field 1. In field 2 the yield was obtained 33980 kg ha^{-1} in solarized plot and 17104 kg ha^{-1} in non-solarized plot.

Profitability of solarization for weed control: The costs of agronomic practices such as cultivation and fertilizer application were the same regardless of weed control method. For solarization, the cost of clear polyethylene was $300 per sheet (Table 2). Labor costs for covering the sheet and watering the soil were $130 ha^{-1}. In non-solarized plots before mulching, there was a need for hand removal of weeds which cost $480 per ha^{-1} (80 laborers at $6/day). Approximately 60,000 strawberry transplants were planted per hectare and at least 5% of these transplants were mechanically damaged during the manual weeding process (personal observation), resulting in a loss of $300. In non-solarized plots, it was necessary to hoe the weeds around the strawberry seedlings, costing $60 (10 laborers at $6/day). In solarized plots, no weeds were observed around strawberry transplants except for horseweed, thereby saving approximately $60. Between the raised beds, farmers may use non-selective herbicides such as glyphosate and/or paraquat twice for weed control, costing an extra $60 Although horseweed was observed between raised beds in solarized plots it grew more slowly than in non-solarized plots, so growers did not apply any herbicide which saved $60. In summary, an estimated saving of $470 per ha was made by the use of solarization compared with traditional weed control methods (Table 2).

Results of this study indicate that an increase in soil temperature of 10°C due to solarization controlled the most important weed species such as common purslane, annual bluegrass, redroot pigweed, wild radish and wild chamomile in strawberry in the Aydin province. The exception was horseweed As solarization was found to be both effective and profitable, it can be recommended in the regions where high temperatures are prevalent in strawberry growing areas. The present studies were conducted on farms, so they provided an opportunity to demonstrate the benefits of this practice to the farmers, who are now using this method.

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