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Effect of Solarization with Polyethylene Sheets Amended with Animal Manure on Soil Nutrients, Fungi, Weed Growth and Yield of Eggplant (*Solanum melongena* L.)

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Abstract A field experiment was conducted in the Agricultural Research Station of King Abdulaziz University at Hada Al-Sham, 120 km Northeast of Jeddah, to evaluate the effect of soil solarization with polyethylene sheets one and two layers) amended with 30 t/ha ofanimal manure (AM) on the soil content of nitrogen (N), phosphorus (P), potassium (K), soil pH,electrical conductivity (EC), number of fungi and weed growth pre– and post– solarization. Furthermore, yield components and yield of eggplant during two seasons (2015-2016) was investigated. The N, P and K were significantly increased pre- and post-solarization.Soil fungi population and weed growth were significantly increased for pre-solarization but were significantly reduced post-solarization, with significant domination of the two layers over the single layer. No significant effect of solarization or AM on soil EC and pH but the EC was reduced under the two layers compared to the single layer. The number of flowers and fruits, the fruit weight and fruit yield increased by 98-68%, 79.3-51.7%, 145.9-90.7%, and 145.9-91% respectively under the two and one layer sheets compared to the uncovered soil. The double layers-polyethylene sheets exceed the one layer sheets in all studied parameters. The flower and fruit numbers, fruit weight and yield were also increased with the addition of 30t/ha of AM at rates of 47.6%, 33.3%, 33.3% and33.7% respectively. The second season exceeds the first season in number of flowers and fruits, in fruit weight and yield. It is recommended to cover soil with two layer transparent polyethylene sheets rather than one sheet, and to amend it with 30t/ha of AM for better yield of eggplant and control of weed and soil fungi.

Keywords: *solarization, polyethylene, sheets, animal manure, fungi, weed, eggplant*

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1. Introduction

Soil solarization combined with organic fertilizers is now practicing all over the world as a friendly practice for eradication of soil-borne diseases, weed control, improvement of soil chemical structure and increasing of plant growth and yield. Covering the soil with polyethylene and plant straw controlled soil pests and grasses and increased crop yield and led to early maturation in some crops [1,2] due to it conserves soil moisture, controlled grasses and gave fast plant growth and high yield of peanut [3], and is most probably due to increase in the concentration of nutrients that are released in the soil after covering [4,5,6]. Cabbage growth rates under soil solarization amended with AM exceeded the uncovered (control) by 231.6%, 215.6%, 239.6%, 222.7%, 235.6%, 210.8% and 236.6% as regard head length, head diameter, rotation index, stem length, stem diameter, inner stem length and root length, and Cabbage yield increased at rates of 39.0 and 17.1% while Eggplant fruit yield increased at a rate of 68.1% and 37.6% respectively compared to the control Hamooh and Al-Solaimani [7,8]. Soil solarization with organic amendment significantly eradicated *Fusariumoxysporum* wilt in a shorter time due to increases in the acidified soil pH and reductions of the soil electrical conductivity [9]. Soil solarization is a non-chemical method of soil disinfection which is successful in pathogen control and nematode, insect, and weed management [10]. It was found by Gilardi *et al*. [11] that soil solarization combined with organic amendments (SS-OA) greatly controlled soil-borne pathogens and is considered one of the most effective methods because it is ecologically friendly and is associated with low costs. Mauro *et al*. [12] used soil solarization with three levels of organic supplementation (0, 0.35 and 0.7 kg m^{-2}), to eradicate broomrape weed seeds which is responsible for high yield losses in tomato, and complete seed bank eradication was achieved after the second year, and tomato yield increased from 3.43 kg $plant^{-1}$ to (6.58 kg FW of plant). The success of soil solarization amended with organic matter in eradicating weeds is because of the

high raise in temperature within the soil [13], due to release of high volatiles [14], and increased minerals availability and improved crops yield performances [15,16,17]. Soil solarization led to control of diseases and weed and was usually accompanied by an increase in plant yield [18,19,20]. Barbour *et al*. [21] found that addition of fertilizers and organic amendments, specially composts or chicken manure, can suppress soil-borne plant pests. It was found by Nasef *et al*. [22], Ozoles-Hampton [23], and Al-Solaimani *et al*. [24] that soil solarization with plastic films and addition of organic materials increases nutrients in the soil, specially N, P, K and makes them available for plants. Zayed *et al*. [25] found significant increase in pepper total yield (75.645 kg/plot) total number of fruits (529.3 kg/plot) and fruit length and diameter with soil solarization compared to control. Lira-Saldivar *et al*. [26] obtained significant increase in melon yield up to (29.39 t/h) compared to control with (18.79 t/h) due to soil solarization. Hamooh and Al-Solaimani [7,8] observed significant increase in soil content of NPK, significant reduction in fungi population and weed fresh weight, and improvement of Cabbage head, stem and root characters, with increase in yield up to (26.9%) ,and similar increase in eggplant fruits and yield weight at rates of 65.4%-60.1% and 65.56% due to soil solarization with transparent polyethylene sheets amended with organic matter. Al-Solaimani *et al*. [27] obtained significant increase in seed yield compared to control with 3.89, 2.90, 2.62, 2.03 t/h under the effect of 100µm, 250µm, 500µm polyethylene thickness and control respectively due to soil solarization with mixture of organic fertilizers. The number of soil pathogens was reduced from 89-100% under soil. Soil solarization, manured with chicken compost gave high yield of lettuce and tomato than either treatment alone [28].

According to some researchers [29,30] solarization increases the current soil fertility by enhancing processes of mineralization of organic matter incorporated while decreasing pH and increases the total nitrogen and available phosphorus, an increase of soluble organic matter is produced in its composition, expressed by the considerable increase in the concentration of nitrate and ammonia by the decomposition of organic matter, thus increasing concentrations of Na, K, Ca, Mg and Cl.

This study was aimed to examine the effect of soil solarization with one and two layers of polyethylene sheets, and animal manure at a rate of 30 t/ha, applied singly or incorporated together, on some soil chemical and physical properties, on densities of fungi population and weed growth, and on yield and yield components of eggplant (*Solanummelongena* L.).

2. Materials and Methods

The experiment was carried out in the Agricultural Research Station of King Abdullaziz University at Hada Al-Sham 120 km North-east Jeddah city, during two seasons 2014-2015 and 2015-2016.

2.1. Experimental Design

The experiment was implemented using split plot design with randomized complete block design with three replications, with polyethylene sheets (uncovered, one layer, double layers) representing the main-plots, and the animal manure (AM)(0 and 30t/ha) the sub-plots.

Soil analysis:

The soil experimental site was analyzed before and after covering the soil with the polyethylene sheets at both depths, 0 – 15 and 15 – 30cm, for its electric conductivity (EC), pH using pH meter, the organic matter using Pansu and Gautheyrou [31], total nitrogen (N) using Kjeletec Auto1030, total phosphorus(P) and potassium(K) using Shelton and Harper [32] method. Also the number of soil fungi was determined using the successive dilution method. These parameters were also analyzed in the irrigation water and in the added AM.

2.2. Preparation of the Experimental Site

The soil was ploughed twice at a depth of 30cm , leveled and then divided into 18 plots each(3x3m), 6 plots for each replicate, each 2 plots for the 2 soil covering treatments. Each covering treatment contained 2 treatments of AM rates(0, and 30 t/ha). Third of the area was covered with one layer transparent polyethylene sheets, and the other third by 2 layer sheets, 10microns in thickness, while the third layer was left uncovered. Each plot was divided into 3 rows, 70cm between rows and 60cm between plants. The plots were fertilized using 217 kg/ha P, 150 kg/ha K_2O and 435 kg/ha urea at three rates, and drip irrigation was used.

2.3. Eggplant Planting and Sample Collection

Eggplant seedlings were prepared in the nursery , and were acclimatized for one month before being planted in the site.

Five plants were selected randomly from each plot after maturation, to take the different measurements (flower number, fruit number, fruit characteristics, fruit weight, fruit yield, and total yield)

Total yield:

All the remaining fruits in the plots were collected, and the total yield was determined in kg/ha for each treatment during both seasons.

2.4. Weed Growth

The total fresh weight of weed growing in each replicate was determined after being collected three times by hand during eggplant growth. Soil temperature degrees were recorded in the uncovered and covered soil at 5,15 and 30 cm depth after 4, 8 and 12 weeks (Figure 1).

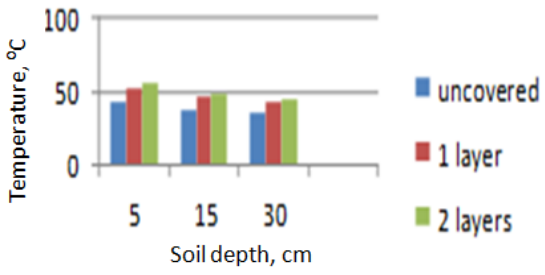

Figure 1. Maximum temperature for single and double layer polyethylene sheets

2.5. Statistical Analysis

The statistical analysis of the data was carried out according to the type of the design (ANOVA) according to El-Nakhlawy [33] running the analysis of variance, and comparison of means using LSD 0.05, and combined analysis was carried out for the two seasons using SAS2000.

3. Results

3.1. Soil Chemical Analysis and Fungi Population

3.1.1. Before Soil Solarization

The results (Table 1) showed no significant effect of the addition of AM on the soil EC and pH in spite of the fact that the EC increased but not significantly with the addition of AM. The soil content of N, P and K increased and the number of fungi decreased respectively with the addition of animal manure. Number of soil fungi and EC decreased with increase in soil depth from 0-15 to 15-30 cm, while no effect was observed by the soil depth on the content of N, P and K (Table 1).

3.1.2. Post Soil Solarization

There were significant increases in N, P and K and a decrease in the fungi numbers with solarization and addition of 30 t/ha AM, and the effect was greater under the two layers compared to the one layer sheets (Table 2 and Figure 2). The soil pH was not affected by soil covering, but significantly decreased with addition of AM. On the other hand the EC was not affected significantly with solarizaion or AM, but was significantly reduced with increase in depth from 0-15 to 15-30 cm. Soil contents of N, P and K were not affected by soil depth, but fungi numbers were significantly reduced by increase in soil depth from 0-15 to 15-30 cm.

3.2. Weed Growth

Weed growth (Fresh weight) was significantly reduced by soil solarization, with a domination of the 2 layers giving a reduction of 61.5% over the one layer with 39.8% compared to the uncovered soil (Table 3). Weed fresh weight was also reduced but not significantly when the solarized soil was amended with 30 t/ha AM, reaching a reduction of up to 49.6% compared to the control. High weed growth occurred during the second season than the first season.

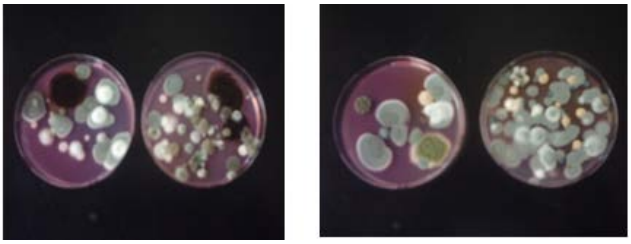

Figure 2. Number of fungi grown on petri dishes, on the right pre soil solarization and left after soil solarization

Table 1. Effect of animal manure (AM) rates and soil depth on means of pH, EC, soil content of N, P, K and fungi number pre soil solarization

Characters		pH	EC (d mose/m)	N(%)	P(%)	K mg/kg	Fungi No/g dry soil
AM (t/ha)	0	7.86 a	2.26a	0.10 b	0.02 b	56.89 b	46631 b
	30	7.78 a	2.56a	0.14 a	0.03 a	86.67 a	67333 a
Depth (cm)	0-15	7.85a	2.85 a	0.13 a	0.02 a	70.89 a	66853 a
	15-30	7.79 a	1.97 a	0.12 a	0.02 a	72.67 a	47111 b

Means with similar letters do not have significant differences between them at 5%.

Table 2. Effect of animal manure (AM) rates and soil depth on means of pH, EC, soil content of N, P, K and fungi numbers post soil solarization

Characters / Source of difference		pH	EC (d mose/m)	N (%)	P (%)	K (mg/kg)	Fungi No/gm dry soil
Soil cover Polyethylene	Uncovered	7.7a	1.7a	0.06b	0.018b	55.91c	28896a
	One layer	7.7a	2.01a	0.09b	0.025ab	74.66b	16758b
	double layers	7.7a	1.6a	0.1b	0.029a	95.33a	7943cb
AM (t/ha)	0	8.5a	1.6a	0.07b	0.022b	69.62b	17028a
	30	6.96b	1.8a	0.12a	0.029a	93.25a	12408b
Depth(cm)	0-15	8.5	2.3a	0.101a	0.027a	87.29a	17431a
	15-30	6.96b	1.1b	0.09a	0.025a	85.58a	12005b

Means with similar letters do not have significant differences between them at 5%

Table 3. Effect of solarization and animal manure (AM) addition on weed fresh weight

characters	Season			Solarization			AM t/ha
	First	Second	Uncovered	One layer	Two layers	0	30
Fresh weight kg/9m^2	0.5^b	3.1^a	2.99^a	1.8^{ab}	1.15^b	2.6^a	1.3 b

Table 4. Means of number of flowers and fruits, fruit length and thickness, fruit and yield weight of eggplant under soil solarization and different AM rates during two seasons(2014-2015/2015-2016)

Characters / Source of difference	Flower number Per 5 plants	Fruit number per 5plants	Fruit characteristics(cm)		Fruit wt. g/5plants	Yield Kg/ha
			Length	Thickness		
Season						
First 2011	63.64b	29.22b	8.51a	6.88[a]	3499.6b	8749b
Second 2012	91.91a	54.58a	8.14a	5.37[b]	8430.9a	21077a
Solarization						
Uncovered	50.19b	29.24c	5.7c	4.37[c]	3335.4c	8338c
One layer	83.9a	44.31b	8.36b	6.1b	6359b	15898b
2 layers	99.23a	52.15a	10.91a	7.88[a]	8201.04a	20503a
Animal manure (t/ha)						
0	62.5b	36.14b	6.71b	4.98[b]	5109.2b	12773b
30	93.04a	47.66a	9.93a	7.27[a]	6821.3a	17053a

Means with similar letters do not have significant differences between them at 5%.

3.3. Yield and Yield Components

3.3.1. Yield Components

There were significant increases in yield components (number of flowers, number of fruits, fruit characters, fruit weight) under soil solarization, with the domination of the 2 layer sheets over the one layer sheets in all these traits. There were significant increases in the number of flowers and fruits, fruit length and thickness, fruit weight and yield by 98 and 68%, 79.3 and 51.7%, 100 and 60%, 80.3 and 40.3, 145.9 and 90.5% and 144.1 and 90.0% under the 2 and one layer sheets, respectively compared to the uncovered soil. Addition of 30 t/ha AM significantly increased number of flowers and fruits, fruit length and thickness and fruit weight by 47.9%, 33.3%, 50%, 53.3% and 33.3% respectively (Table 4).

3.3.2. Yield

The total eggplant yield increased significantly under the soil covered by the double layer sheets at a rate of 145.9% and under the one layer sheets at a rate of 90.7% compared to the uncovered soil (control). Consequently eggplant yield was significantly increased with addition of 30 t/ha AM up to 33.3% (Table 4).

4. Discussion

4.1. Soil Chemical Analysis and Fungi Population

4.1.1. Pre-solarization

The increase in the soil N, P and K with addition of animal manure, agree with the findings of Al-Solaimani *et al*. [4], and Deboszet *al*. [34].Soil EC and pH were not affected significantly with AM, but fungi numbers increased significantly with AM addition. Consequently fungi population and EC were reduced with increase in soil depth from 0-15 to 15-30cm, with no significant effect of soil depth on the soil N, P, K and pH. Sunbol [35] also found reduction in fungi population with soil depth from 10 to 20 cm, in uncovered soil with AM additions.

4.1.2. Post-soil Solarization

The significant increase in the soil N, P, K and decrease of fungi population and weed growth by polyethylene sheets covering is due to the rise in temperature degrees especially under the two layers (Figure 1). found increase in soil temperature degrees under the double layer sheets compared to the one layer, and also in the covered soil compared to the uncovered. Works carried out on soil covered with polyethylene sheets by many researchers indicated significant reduction in the numbers of the microorganisms. Stapleton and DeVay, [36,37], and Ristaino *et al*. [38] found significant reduction in population of Agrobacterium sp., Fluorescent pseudomonads, Gram-positive bacteria and fungi. Sunbol [35] detected complete eradication of the fungi Pythium and Fusarium from the soil after2 weeks of solariztion, and the total fungi numbers were reduced at a rate of 99% in the soil depth up to 10cm compared to78% at the depth of 20cm. Sadik*et al*. [39] found significant reduction in the population of the fungi *Penicilliumexpansum*, *Aspergillusflavus*, A. terreus in the solarized soils compared to the uncovered soils, and many other researchers [1,2,10,11].

The reduction in fungi numbers under AM amended solarized soils may be due to the accumulation of some toxic gasses. Gamliel*et al*. [40] said that soil temperature rise under solarized soil amended with AM leads to emission of some gasses like ammonia or sulphate compounds gasses, and the gasses are trapped under the sheets to produce negative effects on fungi. Many researchers have reached this result [2,13,41,42,43].

Gamliel et al. [40] and Stapelton [44] detected reduction in weed growth under AM amended solarized soil and attributed this to the high rise in temperature that caused emission of toxic gasses which suppressed weed seed germination. It was found by Benliogl*et al*. [2], Sunbol and Al-Fasi [43], and Al-Kamsan [45] that significant reduction in weed fresh weight under soil cover amended with AM. Sunbol and Al-Solaimani [1] found significant reduction in growth of Amaranthus, *Cyperusrotundus*, *Sonhusoleracous*, and many other grasses with soil solarization with polyethylene sheets amended with chicken manure.

4.2. Yield and Yield Components

The significant increase in eggplant yield and yield components after covering the soil with polyethylene sheets and amendment with AM can be attributed to many factors, like the rise in soil moisture content, the significant reduction in soil fungal populations, the increase in the available plant nutrients, the improvement of soil characteristics and reduction of weeds in the soil. These factors made the soil more favorable and enhanced better eggplant growth and yield. Many research papers have reported increases in plant height, dry weight and yield in solarized soil compared to the uncovered soil [4,18,19,20,46,47,48]. It was found by Ahmad *et al.* [46] that better growth and grain yield of corn planted under solarized soil than uncovered soil.Solarized soil gave significant increase in cabbage and lettuce growth and yield compared to the uncovered soil in Egypt.Abdullah *et al*. [47] and Minito [49] found an increase in tomato, lettuce and cucumber yield under solarized soil, due to the control of the disease causing fungi like *Fusarium, Sclerotium, Verticillum*.

5. Conclusion

Soil solarization by one and two layers polyethylene sheets and AM at a rate of 30 t/ha, when applied singly significantly affected the chemical characteristics of the soil, its fungi population, weed growth and eggplant yield components and yield. And when the soil solarization was amended and incorporated with 30t/ha AM the effects on these studied parameters were more pronounce. There were significant increases in soil contents of N, P, K, and significant reduction in fungi population in the soil, and in weed growth. No significant effects were noticed in EC and pH due to soil solarization and AM additions, but the EC was reduced under the 2 layer sheets compared to the one layer. Eggplant yield components (flower numbers, fruit numbers, fruit length and thickness, fruit weight) and yield increased significantly with soil solarization and addition of AM during the two seasons. Covering the soil with transparent double layers polyethylene sheets dominated covering the soil with one layer sheets in all studied parameters, and also the addition of AM at a rate of 30 t/ha dominated the 0 t/ha. The season has no significant effect on all cabbage yield studied parameters.

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