Effectiveness of Soil Solarization with Polyethylene Sheets & Organic Manure to Control Weeds & Fungi & to Increase the Lettuce Yield

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Abstract–This experiment was conducted at King Abduaziz Agricultural Research Station at Hada Al-Sham. We investigated the effect of soil solarization with polyethylene sheets (100, 200 microns and uncovered soil) and organic manure (animal manure, cabbage leaves, date palm fronds, animal manure + cabbage leaves, animal manure + date palm fronds, cabbage leaves + date palm fronds, animal manure + cabbage leaves + date palm fronds) on some soil chemical characteristics, soil fungi population, weed growth and lettuce yield during two seasons (2009-2010). The treatments caused significant increase in the soil content of N, P and K with pronounced effect of the 100 micron sheet followed by 200 micron sheet over unsolarized soil. The polyethylene sheet (100 µ) significantly decreased the weed growth and fungal count cfu g^{-1} dry soil compared with 200 micron sheet and unsolarized soil. The 100 and 200 microns sheets significantly improved the lettuce yield up to 347.5 and 237.2 %, respectively, over unsolarized soil. Animal manure at 30 t ha^{-1} increased lettuce yield by 77.6 % compared with control. Thus, soil solarization with polyethylene sheet (100 µ) with animal manure is wise approach for sustainable control of weed and soil fungi and for improving lettuce yield.

Keywords- Solarization, polyethylene sheet, Organic manures, soil fungi, weeds, lettuce yield

INTRODUCTION

Soil solarization is a non-chemical disinfestations practice that provides excellent control of weeds and soil-borne pathogens with resultant increase in growth, yield, and quality of crops [1, 2]. Solarization involves covering of wet soil with clear plastic film, resulting in raised soil temperatures through passive solar heating that promote thermal inactivation of weeds and pathogens [3, 4]. Solarization induced certain biological and chemical changes in soil including microbial community alterations, temporary production of biotoxins and increases availability of plant nutrients [5]. Since relatively small increases in temperature can have a drastic effect on the time necessary for inactivating microbial pathogens [6] and weed propagules [7], increased soil heating during solarization may lessen the time required. Additionally, elevating soil temperature through non-solar means may make solarization viable in areas with cooler climates.

Soil solarization with transparent polyethylene sheets has been reported to reduce the N losses from soil [8, 9]. Stapleton [10] reported that maximum soil temperatures beneath transparent polyethylene cover were increased up to 6-13 ^{0}C over non-treated soil, subsequently, soil borne fungal and bacterial population densities were reduced up to 62-100 % in pre-plant experiments, and weed emergence was reduced up to 97-100 %. Soil solarization strongly reduced weed density and biomass in both greenhouse and field, therefore, improve crop yield [5, 9]. Soil solarization provides a good level of control over some important pests and weeds, while at the same time improves crop productivity in an environment friendly manner [11].

Organic fertilizers are essential for the proper development of crop plants as they offer rapid growth with superior quality of harvest. They serve as nutrient and source of energy for soil microorganisms [12]. The suitability and usefulness of animal manures and organic matter has been attributed to high availability of N, P and K content, and improvement of the physical properties of the soil as well [13, 14]. The increments in crop yields due to soil solarization and organic manure was reported due to various mechanisms such as increased nutrients uptake especially P, which has special effect on the plants physiology [15, 16, 17], water exploitation [18] and production of plant growth promoting substances [19]. This study was aimed to examine the effect of soil solarization with polyethylene sheets of different thicknesses and organic manures on some soil chemical and physical properties, fungal density and weed growth and subsequent effect on yield of lettuce during the two growing seasons.

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MATERIALS AND METHODS

The experiment was carried out at Agricultural Research Station of King AbdulAziz University at Hada Al-Sham 120 km northeast Jeddah city, during the 2009 and 2010 seasons.

Experimental Design

The experiment was implemented using the split plot design with three replications, where the polyethylene sheets thickness (uncovered, 100 and 200 microns) occupied the main plots and organic manures (animal manure, cabbage leaves, date palm fronds, animal manure + cabbage leaves, animal manure + date palm fronds, cabbage leaves + date palm fronds and animal manure + cabbage leaves + date palm fronds) at 30 t ha^{-1} as the sub-plots. Plot size was 3 × 4 m with 40 cm distance between each 2 lettuce rows. Recommended doses of N, P and K were applied to each plot at 435, 217 and 150 kg ha^{-1}, respectively. The drip irrigation system was used to irrigate the experiment.

Soil Analysis

The soil of experimental site was analyzed before and after covering the soil with the polyethylene sheets for its electrical conductivity (EC) using EC meter and pH using pH meter. The organic matter (OM) contents of soil samples were analyzed using Walkeley and Black method as mentioned by Jackson [42]. Total nitrogen (N) content of soil was determined with help of Kjeletec Auto1030. Total phosphorus (P) and potassium (K) were determined by following the method as described by Shelton and Harper [20]. The irrigation water and animal manure were also analyzed for these parameters.

Lettuce Planting and Collection of Data

Lettuce seedlings were prepared in the nursery, and were acclimatized for one month before being planted in the site. Lettuce seedlings were transplanted on December 30 in both seasons. At harvesting, ten plants were selected randomly and tagged from each subplot, and lettuce yield (t/ha) were determined. Weeding was carried out three times to determine the total fresh weight of weeds (t/ha) growing in each replicate during lettuce growth. The soil fungi population was determined before and after the experiment using the successive dilution method as described by Dhingra and Sinclair [21].

Statistical Analysis

The statistical analysis of the obtained data was carried out according to the type of the design using analysis of variance [22] and comparison of means using LSD (0.05), and the combined analysis was carried out for the two seasons using SAS 2000 software.

RESULTS

Lettuce Yield

The results (Table 1) showed significant effects ($p<0.01$) of the polyethylene covering and organic manure mixtures on lettuce yield (t ha^{-1}) during the two seasons. The interaction between polyethylene sheet and the organic manure treatments showed highly significant effects on lettuce yield during the two seasons. Significant improvement in lettuce yield was recorded with 100 micron sheet (21.04 and 16.91 t/ha) followed by 200 microns sheet (15.99 and 12.78 t/ha) in comparison with uncovered soil (11.26 and 8.87 t /ha) during both seasons. Among the organic manures treatments, maximum lettuce yield was obtained with AM + CL (23.17 and 20.84 t/ha) followed by the animal manure alone (17.99 and 15.41 t/ha), and the least yield was recorded with the DPF (9.45 and 6.65 t/ha) during the two seasons.

Weed Biomass

Table 1 showed significant effects ($p<0.01$) of the different polyethylene sheet thickness and the different organic manure mixtures on weed growth (t ha^{-1}) during the two seasons. The interaction between polyethylene sheet and the organic manure treatments showed highly significant effects on weed growth during the two seasons. Significant reduction in weed growth, as shown in table 2, was observed with 100 micron polyethylene sheet (0.29 and 1.95 t/ha) followed by the 200 micron sheet (2.135 and 5.002 t/ha) compared with uncovered soil (7.767 and 10.30 t/ha) during both seasons. Organic manures significantly suppressed the weed growth, especially, in soil amended with AM + CL remarkable weed suppression was observed with 1.004 and 3.86 t/ha weed biomass, secondly, the animal manure alone with 2.736 and 4.46 t/ha weed biomass during the seasons 2009 and 2010, respectively. While the DPF gave the significantly highest weed biomass with 5.728 and 8.19 t/ha during the seasons 2009 and 2010, respectively.

Effects of Soil Solarization on Soil Chemical Properties and Fungi Population

The soil solarization showed significant effect on soil pH, nutrient contents and fungi number however, non-significant effect was recorded in EC of post-solarized and pre-solarized soil. Table (2) showed that soil solarization led to significant increase in the soil nutrient contents of N, P and K from 0.12, 0.024 and 65.0 mg kg^{-1} in pre-solarized soil to 0.14, 0.029 and 69.33 mg kg^{-1}, respectively, in post-solarized soil. The number of fungi in the soil also significantly decreased with solarization from 4.4×10^4 to 2.6×10^4 colony forming unit (cfu) g^{-1} dry soil.

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Table (1): Means of lettuce yield (t/ha) and weed weight (t/ha) under effect of solarization treatments and different organic manures as combined effect of the two seasons.

Treatments	Lettuce yield (t/ha)		Weed weight (t/ha)	
	2009	2010	2009	2010
Polyethylene sheets				
Uncovered soil	11.26 c	8.87 c	7.76 a	10.13 a
Polyethylene (100 µ)	21.04 a	16.91 a	0.29 c	1.95 c
Polyethylene (200 µ)	15.99 b	12.78 b	2.13 b	5.00 b
Manures				
Animal manure (AM)	17.99 b	15.41 b	2.73 d	4.46 e
Cabbage leaves (CL)	15.19 c	13.5 c	3.37 c	6.15 b
Date palm fronds (DPF)	9.45 d	6.95 e	5.72 a	8.19 a
AM + CL	23.17 a	20.84 a	1.00 e	3.86 f
AM + DPF	13.00 c	10.94 d	3.94 c	5.89 c
CL + DPF	13.16 c	10.9 d	4.59 b	6.13 b
AM + CL + DPF	14.17 c	11.44 d	2.85 d	5.16 d
Significance				
Polyethylene covering (A)	**	**	**	**
Organic manure mixtures (B)	**	**	**	**
A x B	NS	**	**	**

Means with the same letter are not significantly different according to LSD at $p \leq 0.05$
NS, not significant at $p \leq 0.05$
** significant at $p \leq 0.01$

Effects of Polyethylene Sheet Thickness on Soil Chemical Properties and Fungi Population

Different polyethylene sheet thicknesses led to significant changes in soil EC, nutrient status and fungal number compared with the uncovered soil (Table 2). However, both thicknesses of polyethylene sheet have non-significant effects on soil pH compared with uncovered soil. Polyethylene sheet (100 µ) significantly reduced the soil EC from 4.54 in the uncovered soil to 3.44 dS m^{-1} under the 100 microns sheet. The significant improvement in soil content of N, P and K was observed under polyethylene sheet 100 µ thickness (0.14, 0.034, 70.83 mg g^{-1}) followed by 200 µ polyethylene sheet 0.13, 0.024 and 67.83 mg g^{-1} compared with uncovered soil (0.12, 0.022, 62.83 mg/g). The different polyethylene thicknesses also significantly reduced the number of soil fungi from 3.8×10^4 cfu g^{-1} dry soil in the uncovered soil to 3.2×10^4 cfu g^{-1} dry soil under the 100 microns sheet, and 3.5×10^4 cfu g^{-1} dry soil under the 200 microns sheet.

Effects Organic Manures on Soil Chemical Properties and Fungi Population

Table (2) illustrated that the least soil pH value was recorded under animal manure (7.77) followed by animal manure + cabbage leaves + date palm fronds (7.81) while highest soil pH value was observed under date palm fronds (8.06). Organic manures significantly influence the soil EC, especially, the effect of date palm fronds and cabbage leaves manure was pronounced in reducing the EC value to 2.84 and 2.96 dS m^{-1}, respectively. The maximum improvement in soil contents of N, P and K were observed under the animal manure with 0.14, 0.035 and 71.5 mg g^{-1} dry soil, respectively, followed by animal manure + cabbage leaves with 0.14, 0.03 and 70.83 mg g^{-1} dry soil, respectively. The least concentrations of N, P and K in the soil were recorded from the date palm fronds with 0.121, 0.021 and 59.83 mg/g dry soil, respectively. The least soil fungi number was attained in soil amended with the animal manure + cabbage leaves 3.307×10^4 cfu g^{-1} dry soil followed by cabbage leaves alone 3.439×10^4. While the significantly higher fungi number was recorded under the date palm fronds 3.78×10^4 cfu g^{-1} dry soil. Table (1) indicated that the interaction of solarization, polyethylene sheet thickness and organic manures have non- significant effect on soil chemical properties and fungi number according to LSD ($p \leq 0.05$).

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Table (2): Effect of solarization, polyethylene sheet thickness and organic manures on means of pH, EC, soil content of N, P, K and fungi numbers

Treatments	pH	EC (dS m^{-1})	N (%)	P (%)	K (mg kg^{-1})	Fungi (cfu g^{-1}) 10^4
Solarization						
Pre-solarization	8.29 a	4.16 a	0.12 b	0.024 b	65 b	4.448 a
Post-solarization	7.5 b	4.16 a	0.14 a	0.029 a	69.33 a	2.682 b
Polyethylene thickness						
Uncovered soil	7.91 a	4.54 a	0.12 c	0.022 c	62.83 c	3.864 a
Polyethylene sheet (100 µ)	7.87 a	3.44 b	0.14 a	0.034 a	70.83 a	3.292 c
Polyethylene sheet (200 µ)	7.90 a	4.5 a	0.13 b	0.024 b	67.83 b	3.526 b
Manures						
Animal manure	7.77 c	6.75 a	0.14 a	0.035 a	71.5 a	3.643 c
Cabbage leaves	8.01 a	2.96 d	0.125 d	0.023 d	65.83 e	3.439 d
Date palm fronds	8.06 a	2.84 d	0.121 c	0.021 e	59.83 g	3.788 a
Animal manure+ Cabbage leaves	7.87 b	4.63 b	0.14 a	0.03 b	70.83 a	3.307 e
Animal manure+ Date palm fronds	7.86 b	4.02 c	0.13 c	0.027 c	70.3 a	3.715 b
Cabbage leaves+ Date palm fronds	7.87 b	3.94c	0.12 d	0.024 d	61.5 f	3.725 b
Animal manure+cabbage leaves+date palm fronds	7.81 c	3.99 c	0.13 c	0.025 d	70.16 c	3.306 c
Significance						
Solarization (T)	**	NS	**	**	**	**
Polyethylene (S)	NS	**	**	**	**	**
TxS	NS	NS	NS	NS	NS	**
Organic material (M)	**	**	**	**	**	**
TxM	NS	NS	NS	NS	NS	**
SxM	NS	NS	NS	NS	NS	NS
TxSxM	NS	NS	NS	NS	NS	NS

Means with the same letter are not significantly different according to LSD at $p \leq 0.05$
NS, not significant at $p \leq 0.05$
** significant at $p \leq 0.01$

DISCUSSION

The results obtained from this study revealed the importance of soil solarization using transparent polyethylene sheets along with organic manure for increase of lettuce yield, soil nutrients and decrease in weed growth and number of fungi. Crop yield increased due to the reduction in weeds and soil borne pathogens [23], and increase availability of soil nutrients [8, 9]. However, it has also been suggested that solarization can promote plant growth independently of this effect as recognized by the "increased growth response" (IGR) theory [24]. A number of factors, either alone or in combination, may underlie this phenomenon. Chief among these are likely to be the stimulation of beneficial soil microflora, an improvement in soil structure and the more rapid release of mineral nutrients [24, 4, 23]. Our results agree with the results of other researchers, as they found increase in crop yield and control of weeds and pathogens due to soil solarization [25, 26, 27, 28]. Previous studies suggested that soil solarization increased the crop yield due to improved NH_4-N availability in soil [8, 9]. According to these authors soil solarization with polyethylene sheet and organic manure enhanced N mineralization of organic matter due to high temperature, thus, build up NH_4-N in soil. Chen et al. [8] related the accumulation of NH_4-N in soil with decrease in nitrifying bacteria due to soil solarization. Solarization with polyethylene amended with organic manure was found positive in lettuce yield and soil nutrient contents compared to the use of each separately. Our results are in agreement with the results of other researchers [29, 30, 26, 27, 11, 31].

Our results showed positive effect of soil solarization on weed control which corroborates those of many other studies [9, 32, 33, 34]. The strong reduction of weed cover was observed with SS with plastic sheet of 100 micron thickness coupled with animal manure and cabbage

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manure. This reduction might be due to the high soil temperatures in the surface soil layers under polyethylene sheet cover. Temperature might probably higher due to higher SOM and moisture content in the solarized soil than non-solarized soil which improved heat conductivity of soil [34]. Also, organic manures with narrow C:N ratio were reported to produce phytotoxins such as ammonia that can reduce weed populations [35, 36].

As demonstrated in various studies, the soil solarization decreased the soil borne pathogen diversity including bacteria and fungi [32, 11, 37] which cause root diseases during germination [29, 26]. In this study, soil solarization with 100 micron polyethylene sheet amended with the organic manure mixture (animal manure + cabbage leaves) and (animal manure + cabbage leaves + date palm fronds) significantly reduced soil fungi numbers. The results are supported by finding of Bonanomi et al. [33] where soil solarization with both biodegradable and plastic films significantly decreased fungal and bacterial band richness. Among the solarizing treatments, biodegradable film showed the most negative effect on fungal diversity. The reduction in fungi numbers under amended solarized soils may be due to the accumulation of some toxic gasses. It is well documented that soil temperature rise under solarized soil amended with animal manure leads to emission of some gasses like ammonia or sulfur dioxide which negatively affect the fungi count [38, 39, 40, 25, 26]. Our results indicated that soil solarization with polyethylene sheet and organic manure has significant effect on soil nutrient contents of nitrogen, phosphorus and potassium. These results are in conformity with the results of several workers [41, 4, 37]. Sofi et al. [37] reported that Ca, Mg, N, P, K and C recorded in solarized soil was higher than in non-solarized.

CONCLUSION

Soil solarization using polyethylene sheets (especially 100 microns thickness) and organic manure mixtures (t/ha) (especially, animal manure and animal manure + cabbage leaves) when applied alone or amended together significantly increased lettuce yield, reduced weed growth and fungi count, and increased soil content of N, P and K. It is recommended to solarize soil with 100 microns transparent polyethylene sheets amended with organic manure to control of soil fungi and weeds, and to increase the lettuce yield.

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