Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 07 August 2023
https://doi.org/10.14295/CS.v14.3906

Lettuce weed control with prior soil solarization

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Abstract

Lettuce is a leafy crop appreciated for the supply of nutrients that favor the immune system. However, like other crops, it is subject to weed interference. Due to its low competitiveness and the impacts of herbicides, it is necessary to search new ways to control weeds. This work aims to determine the effects of solarization on weed control and on the productivity of 'Verônica' lettuce with or without soil revolving after solarization. The experimental design was randomized blocks in a factorial scheme 7x2 with four replications. The beds were weeded, irrigated and covered with 150 µm thick transparent polyethylene in different periods (first factor): five solarization periods (75, 60, 45, 30, and 15 days with solarization) and two controls (without and with weeds), with or without soil revolving (second factor). Weed phytosociology (frequency, density and relative dominance, importance value index, and relative importance) and lettuce productivity were evaluated. The control of the weed community (with a predominance of *Cyperus rotundus*, *Eleusine indica* and *Digitaria* spp.) with solarization was not efficient. However, the non-revolving treatment decreases the density of some weeds and positively affects the productivity and commercial characteristics of lettuce.

Keywords: Lactuca sativa L., physical weed control, plastic film covers

Introduction

Lettuce is one of the most economically important leafy crops in the world (Shatilov et al., 2019). It is highly appreciated for the concentration of vitamin C, fiber, and polyphenols (Materska et al., 2019), compounds that strengthen the immune system and prevent diseases. In Brazil, it is considered the most important leafy crop and one of the five main vegetables (Conab, 2020).

One of the greatest challenges in lettuce agronomic management is weed control, since this crop has little capacity for competition because it is a small-sized plant (Casadei et al., 2020). Weeds cause losses in lettuce production through competition for nutrients, light, water, space, and release of allelochemicals, compounds that are secondary metabolites to which lettuce is sensitive (Grisi et al., 2011). (Galon et al., 2016) reported lettuce leaf area losses of up to 80% when it competed with populations of *Lolium multiflorum*. (Casadei et al., 2020) found that lettuce co-living with red-root amaranth (*Amaranthus retroflexus*) causes reductions in the total dry mass of up to 45% for the cultivar 'Lídia,' 41% for 'Salad Bowl,' 33% for 'Verônica' and 28% for 'Lucy Brown'.

Among the managing methods of weeds in lettuce, mechanical methods require labor and increase production costs, while chemical methods could lead to weed resistance, in addition to residues in food, soil, groundwater, and atmosphere (Abouziena & Haggag, 2016). Additionally, lettuce producers generally growth it in succession system, so herbicides could not be a suitable option because they may leave residues in the soil or in plants.

Solarization is a sustainable management method, which consists of covering the moist soil with transparent plastic to convert solar energy into heat aiming to control weeds, insects, and pathogens before planting (Bajwa et al., 2015). In a solarized soil, temperatures may reach 40

Received: 03 February 2022
Accepted: 13 December 2023

to 50 °C at 10 cm depth (Candido et al., 2011), but may decrease with deeper depths. In addition, the high levels of CO_2 in the soil may impair the twinning of some species (He et al., 2016), although they may favor others.

Regarding the benefits of solarization, excellent yield has been reported for tomato (Díaz-Hernández et al., 2017) and lettuce (Candido et al., 2011). Good results are due to a greater availability of nutrients and microbiological activity in the soil (Singh et al., 2012), pest control and improved germination, in addition to being an eco-friendly technique with no risks for farmers, workers, or consumers.

Searching for sustainable weed management techniques, the objective of the present work is to analyze the effects of soil solarization on weed control and lettuce productivity with or without soil revolving after solarization.

Material and Methods

The experiment was installed in an area of Sao Paulo State University (UNESP), Jaboticabal-SP, Brazil (21°15'17" S, 48°19'20" W, 590 m altitude). The soil was classified as a Oxisol, clay texture (fine sand = 170 g kg^{-1}, coarse sand = 450 g kg^{-1}, silt = 40 g kg^{-1}, clay = 340 g kg^{-1}), pH ($CaCl_2$) = 5.1, organic matter = 23 g dm^{-3}, P (resin) = 28 mg dm^{-3}, K = 4.7 $mmol_c$ dm^{-3}, Ca = 17 $mmol_c$ dm^{-3}, Mg = 10 $mmol_c$ dm^{-3}, and H+Al = 28 $mmol_c$ dm^{-3}.

According to the Köppen-Geiger climate classification, the region's climate is Cwa, characterized by a humid subtropical climate, with rainfalls in the summer and dry winters (André & Garcia, 2015). The climatic data are presented in **Figure 1**.

The experimental plots consisted of 28 beds, 1.20 x 4 m each, 2 m apart. Before the installation of the

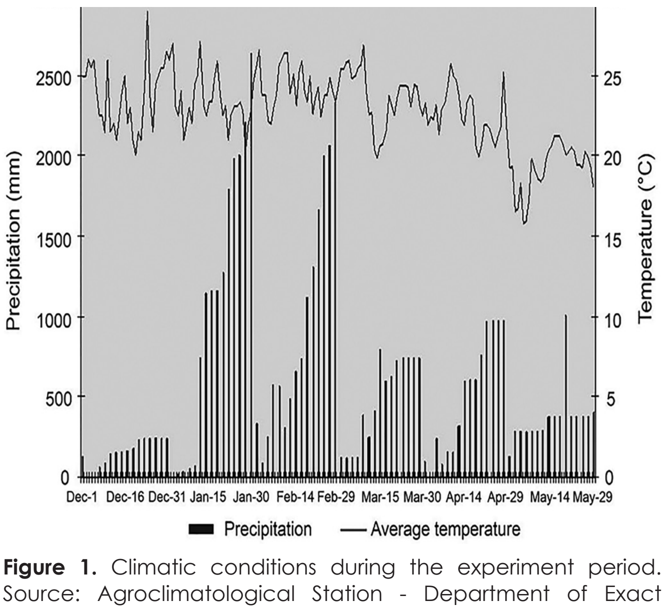

Figure 1. Climatic conditions during the experiment period. Source: Agroclimatological Station - Department of Exact Sciences, FCAV/UNESP - Jaboticabal Campus, São Paulo, Brazil

plastic cover, the weeds were identified and counted to determine the density of the weed community. Then, the beds were weeded, irrigated with 300 mm of water and covered with 150 µm thick transparent polyethylene in different periods according to treatments (75, 60, 45, 30, and 15 days with solarization or DWS), with two uncovered controls: weed-free (with weed control until lettuce seedlings were planted) and weedy -check (without weed control until the lettuce seedlings were planted) After solarization and before lettuce transplanting, the beds were divided; half of them was kept without soil revolving and the other half was tillage with a manual hoe at 20 cm of depth.

The experimental design was randomized blocks with four replications. The treatments were arranged in a 7x2 factorial design. The main factors were five solarization periods plus two uncovered controls and the adoption or not of soil revolving after solarization.

The concentration of CO_2 was monitored in 15 DWS treatment for seven days using a Finnigan GC-9001 chromatograph. Temperature was measured in 15 DWS and weed- free treatments for eight days at two times (9:00 a.m. and 3:00 p.m.) and at three depths using a mercury thermometer for 0 cm and a digital soil thermometer for 5 and 10 cm depth.

The transplanting of lettuce cultivar 'Verônica' was carried out on February 28th, 2008 after the solarization periods, at the spacing of 0.25 x 0.25 m and, after that, pest control, fertilization, and irrigation of plots were performed as prescribed for lettuce crops. The planting fertilization was performed by adding 0.4 gm^{-2} of N, 3 g m^{-2} of P, 1.5 g m^{-2} of K and 0.01 g m^{-2} of B. In topdressing, two applications of 2 $gplant^{-1}$ of ammonium nitrate were carried out at 15 and 30 days after transplanting. Sprinkler irrigation of the plots was executed daily, twice a day, with a total volume of 200 mm of water throughout the cycle. The harvest took place at 56 days after planting in a central area of 2 x 1.20 m per plot, and the harvested plants were counted and measured the weight of fresh biomass to yield estimate. Then, the leaves of five plants were counted, measured with a leaf area meter (LiCor, LI 3100 A), and placed in an oven at 70 °C for 96 hours, after which they were weighed to obtain the dry biomass.

Weeds were evaluated at harvest by placing a 0.5 m x 0.5 m box in a central area of each plot where the plants were identified, classified, cut, counted, and taken to dry in an oven at 70 °C for 96 hours, thus measuring dry biomass. The phytosociological analysis of the infesting community was performed according to the procedure of (Mueller-Dombois & Ellemberg, 1974). The relative frequency, relative density, relative dominance, importance value index, and relative importance were determined for each species.

The results were subjected to analysis of variance (F test) and the means were compared by Tukey test at 5% probability using the software Stat version 2.0.

Results and Discussion

The weed community was composed by 21 species. The families Poaceae (five species), Asteraceae (four species), Fabaceae (two species), and Amaranthaceae (two species) stood out, representing almost 62% of the total species of the experimental area (**Table 1**). Of these families, Asteraceae and Poaceae count many species because of their wide distribution. Asteraceae has more than 23,000 species counted in the world (Garcia, 2014) and Poaceae has 11,000-12,000 species (Kellogg, 2015).

In this weed community, the species that stood out visually in terms of density were *Cyperus rotundus*, *Eleusine indica* and *Digitaria* spp. After the solarization periods(at lettuce harvest)the densities of these three species were not reduced (**Figure 2**A). *Cyperus rotundus* was one of the most infesting species, presenting 13.6% and 32% of the total infestation before and after solarization periods, respectively. The expressiveness of this species is due to its efficient propagation system, i.e., by seeds or vegetatively by basal bulbs, tubers, and rhizomes (Kissmann, 1991) and due to its excellent adaptation under different conditions because of survival strategies, including allelopathy.

Of the three species, *Eleusine indica* had the highest density after solarization when compared with before solarization periods due to its excellent tiller production between 38 and 53 days after emergence (Takano et al., 2016), a period that coincided with the lettuce cycle in this work (Figure 2A). There was a slight reduction in the density of the most infesting species after 30, 45 and60 DWS when compared the weedy-check treatment evaluated at lettuce harvest (Figure 2A) remembering that at 75 DWS there was no survey before solarization since the beds were solarized shortly after their preparation.

There was an increase in weed density in the revolved treatments (R) in relation to non-revolved treatments (NR), especially in the treatment 75 DWS R, which presented a density eight times higher in relation to non-revolved plots (Figure 2B). The expressiveness of *Cyperus rotundus,* in considerable densities for the revolved treatments, stands out, thus confirming the resistance this species offers to weed control (Figure 2B).

As the solarization is based on the sterilization of soil superficial layers, soil revolving brought deeper layers to the surface, where seeds and tubers unaffected by temperature and CO_2 rises due to solarization, found germination/sprouting conditions and infested the area in a greater density compared to non-revolved areas.

Regarding the relative importance (RI), the scarce effect of solarization on the weed community is confirmed, mainly in *Cyperus rotundus, Eleusine indica* and *Digitaria* spp., the first of which has the highest RI

Table 1. Species that compose the weed community in the experimental area with the respective family, specie, common name and class.

Family	Specie	Common name	Class
Amaranthaceae	*Alternanthera tenella*	*Joseph's coat*	Eudicotyledon
	Amaranthus spp.	*Red-root amaranth*	Eudicotyledon
Asteraceae	*Blainvillea rhomboidea*	*Blainvillea*	Eudicotyledon
	Emilia sonchifolia	*Lilac tasselflower*	Eudicotyledon
	Parthenium hysterophorus	*Santa Maria feverfew*	Eudicotyledon
	Tridax procumbens	*Tridax daisy*	Eudicotyledon
Brassicaceae	*Lepidium virginicum*	*Virginia pepperweed*	Eudicotyledon
Commelinaceae	*Commelina benghalensis*	*Benghal dayflower*	Monocotyledon
Convolvulaceae	*Ipomoea grandifolia*	*Morning glory*	Eudicotyledon
Cyperaceae	*Cyperus rotundus*	*Java grass*	Monocotyledon
Euphorbiaceae	*Euphorbia heterophylla*	*Fireplant*	Eudicotyledon
Fabaceae	*Indigofera hirsute*	*True indigo*	Eudicotyledon
	Senna obtusifolia	*Coffee weed*	Eudicotyledon
Malvaceae	*Sida spp.*	*Sida*	Eudicotyledon
Poaceae	*Brachiaria plantaginea*	*Alexander grass*	Monocotyledon
	Cenchrus echinatus	*Southern sandbur*	Monocotyledon
	Digitaria spp.	*Crabgrass*	Monocotyledon
	Eleusine indica	*Indian goosegrass*	Monocotyledon
	Panicum maximum	*Guinea grass*	Monocotyledon
Portulacaceae	*Portulaca oleracea*	*Purslane*	Eudicotyledon
Solanaceae	*Solanum americanum*	*American black nightshade*	Eudicotyledon

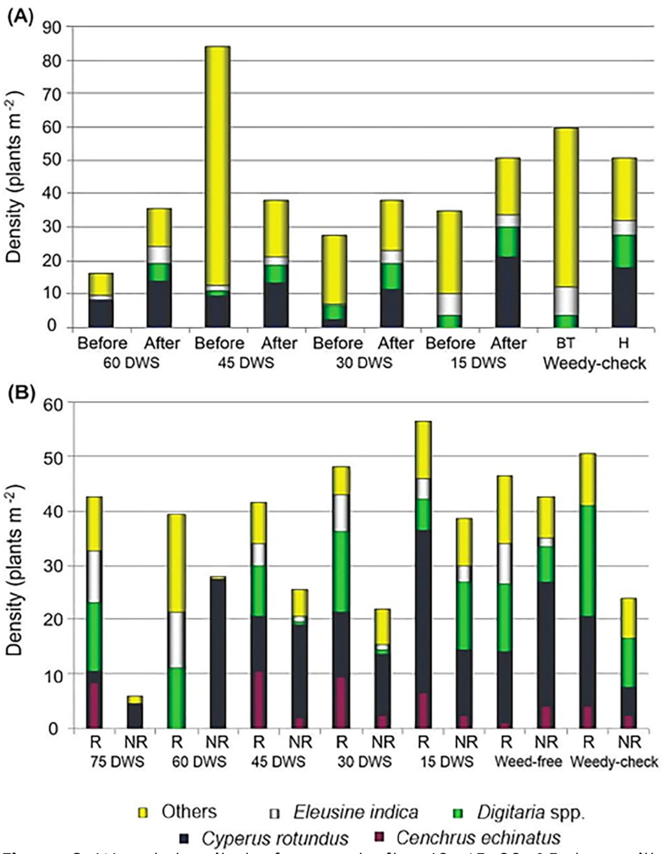

Figure 2. Weed density before and after 60, 45, 30, 15 days with solarization (DWS), weedy-check before transplanting (BT) and at harvest (H) of lettuce (A) and weed density after 75, 60, 45, 30, 15 DWS, weed-free and weedy-check in soil with (R) and without (NR) revolving (B).

(22.32%) among all species at 15 DWS (**Table 2**). This latter period had insufficient solarization for *Cyperus rotundus* and *Commelina benghalensis* control, because of these species had the greatest RI at 15 DWP comparing others solarization periods (Table 2).

Such a low control of *Cyperus rotundus* is also explained because temperatures reached in the soil were not high enough to affect the tubers (**Figures 3**A and 3B). (Iqbal et al., 2012) concluded that temperatures of 42 ± 3 °C delayed the sprouting of tubers but did not cause their death. For solarization to exert an effect on the germination of *Cyperus rotundus* seeds, soil temperatures should remain constant as long as possible (Loddo et al., 2019), a fact not recorded in the present study. On the other hand, *Alternanthera tenella* RI values were lower in all treatments compared to the weedy-check highlighting an 81% decrease in RI at 60 DWS(Table 2). This effect was the result of a longer solarization periodand high soil temperatures, which reached up to 50 °C (Figure 3B) and thus affected this species, since temperatures above 28.2 °C affect the percentage and the germination speed index of *A. tenella* (Canossa et al., 2008).

Digitaria spp. was also not affected by solarization. It showed homogeneous RI values in treatments (Table 2). This happened because the temperatures were insufficient to decrease the germination of this species. According to (Wang et al., 2018), an exposure for five minutes to 60 °C reduced the germination of *Digitaria sanguinalis* by 50%.

The soil temperature increased at 15 DWS compared to the weed-free treatment, both at 9 a.m. (Figure 3A) and at 3 p.m. (Figure 3B), reaching at this time higher values. Soil surface (0 cm) temperatures were higher compared to the depths 5 and 10 cm for both treatments. At 9 a.m., the maximum surface temperature was around 30 °C, at 5 cm 28 °C, and at 10 cm 27.5 °C in the treatment with solarization (15 DWS) at 10 days

Table 2. Relative importance (RI) of the weed community in response to days with solarization (DWS)

Species	75 DWS	60 DWS	45 DWS	30 DWS	15 DWS	Weed-free	Weedycheck
				RI (%)			
Amaranthus spp.	3.41	9.91	2.48	2.46	1.93	2.68	3.27
Alternanthera tenella	21.91	6.52	18.8	12.63	11.28	28.12	34.25
Brachiaria plantaginea		7.72		5.8			
Euphorbia heterophylla					1.84	1.79	
Senna obtusifolia	2.47	2.21	3.88	8.17	5.65	2.51	6.73
Cenchrus echinatus	8.77	2.63	17.53	13.84	12.71	6.84	9.53
Commelina benghalensis	2.41	3.64	6.68	2.53	6.78	35.58	3.08
Cyperus rotundus	9.87	17.62	20.72	15.59	22.32	16.48	13.36
Digitaria spp.	18.26	15.49	12.54	18.14	13.8	10.06	15.81
Eleusine indica	10.52	12	5.38	1.93	9.1	8.9	3.24
Ipomoea grandifolia					1.62	2.37	1.52
Lepidium virginicum					1.88	1.1	
Panicum maximum	12.31	11.52	8.48	14.71	6.88		2.37
Portulaca oleracea	7.39	10.73	3.52	2.51	4.2	6.95	5.54
Parthenium hysterophorus				1.69			1.31
Sida spp.						1.24	
Solanum americanum	4.42					3.02	
Tridax procumbens						3.31	

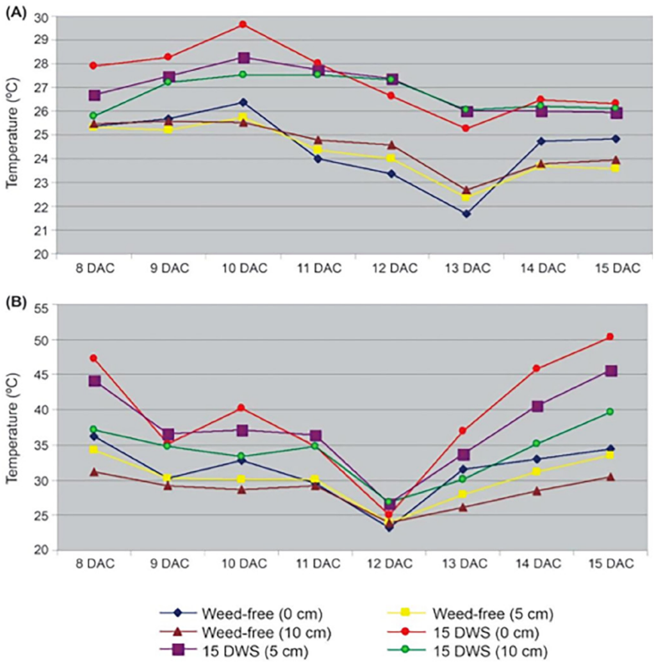

Figure 3. Temperatures at 9 a.m. **(A)** and 3 p.m. **(B)** at 0, 5 and 10 cm depth in 15 DWS and weed-free treatments from 8 to 15 days after covering (DAC) with plastic. DWS (Days With Solarization)

after coverage or DAC (Figure 3A). With regard to 3 p.m., the maximum temperatures were recorded in the same treatment at 15 DAC: 50 °C on the surface, 45 °C at 5 cm, and 40 °C at 10 cm depth (Figure 3B), but they were not lethal for most species. (Dahlquist et al., 2007) stated that seeds of six species were affected by soil temperatures above 50 °C. Of these species, only *Portulaca oleracea* matches data of our work, but it was not affected (Table 2) because it needed temperatures higher than 50 °C to be affected. (Díaz-Hernández et al., 2017) obtained similar results, concluding that there was no effect of solarization on weeds since the temperatures were below 43.3 °C at 10 cm depth, which supports our hypothesis.

Another reason for the low control of solarization could be because the plastic had a 150 μm (0.15 mm) thickness, taking into account that some authors such as (McGovern & McSorley, 1997) observed that thinner transparent plastics (25-30 μm) are proper for solarization because they improve solar transmission and soil heating. (Gill et al., 2017) noted that black and transparent polyethylene plastics from 50.8 to 101.6 μm may increase soil temperatures up to 54 °C in the 0-5 cm layer, reducing weed emergence by 45-78%.

The concentration of CO_2 in the soil covered with plastic increased up to 13 DAC; from then on, it remained close to 38% (**Figure 4**), which is considerably higher than the concentration of CO_2 in the atmosphere (mean: 0.035%). (He et al., 2016) concluded that concentrations of CO_2 of 29.4% and 52.9% in the soil did not allow the

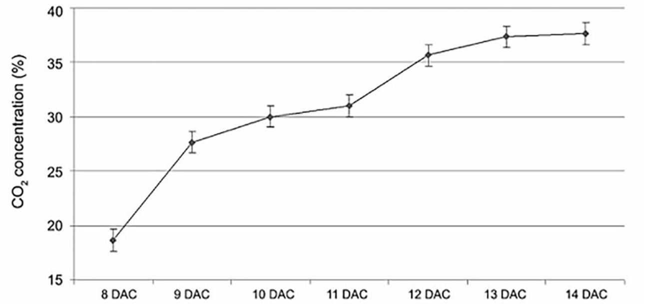

Figure 4 CO_2 concentration (%) and standard deviation from 8 to 14 days after covering (DAC) in the 15 DWS treatment. DWS (Days With Solarization)

germination of corn, wheat, beans, and cabbage. In the present study, 38% of CO_2 did not affect weeds, which suggests that weeds are more resistant than crops and could need a higher concentration of this gas in order not to germinate. Such concentrations of CO_2 favored *Cenchrus echinatus*, *Cyperus rotundus*, *Digitaria* spp., *Eleusine indica*, *Panicum maximum* and *Portulaca oleracea* (Table 2) probably due to the increase in ethylene, which promotes germination of non-dormant seeds due to antagonism with abscisic acid (Hernández-López et al., 2018). In addition, other positive effects on weed development could have occurred due to the presence of CO_2 in the soil, as (Steinger et al., 2000) reported. The authors did not observe changes in the germination of *Bromus erectus* under high concentrations of CO_2, but the seedling size of this species increased.

There was a significant effect of the interaction between soil revolving and solarization periods for dry matter, number of leaves, and leaf area of lettuce plants, but not fresh matter (**Table 3**). For this characteristic, soil revolving, regardless of covering periods, caused a 10% reduction of lettuce fresh matter (data not shown).

The 75 DWS without soil revolving was the most outstanding due to the increase in dry matter, number of leaves, and leaf area of lettuce, showing increases of 27.5%, 12% and 15.3%, respectively, compared to weed-free treatment (Table 3). (Candido et al., 2011) reported a similar result and stated that 62 days of solarization increased lettuce productivity between 18.4% and 23.8% compared to soil without plastic cover. According to (Díaz-Hernández et al., 2017) with 62 days of solarization there was an increase of 20.4% in tomato productivity compared to the control.

The good results of lettuce obtained in the present work may be due to a better rooting resulting from the temperatures obtained and to the control of some soil pathogens (Bajwa et al., 2015), in addition to more available nutrients because of a higher soil temperature (Singh et al., 2012).

Table 3. Lettuce characteristics as a function of solarization periods and soil revolving

Dry matter (g)		
Period (DWS)	With Revolving	Without Revolving
75	7.37 Bab[1]	15.45 Aa
60	4.88 Bb	14.13 Aab
45	7.36 Aab	8.10 Ab
30	9.90 Aab	13.44 Aab
15	10.13 Bab	14.15 Aab
Weedy-check	11.80 Aa	8.37 Ab
Weed-free	7.64 Bab	12.12 Aab
DMS (revolving Period) = 3.80; DMS (revolving period) = 6.07; CV = 16.98%		
Number of Leaves		
Period (DWS)	With Revolving	Without Revolving
75	4.50 Aab	4.97 Aa
60	3.43 Bb	4.57 Aab
45	3.97 Aab	4.30 Aab
30	4.71 Aa	4.58 Aab
15	4.43 Aab	4.46 Aab
Weedy-check	4.31 Aab	3.31 Ab
Weed-free	3.69 Bab	4.44 Aab
DMS (revolving Period) = 0.80; DMS (revolving period) = 1.27; CV = 8.63%		
Leaf Area (dm^2)		
Period (DWS)	With Revolving	Without Revolving
75	2.50 Aab	3.32 Aa
60	1.38 Bb	3.09 Aa
45	2.49 Aab	2.17 Aa
30	2.67 Aab	2.78 Aa
15	2.86 Aa	3.23 Aa
Weedy-check l	2.47 Aab	2.56 Aa
Weed-free	1.75 Bab	2.88 Aa
DMS (revolving Period) = 0.89; DMS (revolving period) = 1.42; CV = 15.92%		

*DWS (DaysWith Solarization)

Conclusions

The study showed that the control of weed community with solarization and low thermal amplitude is not efficient, but the non-revolving of soil after solarization decreases the density of some weeds. Moreover, lettuce productivity and commercial characteristics are positively affected when there is no revolving in solarized beds prior to transplanting.

References

Abouziena, H.F., Haggag, W.M. 2016. Métodos alternativos de controle não químicos de plantas daninhas: Uma revisão. *Planta Daninha* 34: 377–392.

Bajwa, A.A., Mahajan, G., Chauhan, B.S. 2015. Nonconventional Weed Management Strategies for Modern Agriculture. *Weed Science* 63: 723–747.

André, R.G., Garcia, A. 2015. Alguns Aspectos Climaticos do Município de Jaboticabal – SP. *Nucleus* 12: 263–269.

Candido, V., D'addabbo, T., Miccolis, V., Castronuovo, D. 2011. Weed control and yield response of soil solarization with different plastic films in lettuce. *Scientia Horticulturae* 130: 491–497.

Canossa, R.S., Oliveira, R.S., Constantin, J., Braccini, A.L., Biffe, D.F., Alonso, D.G., Blainski, E. 2008. Effect of temperature and light on joyweed (*Alternanthera tenella*) seed germination. *Planta Daninha* 26: 745–750.

Casadei, E., Bacha, A.L., Rodrigues, J.S., Santos, R.T.S, Alves, P.Ç.C.A., Filho, A.B.C. 2020. Redroot pigweed interference with lettuce crop. *Planta Daninha* 38: 1–8.

Conab. Companhia Nacional de Abastecimento. Boletim Hortigranjeiro. 2020. https://www.conab.gov.br / info-agro / hortigranjeiros - prohort / boletim -hortigranjeiro /item/ download/ 31857_4042735a07431f5675cdac24e547928e <Access on 20 Jul. 2020>

Dahlquist, R.M., Prather, T.S., Stapleton, J.J. 2007. Time and temperature requirements for weed seed thermal death. *Weed Science* 55: 619–625.

Díaz-Hernández, S., Gallo-Llobet, I., Domínguez-Correa, P., Rodríguez, A. 2017. Effect of repeated cycles of soil solarization and biosolarization on corky root, weeds and fruit yield in screen-house tomatoes under subtropical climate conditions in the Canary Islands. *Crop Protection* 94: 20–27.

Galon, L., Forte, C.T., Giacomini, J.P., Reichert, F.W., Scariot, M.A., David, F.A., Perin, G.F. 2016. Competitive Ability of Lettuce with Ryegrass. *Planta Daninha* 34: 239–248.

Garcia, F. 2014. Classificação e mecanismos de sobrevivencia das plantas daninhas. In: Monquero, A. *Aspectos da biología e manejo das plantas daninhas.* Rima, São Carlos, Brasil. 33-60 p.

Gill, H.K., Aujla, I.S., De Bellis, L., Luvisi, A. 2017. The Role of Soil Solarization in India: How an Unnoticed Practice Could Support Pest Control. *Frontiers in Plant Science* 8: 1515.

Grisi, P.U., Gualtieri, S.C.J., Ranal, M.A., Santana, D.G. 2011. Efeito alelopático do fruto de Sapindus saponaria na germinação e na morfologia de plântulas daninhas e de hortaliças. *Planta Daninha* 29: 311–322.

He, W., Moonis, M., Chung, H., Yoo, G. 2016. Effects of high soil CO_2 concentrations on seed germination and soil microbial activities. *International Journal of Greenhouse Gas Control* 53: 117–126.

Hernández-López, A., Beltrán-Peña, E.G., Amancio, A.E., Nuñez, O., Avila-Alejandre, A.X. 2018. Preacondicionamiento del agua en la germinación y emergencia de *Capsicum chinense* Jacq. *Revista Mexicana de Ciencias Agrícolas* 9: 1703–1714.

Iqbal, J., Hussain, S., Ali, A., Javaid, A. 2012. Biology and management of purple nutsedge (*Cyperus rotundus* L.). *Journal of Animal and Plant Sciences* 22: 384–389.

Kellogg, E.A. 2015. Flowering plants. Monocots: Poaceae. In: Kubitski, K. *The Families and Genera of Vascular Plants*. Springer Cham, New York City, USA. 416 p.

Kissmann, K.G. 1991. *Plantas infestantes e nocivas*. BASF-Brasileira, São Paulo, Brasil. 608 p.

Loddo, D., Carlesi, S., Da Cunha, A.T.P. 2019. Germination of *Chloris barbata*, *Cynodon dactylon*, and *Cyperus rotundus* from Angola at constant and alternate temperatures. *Agronomy* 9: 1-11.

Materska, M., Olszówka, K., Chilczuk, B., Stochmal, A., Pecio, T., Pacholczyk, B., Piacente, S., Pizza, C., Masullo, M. 2019. Polyphenolic Profile In Lettuce (*Lactuca sativa* L.) after CaCl2 treatment and cold storage. *European Food Research and Technology* 245: 733-744.

Mcgovern, R.J., Mcsorley, R. 1997. Physical methods of soil sterilization for disease management including soil solarization. In: Rechcigl, N.A., Rechcigl, J.E. *Environmentally Safe Approaches to Crop Disease Control*. CRC Press, Boca Raton, USA. 283–313 p.

Mueller-Dombois, E., Ellenberg, H. 1974. *Aims and methods of vegetation ecology*. John Wiley & Sons, New York, USA. 547 p.

Shatilov, M.V., Razin, A.F., Ivanova, M.I. 2019. Analysis of the world lettuce market. *IOP Conference Series: Earth and Environmental Science* 395: 012053.

Singh, R.K., Sharma, J., Jha, S.K., Singh, A.K. 2012. Solarization technique: its use in the multiplication of in vitro planting materials. *Current Science* 102: 1433–1436.

Steinger, T., Gall, R., Schmid, B. 2000. Maternal and direct effects of elevated CO 2 on seed provisioning, germination and seedling growth in *Bromus erectus*. *Oecologia* 123: 475–480.

Takano, H.K., Oliveira, R.S., Constantin, J., Braz, G.B.P., Padovese, J.C. 2016. Crescimento, desenvolvimento e produção de sementes de capim-pé-de-galinha. *Planta Daninha* 34: 249–258.

Wang, Y.H., Ma, Y.L., Feng, G.J., Li, H.H. 2018. Abiotic factors affecting seed germination and early seedling emergence of large crabgrass (*Digitaria sanguinalis*). *Planta Daninha* 36: 1-10.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.