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Short Communication

Chemical changes in the properties of two semiarid mediterranean soils during solarisation

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Abstract

Soil solarization, a sustainable method of soil disinfection was tried on two semi-arid soils located in Murcia (SE Spain) to study chemical changes in soil properties using polyethylene film as a cover. A decrease in organic matter and an increase in electrical conductivity were observed, while no significant changes in pH, total nitrogen and phosphorus were detected between mulched and unmulched soils. For Diethylenetriaminepentaacetic Acid (DTPA) Extractable (Ext-) micronutrients such as copper, manganese and iron, a weak trend towards increased availability was observed after solar heating, although only iron and manganese showed significant differences between covered (solarized) and uncovered (unsolarized) soils.

INTRODUCTION

Soil-borne pathogens, such as fungi, bacteria, nematodes, parasitic plants and other organisms recurrently cause major losses in horticultural crops, by affecting both quality and yield. The use of chemical fumigants to control pests, diseases and weeds is undesirable due to their residual toxicity in the environment and possible consequences for human and animal health. Therefore, effective methods need to be developed to safeguard crop production and yield permanency.

The exploration for non-chemical methods to control soil-borne pathogens has been intensified in the last decades due to the ban on the use of methyl bromide. Soil solarization, also referred as solar heating, plastic mulching, solar pasteurization, or solar disinfection is a hydrothermal process produced in moist soils when covered by plastic film, mainly polyethylene and heated by sunlight during the warm months [1].

This method is a natural and ecological process for soil disinfection that is carried out by solar heating, involving chemical, physical, and biological adjustments in the soil. In some situations, enlarged or reduced crop growth in solarized soils results from these changes, which may have economic importance in certain cases [2]. Polyethylene (PE) film positioned on wet soil along the summer months contributes to the increase of soil temperatures to lethal levels for many soil-borne plant pathogens and weed seeds. Temperatures commonly reached during solarization heats the soil in the upper layer (15 cm) to ≥ 45ºC although they are mild as compared to other soil heating methods for soil disinfection as soil steaming. Climatic conditions in semi-arid and arid areas of the world results in shorter periods of solarization (4-6 weeks). Combining solarization with other methods of control such as pesticides, organic fertilizers, and biological control agents, frequently gets good results due to a synergistic effect. Also, when organic amendments are used in combination with solarization (biosolarization), the plastic tarp prevents the leak of volatile compounds increasing the effectiveness of the treatment [3].

All forms of soil disinfections, including solarization, result in microbial changes. Soil solarization can be regarded as a relatively mild treatment because solar heating of soil does not create high temperatures as in soil steaming. Microbial mineralization of nitrogen from organic matter results in the enhancement of soil with this element. Moreover, when the soil is heated, a large proportion of the microbiota is killed, thus releasing mineral nutrients such as NO_3^--N and NH_4^+-N [4]. In addition to nitrogen, other nutrients such as calcium, potassium, magnesium, and phosphorus, have been found in some cases in larger concentration after soil mulching [5]. Even though most mesophilic microorganisms present in soil have thermal harm thresholds beginning around 38-40ºC, many thermotolerant organisms can survive temperatures attained during solarization treatment [6]. Soil temperatures reached during solarization are plenty to eliminate target pathogens originating a new microbial equilibrium in the soil. In addition, solarization decreases respiration, microbial biomass and soil enzyme activities originating changes from the variety and conformation of the soil bacterial [7-9]. On the other hand, soil structure and related physical properties of soils play an important role in plant growth and crop production. However, physical properties of soils are not commonly subjected to rapid changes and the time required to observe such changes is much longer than that required to chemical transformations. Consequently, information available on changes in the physical properties of soils due to disinfestations is limited [10]. In addition, solarization provokes changes in the chemical features of soil that improve the growth and developments of plants [6]. According to the above mentioned the aim of this research was to assess the changes in the chemical properties of two typical semiarid soils located in Murcia (SE of Spain) after solarization, a technique commonly used in the Mediterranean basin as disinfection method.

MATERIAL AND METHODS

Soils

The soils selected for this study are located in a semiarid area (Murcia, SE of Spain). An Hypercalcic Calcisol (HC) placed in Campo de Cartagena, developed on quaternary fine silts and a Calcaric Regosol (CR) located in Torre Pacheco, developed on unconsolidated materials, both in fallow land and characterized by their low organic matter content and high percentage of $CaCO_3$ [11]. Samples were taken from the Ap horizon (20-25 cm), air-dried, sieved to 2 mm, and stored at 5±1ºC. Soil analysis began 3-4 days after sampling and storage under cool conditions. Table 1 shows the main physico-chemical characteristics of the studied soils.

Experimental setup

Soil samples (500 g) were weighed in appropriate flasks and placed in holes at 20 cm depth on the soil surface. Fifteen vessels (8 cm id × 20 cm depth) were occupied with 1 kg of soil in each case. Distilled water was added to soil samples to bring them to its soil`s maximum water holding capacity. Three groups of vessels (n=5) were prepared: i) Saturated soil covered with low density PE, ii) Saturated soil covered with high density PE, and iii) Saturated soil not covered with PE (non-mulched). Each experiment was replicated five times. Dow 582E (LDPE, 0.92 g cm-3, 20 µm thickness) and Hostalen GM 9240HT (HDPE, 0.95 g cm^{-3}, 25 µm thickness) used as plastic films were obtained from Plásticos Romero (Murcia, Spain).

All experiments were carried out during the summer season (June-September, 2019) at the Service of Agricultural and Forest Experimentation of the University of Murcia, Spain at 38º01´N and 1º09,W). Maximum ambient temperature along the experiment was 45ºC. Soil moisture and temperature were measured at 5 cm depth with the help of a Testo 635 portable thermo-hygrometer (Testo S.A., Cabrils, Spain). Water content of the samples was controlled weekly and adjusted by adding water to the initial weight of the vessels. The soil temperature was recorded at 13-14 h every two-three days. Maximum temperature in mulched soils during the experiment reached 48ºC (10ºC higher than in non-mulched soil). The maximum global and UVA-radiation recorded during the experiment were 1045 and 28 W m^{-2}, respectively. Soil samples were periodically taken from each container to assess soil characteristics starting from day 0 as well as on 7, 14, 45 and 80 days after mulching.

Analytical procedures

Soil samples were analyzed for pH, Electrical Conductivity (EC), Organic Matter (OM), Total Nitrogen (TN) and Phosphorus (P). DTPA Ext- micronutrients (Fe, Cu, Mn, and Zn) were measured by ICP-OES (Agilent 5110 series). Their characteristics were determined using standard methods [12].

Statistical analysis

To assess significant differences between treatments (mulched and non-mulched soils), data were subjected to one-way ANOVA by means of IBM-SPSS Statistics version 24 software (Armonk, NY). When the F statistic was considered significant ($p<0.05$), the Tukey's HSD post-hoc test was carried out.

RESULTS AND DISCUSSION

The evolution of Total Organic Carbon (TOC) content during soil solarization is showed in figure 1 (top row). In both cases, a reduction in TOC is observed, more marked for covered soils. Significant differences ($p<0.05$) were found between mulched and non-mulched soils. In the non-mulched CR, the Organic Carbon (OC) content falls until 3.8 g kg^{-1}, while for mulched soils the value is lower (3.5 g kg^{-1} and 2.1 g kg^{-1} for LDPE and HDPE cover, respectively) after solarization period. In the case of HC, the final values were 4.3 g kg^{-1}, 2.9 g kg^{-1} and 3.2 g kg^{-1} for non-mulched soil, HDPE cover and LDPE cover, respectively. Several authors have pointed that enhanced decay of OM occurs during/after a disinfestation period. Accordingly, Stapleton et al., [5] found a significant decrease in OM after solarization in a silty clay soil, because of the heat-generated oxidation from the aerobic fraction of solarized soil. Other authors [13, 14] have shown that water-soluble organic matter (or low molecular weight fulvic acid) increased significantly in all solarized soils that were studied.

A parameter commonly used to evaluate changes in the concentration of charged moieties in a soil solution is the Electrical Conductivity (EC). An increase of this parameter during

Table 1: Major physico-chemical properties of the studied soils (n=3).

Parameter	Mean value (RSD, %)	
	Hypercalcic Calcisol	Calcaric Regosol
Sand (%)	19.5 (2)	5.2 (3)
Silt (%)	47.2 (3)	50.2 (5)
Clay (%)	33.3 (5)	44.6 (6)
Textural class	Silty clay loam	Silty clay
Bulk density (g ml^{-1})	1.29 (5)	1.22 (7)
pH	8.3 (3)	7.9 (2)
EC (dS m^{-1})	0.14 (9)	0.68 (10)
CEC (cmol kg^{-1})	12.2 (5)	17.7 (7)
CaCO3 (%)	54 (7)	47 (8)
Total N (%)	0.7 (9)	1.0 (7)
OM (%)	0.98 (10)	1.3 (6)
P (mg kg^{-1})	48.6 (5)	48.0 (4)
Fe (mg kg^{-1})	20.2 (15)	23.0 (7)
Mn (mg kg^{-1})	96.0 (12)	102.5 (9)
Cu (mg kg^{-1})	10.1 (9)	8.0 (8)
Zn (mg kg^{-1})	7.5 (13)	8.3 (10)

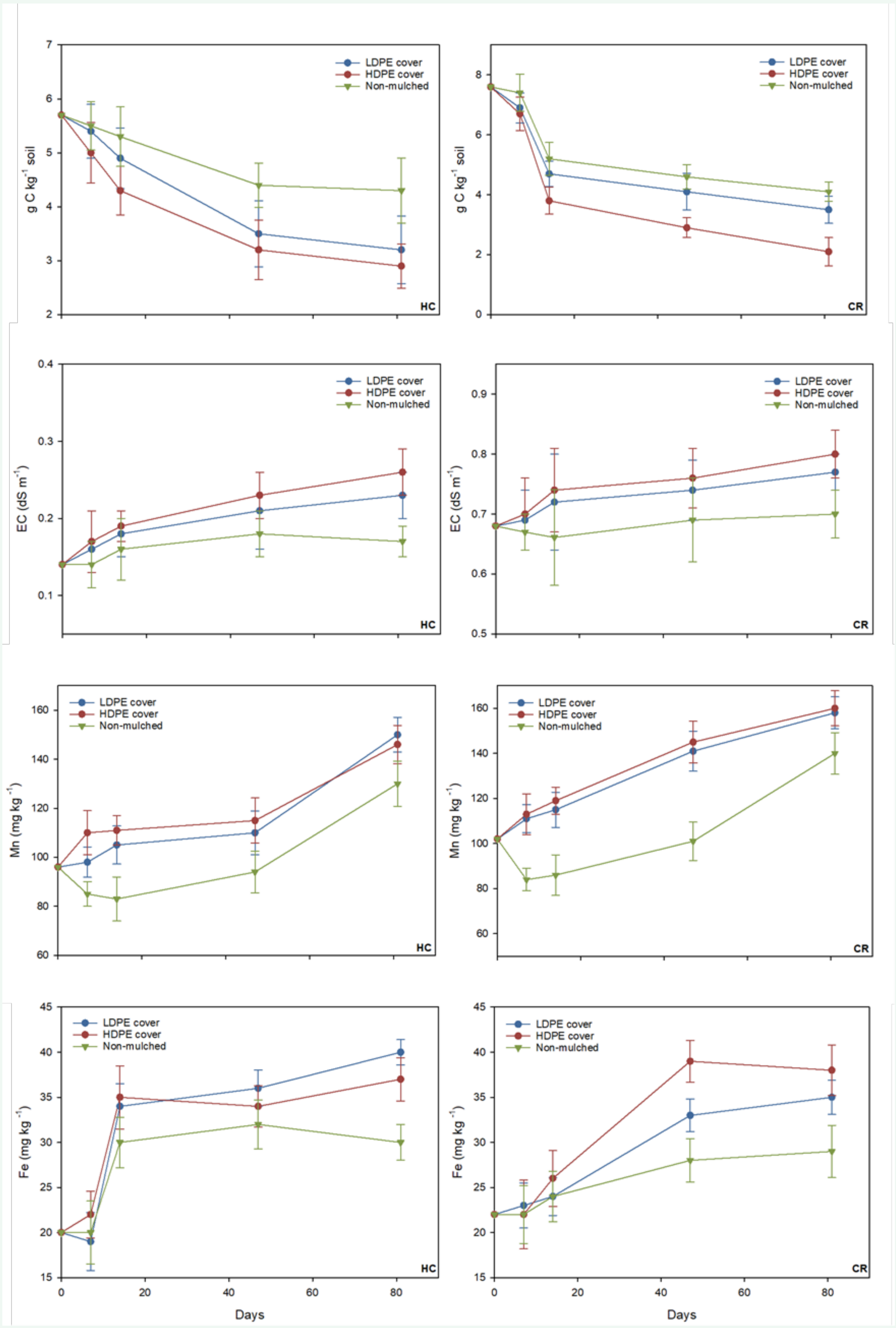

Figure 1 Evolution of organic carbon content, electrical conductivity, iron and manganese during soil solarization (Error bars denote standard deviation). HC: Hypercalcic Calcisol; CR: Calcaric Regosol.

soil solarization was observed as shown in figure 1 (second row). At the end of the treatment the EC values recorded in both covered soils were sharply higher (around 0.1 dS m^{-1}) than in non-mulched soils. The increase in EC can be attributed by Chen and Katan [13], to enhanced decomposition and mineralization of soil organic matter and to the transport of ions toward the heated surface where water evaporates and recondenses on the polyethylene sheets. Water evaporation is minimal in mulched soil because the evaporated water during the day condenses on the film and returns onto the soil surface. Furthermore, water absorption (0.01%, 24 h) by both PE films is very small. Regarding temperature, an increment about 8-10ºC was observed in mulched soils as compared to non-mulched soils, although no significant differences ($p<0.05$) were detected between both PE films [5] also found an increase in EC after soil solarization ranging from 0.3-0.6 dS m^{-1} for loamy sand and silty clay soils, respectively.

Solarization did not affect consistently soil pH and total nitrogen content. No statistically significant differences in pH were observed in our experiment (Table 2). During soil solarization a slight increment in this parameter, no more than 0.2 units, was observed. This weak increase is probably due to the mineralization of the organic matter and the consequent liberation of certain ions. This result is according to [13] and [5] who did not find significant differences between treatments for different soils.

One of the common findings of soil heating is an improvement in the concentration of certain soluble mineral nutrients because much of the regular microbiota is killed and degraded when soil is heated, thus liberating the mineral nutrients. In our case, significant differences ($p<0.05$) in total nitrogen and phosphorus were not observed after the mulching (Table 2). For both, the values found at the end of the treatment were very similar to those recovered at the beginning of the experiment although some authors [6] indicate that the concentrations of NH4+-N and NO3--N and P are significantly enlarged across a range of soils type (loamy sand to silty clay) after solarization. Other authors have reported an increase in pH, EC, Ca, Mg, N, P, K and C in solarized over non-solarized soil [15]. These changes can be attributed to an increase in the rate of decomposition of OM at

Table 2: Evolution of soil parameters (n=5) where no significant differences (p<0.05) were observed between treatments.

		Mean value (RSD, %)				
Treatment	**Days**	**pH**	**TN (%)**	**P (mg kg-1)**	**Cu (mg kg-1)**	**Zn (mg kg-1)**
		Calcaric Regosol				
LDPE cover	0	7.9 (2)	1.0 (7)	48.0 (4)	8.0 (8)	8.3 (10)
	7	8.1 (3)	1.2 (6)	44.5 (4)	8.2 (7)	6.5 (7)
	14	8.1 (4)	0.9 (5)	46.4 (5)	9.8 (9)	5.3 (5)
	45	8.1 (2)	0.9 (7)	44.5 (6)	10.5 (6)	5.1 (9)
	80	8.1 (2)	1.0 (8)	45.5 (5)	10.7 (7)	5.2 (7)
HDPE cover	0	7.9 (2)	1.0 (7)	48.0 (4)	8.0 (8)	8.3 (10)
	7	8.1 (3)	1.4 (5)	46.3 (7)	8.3 (8)	6.4 (6)
	14	8.1 (5)	0.8 (7)	46.3 (8)	11.0 (5)	5.3 (7)
	45	8.0 (3)	0.9 (9)	45.5 (9)	10.5 (7)	5.6 (8)
	80	8.1(3)	0.9 (8)	46.2 (7)	10.6 (8)	5.3 (9)
Non-mulched	0	7.9 (2)	1.0 (7)	48.0 (4)	8.0 (8)	8.3 (10)
	7	8.0 (4)	1.2 (6)	45.4 (5)	8.5 (6)	6.8 (8)
	14	8.0 (3)	0.8 (6)	44.4 (9)	10.0 (5)	5.6 (8)
	45	8.2 (4)	0.9 (5)	46.2 (8)	10.4 (6)	5.4 (7)
	80	8.1 (3)	0.9 (8)	46.9 (9)	10.6 (8)	5.5 (5)
Hipercalcic Calcisol						
	0	8.3 (3)	0.7 (9)	48.6 (5)	10.1 (9)	7.5 (13)
	7	8.5 (4)	0.9 (7)	45.4 (8)	12.1 (10)	4.9 (8)
	14	8.4 (4)	0.7 (6)	45.6 (8)	13.0 (6)	4.6 (9)
LDPE cover	45	8.2 (5)	0.7 (10)	45.4 (10)	12.8 (7)	4.2 (7)
	80	8.5 (3)	0.7 (6)	45.1 (7)	13.8 (8)	4.1 (8)
	0	8.3 (3)	0.7 (9)	48.6 (5)	10.1 (9)	7.5 (13)
	7	8.6 (2)	1.1 (5)	45.9 (8)	11.6 (9)	4.7 (6)
	14	8.5 (3)	0.6 (9)	45.9 (7)	14.2 (7)	5.1 (7)
	45	8.4 (5)	0.7 (10)	45.0 (8)	14.6 (6)	4.3 (9)
HDPE cover	80	8.5 (4)	0.7 (7)	46.1 (7)	14.2 (8)	4.5 (6)
	0	8.3 (3)	0.7 (9)	48.6 (5)	10.1 (9)	7.5 (13)
	7	8.3 (5)	0.9 (8)	46.5 (7)	13.1 (11)	5.1 (6)
	14	8.2 (3)	0.7 (8)	46.8 (9)	12.7 (7)	4.3 (8)
Non-mulched	45	8.3 (5)	0.7 (9)	47.1 (5)	13.8 (8)	4.4 (9)
	80	8.5 (3)	0.7 (5)	46.5 (4)	13.5 (9)	4.6 (6)

high temperatures and as the mesophilic organisms are killed and degraded during solarization, thereby liberating soluble substances into the soil.

Micronutrients have an important role to increase the yield and quality of crops although at requirement levels < 0.1%. Their availability in soil depends on parent material, landform, texture, pH, organic matter content, climatic condition, land use pattern and/or natural vegetation. DTPA-extractable micronutrient increased with the increase in OC content and Cation Exchange Capacity (CEC), and decreased with increasing pH, sand and calcium carbonate content as occurs when comparing the two soils studied. For microelements (especially Fe and Mn), a weak tendency but significant ($p<0.05$) of increase in their availability at the end of the study was observed in both cases as can be seen in figure 1 (third and fourth row). For Cu and Zn, a weak increase and decrease, respectively were observed along the experiments but no significant differences ($p<0.05$) were found between treatments (Table 2). Similar findings were found by Patricio et., [16] where the concentration of DTPA-Ext-Mn increased sharply due to solarization. Plastic-mulched soils frequently contain higher levels of soluble mineral nutrients than non-mulched soils as it has been demonstrated by some authors (Stapleton et al., [5], which found significant increases in NH4+-N, NO3--N, phosphorus, K+ and Cl-. According to Solovitch., [17], water-soluble Mn2+, Cu2+ and Fe3+ increased in most of the solarized soil studied, whereas DTPA-Ext-micronutrients (Fe, Mn, Cu, and Zn) did not exhibit a consistent trend of change [5].

CONCLUSION

Soil solarization, a mild heat soil treatment, enhances Ext-Mn, and Ext-Fe levels only slightly but not above toxic levels. Therefore, it could be a profitable and sustainable method for overcoming these DTPA-Ext-micronutrients deficiencies in some cases, although an addition of organic matter can be necessary after mulching. An increase in available mineral nutrients in soil as consequence of solarization, result in an increased plant growth, reducing consequently fertilization necessities. The increase in available mineral nutrients can be assigned to the mineralization of soil OM along solarization. This environmentally friendly technology is especially interesting for soil disinfection in sunny areas of the Mediterranean basin like southeast of Spain where more than 3000 h of sunshine can be yearly received.

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