Hebron University

College of Graduate Studies

Master Program in Plant Protection

Enhanced Soil Solarization against Tomato Fusarium Diseases in the Uplands

By

Riziq Mohammad Ghyada

Supervisor

Prof. Dr. Radwan Barakat

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Protection, College of Graduate Studies and academic Research, Hebron University, Hebron- Palestine.

2015

Enhanced Soil Solarization against Tomato Fusarium Diseases in the Uplands

By

Riziq Mohammad Ghyada

This thesis was defended successfully on 2014 and approved by:

Examination Committee

Signature

- **Prof. Dr. Radwan Barakat (Supervisor)**
- **(Internal Examiner)**
- **(External Examiner)**

Acknowledgement

First of all, thanks to Allah for granting me strength to live and work on this research.

I deeply thank Prof. Dr. Radwan Barakat, without his endless help, advice, and supervision this work wasn’t possible .

I also thank my colleagues and friends in the Faculty of Agriculture for their support and advices. Special thanks to Mohammad Al Masri for his support

Finally, I would like to thank my family, Mohammad my father, Fatima my mother, Siham my wife, brothers and sisters for their endless love, appreciation and support.

CONTENTS

List of Figures

List of Tables

List of Acronyms

CFU	Colony Forming unit
cm	Centimeter
CRD	Completely Randomize Design
DW	Distilled Water
EPPO	European and Mediterranean Plant Protection Organization
EVA	Ethylene-vinyl acetate
FOL	*Fusarium oxysporum* f. sp. *Lycopersici*
FORL	*Fusarium oxysporum* f.sp. *radices lycopersici*
g	Gram
GPA	Glucose Peptone Agar
GPAD	Glucose Peptone Agar Dodine
LC_{50}	Lethal concentration required to kill 50% of insect pest
LSD	Least Significant Difference
mg	Milligram
ppm	Part per million
PVC	Polyvinyl chloride
RH	Relative humidity
SDW	Sterile distilled water
VOCs	Volatile organic compounds

Abstract

Soil solarization against tomato wilt (*Fusarium oxysporum* f. sp. *Lycopersici*) tomato crown and root rot (*Fusarium oxysporum* f. sp. *radices-lycopersici*) were conducted for seven weeks in the summer 2011 and 2012 in Al-Aroub Agricultural Experimental Station, located in the southern mountains of the West Bank, Palestine. Double polyethylene sheets combined with 10% chicken organic manure (DPE+OM), Double polyethylene sheets (DPE) and regular polyethylene sheets (PE), were compared for their effects on soil temperature, pathogens populations, disease severity, and plant growth. Results showed that in comparison to the control, DPE+OM, DPE, and PE treatments increased the mean maximum soil temperatures by 15.2, 10.5, and 6.3°C, respectively, in 2011 and by 16.4, 12.5, and 9.2° C respectively, in 2012. The pathogens population were highly reduced (97%) under the DPE+OM treatment in both seasons and to a lesser extent by the other treatments. In addition , solarization completely suppressed the diseases under the DPE and DPE+OM treatments in both seasons. Furthermr, it stimulated the plant fresh weight up to 600% under the DPE+OM due to the increase of available nitrogen tow forms, and major cations. The results clearly revealed that using double layer in combination with 10% of chicken manure soil amendment before treatment or the use of double layer sheets alone enhanced the efficiency of soil solarization in the uplands

1. Introduction

1.1 Background

Soil solarization is a hydrothermal soil heating of moist soil covered with clear polyethylene sheets during the summer period. With solarization, soil temperatures reach levels that are lethal to many plant pathogens and pests (Stapleton and DeVay, 1984). The process also results in a series of changes, which affects biological and physiochemical properties of the soil that improve the growth and development of plants (DeVay,1991). Mashingaidze and Chivinge, (1998) described solarization as the enhancement or catchment of solar or sun's radiant energy to heat up the soil to kill the weed seeds and or seedlings, plant pests and disease propagules. Slarization is achieved by covering soil with clear or black plastic film during the hot dry season, which raises soil temperatures to levels, that are lethal or injurious to many plant pathogens, pests and weeds. Soil solarization is therefore, an approach to soil disinfestation which uses passive solar heating of moist soil mulched with plastic sheeting (usually transparent polyethylene). Although the execution of solarization is simple, the overall mode of action can be complex, involving a combination of several interrelated processes which occur in treated soil and result in increased health growth, yield, and quality of crop plants (Katan, 1987; Stapleton and DeVay, 1995; Stapleton, 1997). Solarization has been shown to successfully manage bacterial and fungal pathogens (Hartz et al., 1993; Shlevin et al., 2004), weeds (Standifer et al., 1984; Patterson 1998), and nematodes (Chellemi et al., 1993; McSorley et al., 1999; McGovern et al., 2002). Biological, chemical and physical methods of soil treatments have been used before planting to reduce inoculum density or disease potential of pathogens in the soil. Chemical soil disinfection is mainly accomplished through chemical fumigation. Fumigation with major biocides though effective and commonly used in most parts of the world in some crops, proved to be hazardous to the environment and expensive (Katan et al. 1976).

1.2 Principle of solarization

The mechanism of soil solarization in reducing soil borne pathogens and pests is attributed to the greenhouse effect, elimination of evaporation from the soil and other mechanisms (Katan, 1980). DeVay (1995) highlighted that the duration of soil solarization is important since the effectiveness of the technology is time and temperature dependent. Stapleton (1991) has also reported that many soil-borne pathogens and weeds were adequately controlled by 4-8 weeks of solarization at temperatures above 40°C. The greenhouse effect is produced by the difference in permeability of two categories of radiation: solar and terrestrial radiation. To produce maximum greenhouse effect and to act effectively as a suntrap, the ideal material should be transparent to solar radiation (280 to 2500 nm) but completely opaque to terrestrial radiation (5000 to 35000 nm). In addition, Polyethylene mulch reduces heat convection and water evaporation from the soil to the atmosphere as a result of the formation of water droplets on the inner surface which reduces its transmissivity to long wave radiation, resulting in better heating of the soil (Brown, et al. , 1991).

1.3 Factors influencing effectiveness of soil solarization

The effectiveness of soil solarization in disinfecting soil is directly related to moisture, wavelength transmittance and thickness of plastic covering sheets, intensity of irradiance, day length, air temperature and soil preparation prior to the covering with the plastic sheets (De Vay, 1995).

1.3.1. Soil Temperature

Soil temperature is the most important variable in the process of soil solarization. For mesophylic organisms, a temperature threshold of about 37˚C is critical. The accumulation of heat effects at this or higher temperatures over time is lethal. With increasing temperature, less time is required to reach a lethal combination of time and temperature. During solarization, soil temperatures are achieved which are lethal to many plant pathogens and pests and also cause complex changes in the biological, physical and chemical properties of the soil that improve the growth and development of plants (DeVay et al., 1990).

Organisms sensitive to high soil temperatures, which occur during solarization, have a greater amount of unsaturated cellular lipids than thermo tolerant or thermophylic organisms. Thus, mesophilic organisms, which do not survive the high temperatures in solarized soil, have lower melting fatty acid in their membrane lipids and lower phase transition temperatures for the lipids (DeVay et al.,(1990). DeVay, (1991), reported that depending on soil depth, maximum temperatures of solarized soil in the field are commonly between 42 to 55˚C at the 2.5 cm depth and range from 32to 36C at greater depths. using loosely stretched plastic mulch found consistently higher soil temperatures at 2 cm depth under the clear plastic than the black plastic, but the temperatures generated were not high enough to affect viability of weed seeds resident in the soil layers near the surface Mashingaidze et al., (1996). Results obtained in this research suggested that solarization could be an effective method of sanitizing the soil of weed seeds, disease and pest propagules, if the plastic mulches are laid on the soil surface for the duration of the hot dry part of the season, from September to early November.

Further studies carried out by Jacobsohn et al., (1980) showed that in all cases, soil temperatures in plastic mulched plots were higher than in the non-mulched ones. On extremely hot days, soil temperatures in the top layer of the clear plastic mulched plots reached 56 ˚C. Mansoori and Jaliani, (1996) reported maximum average soil temperatures of 31˚C and 44 ˚C in non-solarized and solarized soil respectively. Temperatures commonly reached under normal conditions of soil solarization during the hot months of the year are 35C and 60 ˚C depending on soil depth, but soil temperatures decrease with increasing soil depth

Concerning plastic sheets color, soil temperatures under transparent plastic films rise by several degrees during the day (2 to 10˚C) depending on the season, soil type, the level of sunshine and moisture. At night, the difference in temperature between transparent plastic covered and bare soil is less (between 2˚C and 4˚C) (DeVay, 1995).

1.3.2. Moisture

Soil moisture is a critical variable in soil solarization since the transfer of heat to weed seeds and micro-organisms in soil is greatly increased by moisture.

The temperature maxima of soils increase with increasing soil moisture (Mahrer, 1984; James, DeVay, 1991). Water helps to conduct heat, and best results obtained if soil is moist but not waterlogged or muddy. If the soil is very dry and dusty, the solarization will not work as well. On sandy soils, the best conditions are after rain or irrigation the day before plastic is applied. If rain or irrigation occur just a short time before applying plastic, the soil can be heavy, muddy, or otherwise difficult to work with, and the clear plastic can get dirty (Robert and Harsimran, 2010). Wet soil conducts heat better than dry soil and makes soil organisms more vulnerable to heat (Elmore et al, 1997). The soil does not usually need to be irrigated again during solarization, although if the soil is very light and sandy, or if the soil moisture is less than 50 percent of field capacity, it may be necessary to irrigate a second time. This will cool the soil, but because of the increased moisture the final temperatures will be greater (Elmore et al, 1997). Wetting agents in the film allow humidity to condense in a thin, continuous layer that also traps heat without significantly reducing the light transmittance of the plastic (Lamberti and Basile, 1991).

1.3.3 Nutrients

Soil solarization increases the release of soluble nutrients (inorganic N forms, extractable P, and K, available cations, and dissolved organic matter) due to soil heating and consequently results in improved plant growth and yield increase (Gelsomino et al., 2006; Barakat and Al Masri, 2012). The availability of many mineral nutrients is increased following the solarization process, particularly those tied up in organic fraction such as N -$^{+}$NH4 N- NO3, Ca and Mg. The nutrients may provide the equivalent of a pre-plant fertilizer dosage (Katan, 1980).

Increases in soluble mineral nutrients including NH4^{+}, NO3^{-}, P, K^{+}, Ca^{+2}, Mg^{+2}, Mn^{+2}, Fe^{+3}, Cl^{-} and Cu^{+2} have been detected in solarized soils (Chen et al., 1991). Wet soils covered with plastic mulch and protected from solar irradiation and heating did not differ in chemical properties from untreated control soils (Stapleton et al., 1985). This suggests that heating causes the release of soluble mineral nutrients from soil organic matter, although mulches can also increase nutrient concentrations by reducing leaching of solutes (Stevens et al., 1991).

1.3.4. Soil properties

Soil solarization is influenced by the thermal conductivies of the soil and in return is affected by soil properties. Liquid and gaseous thermal conductivity depend on the proportions bulk of these ingredients, the size and arrangement of solid particles, and the connection between the phases of solid and liquid (Jury and Horton, 2004). With reduced thermal conductivity, there is a decreased particle size and increased bulk density in soil as well as water content (Klein, 2011). Usually, darker soils absorb more solar radiation compared to lighter colored soils and therefore gain higher temperatures during solarization (Elmore et al, 1997).

1.3.5. Plastic type

Mulches used for solarization are films of plastic polymers, usually polyethylene (PE), polyvinyl chloride (PVC), or ethylene-vinyl acetate (EVA). PE films are the most widely used. Among the desirable characteristics that make PE films popular are tensile strength, resistance to tearing when exposed to strong winds and low cost (Brown et al, 199; Khalid, 2012).

The optical properties of PVC and EVA are more desirable than those of PE for soil solarization, but their manufacture is more complicated and therefore, they are more expensive (Lamberti and Basile, 1991). Gutkowski andTerranova, (1991) observed that temperatures in soils mulched with EVA films are higher than in soils mulched with PE films . Plastic films can contain additives that improve their properties for use in solarization. Additives include pigments, heat-retaining substances, wetting agents, ultraviolet stabilizers and photodegradable or biodegradable additives (Brown et al, 199; Stevens et al, 1991). Pigments alter the photometric characteristics of plastic films. Since the optical properties of the mulch determine the irradiative and sensible heat fluxes in soil under solarization (Ham et al., 1993). Pigmentation of the plastic plays an important role in the efficiency of the mulch in soil energy management. Alkayssi and Alkaraghouli, (1991) tested the performance of different colors of plastic mulches for soil solarization and reported that soil temperatures decreased for the colors in the following order: red, transparent, green, blue, yellow and black. Traditionally, soil solarization has been implemented using either transparent or black mulches. Black PE films are usually pigmented with carbon black fillers, while transparent films have no pigment at all. Abu-Gharbieh et al, (1991) reported that the use of black mulch improved plant growth and yield of several crops in a magnitude equivalent to that of transparent film. Since black film recorded lower temperatures and was slightly inferior in reducing populations of soil-borne pathogens, mechanisms other than thermal death were suggested to explain the equivalent yield response soil temperatures under transparent film were higher than under black mulch. Heat-retaining substances and wetting agents also play a role in the photometric characteristics of the mulch. Mineral additives such as aluminum silicates can be added to PE films to increase their opacity to long-wave radiation and enhance the greenhouse effect in the soil (Brown et al., 1991; Stevens et al., 1991; Chase et al., 1999). Plastic films degrade when exposed to ultraviolet (UV) radiation. The durability of plastic films can be further controlled by the addition of other substances that increase the rate of degradative processes. Photodegradable PE films contain substances that accelerate the degradation of plastic exposed to light (for example, ferric ion complexes or calcium carbonate). Biodegradable plastics include substances in the polymer matrix that can be metabolized by microorganisms in the soil, accelerating the disintegration of the film into small particles. Film degradation has been considered as an alternative to inconvenient and costly removal and disposal procedures traditionally used for plastic mulches (Brown et al., 1991; Stevens et al., 1991).

1.3.6. Weather

Highest soil temperatures occur when days are long, high air temperatures are, skies are clear, and there is no wind. The soil heating effect may be limited on cloudy days. Wind will disperse the trapped heat and may damage the plastic sheets (Clyde, et al, 1997). There are occasions when even during optimal periods of the year, cool air temperatures, extensive cloud cover, frequent or persistent precipitation events, or other factors may not permit effective soil solarization (Khalid, 2012; Sesveren, et al. , 2011).

1.3.7. Soil borne microorganisms and pathogens

The success of soil solarization relies on the fact that plant pathogens tend to be less competitive than saprophytic microorganisms. Soon after the end of a solarization treatment, microorganisms begin to re-colonize soil, with highly competitive organisms proliferating at increased rates and faster than other organisms (Chen et al. , 1991). Saprophytes become dominant after soil treatment, outcompeting soil-borne pathogens (DeVay and Katan, 1991).

Solarization controls populations of many important soilborne fungal and bacterial plant pathogens, suh as *Verticillium dahliae*, certain *Fusarium* spp. that cause Fusarium wilt in some crops; *Phytophthora cinnamomi*, which causes Phytophthora root rot; *Agrobacterium tumefaciens*, which causes crown gall disease; *Clavibacter michiganensis*, which causes tomato canker; and *Streptomyces scabies*, which causes potato scab. Some fungi and bacteria are more difficult to control with solarization, such as certain high temperature fungi in the genera *Macrophomina, Fusarium*, and *Pythium,* and the soilborne bacterium *Pseudomonas solanacearum*. (1997 and 1999; Hartz *et al.*, 2004 ; Patterson 1998 ; McGovern *et al.*, 2002).

Trichoderma, *Talaromyces*, and *Aspergillus* spp., survive or even increase in solarized soil (Wilen, and Elmore 2007). Mycorrhizal fungi are more resistant to heat than most plant pathogenic fungi. Their populations may be decreased in the upper soil profile but studies have shown that this is not enough to reduce their colonization of host roots in solarized soil (Ben-Yephet. et al., 1988). Populations of the beneficial bacteria *Bacillus* and *Pseudomonas* spp. are reduced during solarization but recolonize the soil rapidly afterward (Stapleton, et al., 2008)

Population of *Rhizobium* spp., which fix nitrogen in root nodules of legumes, may be greatly reduced by solarization and should be reintroduced by inoculation of leguminous seed. Soilborne populations of other nitrifying bacteria are also reduced during solarization. Population levels of actinomycetes are not greatly affected by soil solarization. Many members of this group are known to be antagonistic to plant pathogenic fungi (Elmor et al , 2005). Solarization reduces as well nematode populations in the soil. Barbercheck and von Broembsen (1986), reported reductions between 37 and 100% in nematode populations in soil solarized with clear plastic mulch.

Stapleton and DeVay (1983), observed that soil solarization resulted in a significantly better control of nematodes than fumigation with 1.3-dichloropropene. Stapleton and Heald (1991), reported that significant decrease in populations of *Meloidogyne javanica* and increased cucumber and eggplant yields after soil solarization.

Soil solarization controls also many annual and perennial weeds. While some weed species are very sensitive to soil solarization, others are moderately resistant and require optimum conditions (good soil moisture, tight-fitting plastic and high radiation for control (Elmore, et al., 1997).

Winter annual weeds seem to be especially sensitive to solarization, and control of winter annuals is often evident for more than one year following treatment. Soil solarization is especially effective in controlling weeds in fall-seeded crops such as onions, garlic, carrots, broccoli and other brassica crops (Stapleton, et al., 2008).

1. 3.8. Agricultural practices

1.3.8.1. Soil amendments

Efforts have been made to shorten the required duration, and expand the geographic feasibility of solarization by increasing the temperatures achieved during the process. One strategy includes the addition of organic matter amendment to the soil prior to solarization. This increase in mineralizable carbon content results in a sharp increase in thermophilic microbial growth and respiration accompanied by the generation of heat. It has been shown that relatively small increases in temperature can have a disproportionate effect on the time necessary for inactivating pathogens (DeVay, et al 1981) and weed propagules (Egley, 1990). Gamliel and Stapleton, (1993) reported an increase in temperature (2-3˚C) in soils amended with chicken compost versus non-amended soils during solarization, as well as increased crop yield, improved control of root-knot nematodes, and increased soil suppressiveness for pathogenic fungi and bacteria. Some of these benefits were attributed directly to the temperature increase though complimentary effects of increased levels of beneficial thermophilic microbes and release of volatile organic compounds (VOCs) were considered. The increased temperature due to exothermic microbial degradation of organic matter may also allow for treatment at deeper levels than afforded by solarization alone. Amendment of soil with organic matter can significantly increase soil temperatures. However, during the stabilization process, soils can become phytotoxic due to the evolution of the same (VOCs) that may contribute to the enhanced effectiveness of amended solarization. The solarization treatment must be long enough to allow sufficient stabilization of the soil and adequate dissipation of the VOCs prior to the planting of crops. However, Simmons *et al*., (2012) showed that by the end of 22 days of solarization, the remaining biological activity did not produce sufficient levels of phytotoxic compounds to significantly decrease seedling germination and growth compared to the control.

1.3.8.2. Tillage

Soil temperature during solarization depends on soil heat capacity, thermal conductivity and environmental factors like solar radiation and climate. Thermal characteristics of soil are influenced largely by soil water content, bulk density, soil chemistry and mineralogy. Tillage is among the treatments that changes soil bulk density and therefore influences heat conduction.

1.4. Control of Fusarium diseases of tomato by solarization

1.4.1. Fusarium Wilt

Tomato fusarium wilt caused by *Fusarium oxysporum* f. sp. *lycopersici* is a serious disease which causes heavy crop losses worldwide. Several management options have been suggested to control the disease, including using plant resistant varieties, balanced nitrogen fertilizer, four year crop rotation, soil fumigation and soil solarization (Ioannou, et al., 2000). In palestine, Fusarium wilt of tomato is a serious disease under greenhouses and open field conditions (Barakat and Al Masri, 2011). The disease management is very difficult due to its endophytic growth and persistence in soil. It has become one of the most damaging diseases wherever tomatoes are grown intensively due to the pathogen persistence in the infested soils (Antonio, 2009; Soytong, 2012). Soil solarization is a good alternative for controlling soil borne pathogens including *Fusarium* spp. (Ashrafi et al., 2010; Saremi et al., 2012). Soil solarization combined with herb residues soil amendment improves the disinfestation efficacy against soil borne pathogens including *Fusarium* (Klein et al. 2011). In addition, Gamliel et al. (2000 a) successfully controlled *Fusarium oxysporum* in tomato, by combining soil solarization and fumigation with either methyl bromide or metham sodium at reduced rates. Minuto et al. (2000) reduced fumigation rates of dazomet in half by implementing soil solarization, effectively controlling Fusarium, Verticillium and Sclerotium in tomato, basil and lettuce crops.

1.4.2. Fusarium Crown and root rot

Fusarium crown and root rot disease caused by *F, oxysporum* f.sp. *radicis-lycopersici* (FORL) is an important soil-borne disease, with the potential to limit productivity in green house and field tomato crops. Substantial crop losses in infected fields have given the disease international attention. In contrast to Fusarium wilt, crown and root rot is favored by cool temperatures

(10°C to 20°C), low soil pH, ammoniacal nitrogen, water-logged soil further exacerbate the disease. (Zhang et al., 2011 and Elmhirst, 2006).

Disease incidence and severity of crown and root rot in cucumber plants inoculated with *Fusarium oxysporum* f. sp. *radices cucumerinum* macroconidia were reduced by 20 to 80% when seedlings were planted in solarized soil (Klein et al. 2011). In further studies, soil solarization reduced significant population of *F. oxysporum* f.sp. *radicis-lycopersici* down to a depth of 5 cm (Chellemi et al, 1994). Furthermore, crown rot incidence was significantly reduced by Metam Sodium (29%), solarization + Metam Sodium (51%) and by Methyl bromide chloropicrin (50%); disease severity was significantly reduced (74%) by using the latter two treatments. Cartia, (2002) reported that soil solarization in the open field after 12 days of soil solarization, reduced survival of FORL propagules significantly. The effectiveness of FORL control was improved by combing solarization with manure, or extending the solarization treatment to 27 days. In a closed greenhouse, solarization and biofumigation with bovine manure proved effective in reducing the viability of FORL chlamydospores, reducing disease incidence and in increasing commercial yield.

1.5. Induced Growth Response (IGR)

Soil solarization often enhances plant growth and yield in pathogen-free soils. Noto (1994) reported higher yields and reduced diseases damage for tomato plants grown on solarized soil, compared to those planted in non-solarized soil. However, yield was not related to root infection, indicating that solarization effects could be attributed to mechanisms other than diseases control. Abd El-Megid (1998) documented increased plant growth of onion transplants produced in solarized seedbeds, apparently without incidence of diseases. These reports correspond to a phenomenon known as increased growth response (IGR) that has been attributed to several mechanisms, including increases in nutrient levels in the soil solution, stimulation of beneficial organisms and control of minor pathogens (Gruenzweig, 1993). The influence of solarization on the chemical and physical characteristics of soil has been documented. Increases in soluble mineral nutrients (Chen and Katan, 1980; Stapleton *et al.*,1984) and dissolved organic matter (Chen *et al.*,, 2000) have been related to soil solarization and IGR in plants. Chemical characteristics of soil determine the nutritional status of plants, therefore affecting its growth and development. Grunzweig *et al.*, (1998) documented increased concentrations of N, Cu, and decreased Cl and SO4 in the xylem sap of tomato plants grown in solarized soil. Solarization can induce IGR also by enhancing biocontrol processes. Le Bihan *et al.,* (1997) documented significant decreases in damping-off in solarized soils that were associated with frequent isolations of *Trichoderma* spp., Tjamos and Fravel (1995) reported a synergistic interaction between soil heating and the activity of the biocontrol *Talaromyces flavus* that increased the mortality of microsclerotia of *Verticillium dahliae*. Yücel and Çali (1998) reported a synergistic interaction between soil solarization and the application of *Trichoderma harzianum* that increased tomato yields to levels equivalent to those obtained by fumigation with methyl bromide. Furthermore, Gruenzweig *et al.,* (1993) studied the effects of solarization on growth patterns and physiological processes as related to IGR for tomato, corn, cucumber, sorghum and tobacco. Increased growth, accelerated development, extended photosynthetic activity, increased protein levels and delayed senescence of tissues were documented for plants grown in solarized soils. Grunzweig *et al.,* (2000) investigated the involvement of giberellins in the regulation of increased tomato growth in solarized soil. Seedlings from solarized soil had higher dry weights and leaf weight ratios.

1.6. Combining soil solarization with other control methods

1.6.1. Soil solarization combination with chemical pesticide

Combining solarization with soil fumigants appears to be a practical and powerful approach to improving the control of soilborne diseases and broadening the spectrum of affected pathogens (Gamliel and Katan, 2009). Such combinations may enable reducing the dose of the needed pesticide while extending the effectiveness of the treatments. Indeed, exposure of organisms to fumigants, at a lethal or sublethal dosage in combination with solarization should be considered from two points of view: as a way of improving solarization, i.e. by shortening length of application and improving pathogen control, or as a way of improving the other methods with which solarization is combined. Furthermore, the combination of solarization with a low rate of the appropriate pesticide may provide the benefit of a more predictable treatment, which is a requirement for commercial users, as it provides a wider safety margin for the treatment's long-term success. Eshel *et al.* (2000) established an important and practical rationale for the sequence of application of solarization and fumigants. They showed that control efficacy of a reduced dose of methyl bromide (MB) or metham sodium is strongly increased when applied after a short solarization period of 8 days, after mulching. Thus, it was recommended to apply solarization for a short period and then introduce the desired fumigant.

1.6.2. Soil solarization combination with biological control agents

Soil solarization has been effectively combined with biological control agents including *Talaromyces flavus*, *T, harzianum*, and the Vesicular Arbuscular Mycorrhizal (VAM) fungus *Glomus fasciculatum*, to control plant diseases. Synergistic interactions have also been observed among soil solarization and biological control agents. According to Davis (1991), the use of *T,harzianum* with solarization in fields infested with *Rhizoctonia solani* improves disease control while delaying the buildup of the inoculum. He also reported that solarized soils are frequently more suppressive and less conducive to certain soil borne pathogens than non-solarized soils.

The successful addition of biological control agents to soil before, during, or after the solarization process in order to obtain increased and persistent pesticidal efficacy has long been sought after by researchers (Tjamos and Fravel, 1995 and Hibar et al., 2005). There have been great hopes of adding specific antagonistic and/or plant growth promoting microorganisms to solarized soil, either by innundative release or with transplants or other propagative material, to establish a long-term disease-suppressive effect to subsequently planted crops (Katan, 1987; Stapleton and DeVay, 1995). Tjamos and Fravel (1995) showed that the fungus *Talaromyces yavus*, when added to solarized soil which was heated only to sublethal levels, was detrimental to the survival of *Verticillium dahliae* microsclerotia. In most studies, however, it appears that re-colonization of solarized soil by the native biota is just as beneficial to subsequent crops as the addition of specific microorganisms (Stapleton and DeVay, 1995).

Microbial suppression of *Fusarium* crown and root rot of tomato results from microbial antagonism during the saprophytic growth of the pathogen (Hibar et al., 2005).

1.7. Study Objectives

The objectives of this study is to evaluate the efficiency of a double layered polyethylene (DPE) in combination with organic matter (chicken manure) soil amendment in the control of Fusarium wilt and Fusarium crown and root rot diseases of tomatoes in the southern uplands of the West Bank, Palestine.

2. Materials and Methods

2.1 Soil preparation and solarization treatments

Two soil solarization field experiments were conducted during July 10th - August 27th, 2011, and July 17th - August 28th, 2012 in Al-Aroub Agricultural Experimental Station of the Faculty of Agriculture, Hebron University, Hebron - Palestine. The soil was deeply plowed (30 cm) two weeks before starting the experiment and rotivated before mulching. Experimental plots were then irrigated with 80% field capacity, two days before the start of the solarization period. The experimental design (Table 1) was a randomized complete block design with three blocks (replicates) for each treatment (5x5m). Four treatments were involved: non-solarized soil (CK), solarized soil using 50 µm regular polyethylene (PE) sheets, solarized soil using double polyethylene sheets separated by a 2 cm (DPE), and solarized soil using double layered polyethylene sheets (DPE) plus organic matter (mature chicken manure10 % v:v). Two sets of inoculum bags of *F. oxysporum* f.sp. *lycopersici* and two sets of inoculum bags of *F. oxysporum* f.sp. *radicis-lycopersici* were incorporated at 20 cm and 30 cm depths in each experimental plot. Experimental plots were separated by 1-meter borders.

Figure 1. Soil preparation and set up of solarization treatments.

2.2. Pathogens Inoculum Preparation

The isolates of *Fusarium oxysporum* f. sp. *lycopersici* (FOL) and *F. oxysporum* f. sp. *radicis lycopersici* (FORL) used in the experiment were obtained from diseased tomato plants. Both fungi were grown on Potato Dextrose Agar (PDA) medium amended with 300 mgl^{-1} chloramphenicol. A single-conidium cultures were prepared and sub cultured. Petri plates were incubated for 40days in the growth chamber at $25^{\circ}C$, with 12 hours photoperiods. Fungal growth in the growing media was used to prepare the chlamydospore inoculum. Forty days were enough for most of the mycelial cells to develop into chlamydospores. The chlamydospore inoculum were shredded and mixed with dry sandy soil and propagules measured as CFUg^{-1}. The dilution plate technique (Barakat and Al Masri, 2011) was used to measure inoculum in which 2.5 g of previously prepared soil inoculum were placed in 23 ml sterilized distilled water (1:10), and 0.2 ml of the suspension were spread on each of the six Petri dishes containing 15 ml of selective peptone-PCNB agar medium prepared earlier. The Petri dishes were then incubated at 25°C under darkness for three days and under natural room light for 4 days. The numbers of *F. oxysporum* f. sp. *lycopersici* (FOL) and *F. oxysporum* f. sp. *radicis lycopersici* (FORL) colonies were counted and the mean of inoculums concentration was calibrated to 6×10^4 CFU g^{-1}soil in 2011 and $8*10^4$ CFU g^{-1} soil in 2012 for FOL, and $5*10^4$ CFU g^{-1} soil in 2011 and $7*10^4$ CFU g^{-1} soil 2012 for FORL. Ninety grams of sandy soil mixed with inoculum of each pathogen were placed in each muslin bag. Small muslin bags containing the inoculum were closed with plastic silks and incorporated in experimental plots at a depth of 20 and 30cm for both pathogen’s and season’s experiments.

Table 1. Experimental design layout

2011

Block 1	**Block 2**	**Block 3**
DPE+O.M	DPE	CK
PE	DPE+O.M	DPE
CK	PE	DPE+O.M
DPE	CK	PE

2012

Block 1	**Block 2**	**Block 3**
DPE+O.M	CK	DPE+O.M
DPE	DPE+O.M	DPE
PE	DPE	CK
CK	PE	PE

CK: Non solarization soil (Control)

PE: Solarizationsoil whith polyethylene sheet

DPE: Solarization soil whith double layer of polyethylene sheet

DPE+OM: Solarization soil whith double layer of polyethylene sheet + organic matter (chicken manure)

2.3. Soil temperature recording

The soil temperature was recorded by HOBO data loggers (Onset Computer Corporation, Bourne, USA), during the two solarization periods. The loggers were calibrated to take a reading every 40 minutes during the two solarization periods at the depth of 15 cm in the middle of all experimental plots. The loggers were removed at the end of the period, and the data downloaded using the BOXCar version 3.7 software (Onset Computer Corporation, Bourne, USA).

2.4. Diseases severity

The disease severity of Fusarium wilt and Fusarium crown and root rot (%) of tomato plants growing in solarized and non-solarized soils were evaluated at the end of the solarization period. In each experimental plot, three soil sub samples were randomly collected at 20 cm and 30 cm depths and mixed thoroughly to make one composite sample. Each composite soil sample at both depths were divided to two parts (1000 g each). One part was inoculated with 85 grams of the inoculum bags of FOL and the other part with 85 grams with the inoculum FORL. The experimental design was completely randomized with 5 replicates (pots) for each treatment. Each inoculated soil sample (1000 gm.) was subdivided evenly into 5 planting pots (200 gm. each). The weight of each of the 5 pots was finally adjusted with additional soil to 1000 gm. In each pot, 3-5 tomato seeds were seeded in soil. After emergence, the number of seedlings was reduced to three per pot. Plants were then incubated in a greenhouse at 25 - 30°C, with 15 hours photoperiods. Plants were drip irrigated regularly with water. The number of diseased plants was recorded weekly from week 2 to week 10 after sowing. The accumulated number of dead plants for both diseases was documented and percentages of both diseases were calculated. The experiment was repeated in the same manner in the second solarization season.

2.5. Estimation of pathogen's population

The population of FOL and FORL in the muslin bags buried earlier in solarized and no solarized plots at two depths (20and 30 cm) in both seasons was assessed after 6 weeks of solarization at the end of the solarization period. The pathogen population in the muslin bags was measured as CFU/g soil by using the dilution plate technique on selective peptone-PCNB agar medium (Nelson, et al.,1983). Soil dilutions were prepared by taking 2.5g of soil in 25mL of sterilized distilled water (1 : 10) as stock and made serial dilutions (10^{-2}, 10^{-3}, 10^{-4}); 0.2 mL of the suspension 10^{-4} was spread on each Petri dish. Petri dishes were then incubated at 25°C under darkness for three days and under natural room light for 4 days. The number of propagules grown was counted and calculated as CFU per gram soil. The experimental design was completely randomized with five replicates (Petri dishes) for each treatment.

2.6. Chemical analysis of soil

The solarized soil was classified as clay soil (28% sand, 13% silt, and 59% clay; pH 7.3; $EC_{1:2.5}$ **(**25 °C**)** 0.4 ms cm^{-1}; 22% $CaCO_3$; 2.1% organic matter; 40 mg kg^{-1} NH_4^+; 4.7 mg kg^{-1} NO_3^- ; 27 mg kg^{-1} P; and 174 mg kg^{-1} K^+**)**. Composite soil samples (1000 g) were collected from experimental plots. Dry soil samples were then sieved (2 mm) and the fine soil was used for chemical analysis (pH, $EC_{1:2.5}$, organic matter, total nitrogen, ammonium, nitrate, phosphorus, and available potassium). The soil pH and EC were evaluated in water extracts (1: 2.5, w/v) by pH meter (pH meter 3305, Jenway, UK) and conductivity meter (conductivity meter 4010, Jenway, UK). The organic matter was evaluated by acidic wet oxidation with potassium dichromate according to the Weakley-Back wet combustion method (Tan, 1995). The exchangeable ammonium and nitrate were evaluated according to the methods described by (Keeney and Nelson, 1982). Available phosphorus was measured by using the moly date ascorbic acid method (Sommers and Olsen,1982). Exchangeable potassium was evaluated by the neutral ammonium acetate method. The chemical analysis was repeated in the second seasons.

2.7. Plant growth

To evaluate the effect of treatments on plants growth, three soil subsamples were randomly collected from the upper 20 cm of each experimental plot. After removing the top 2-3 cm of soil, the subsamples were mixed thoroughly to make one composite sample. Each composite soil sample (5kg) was divided into 5 pots (replicates) 1000 g each. Tomato seeds (3–5) were then seeded in each pot. After emergence, the number of seedlings was reduced to 1 per pot.

Plants were then incubated under greenhouse conditions at 25°C for two months and irrigated daily. After 60 days, the plants height were measured and the plant's fresh and dry weights were evaluated. The dry weight was evaluated after drying the plants at 105°C. A completely randomized design was used with five replicates (plants) for each block.

2.8. Statistical Analysis

The data were statistically analyzed using one way repeated analysis of variance (ANOVA). Fisher LSD test (P=0.05) was used for mean's separation (Sigma stat 2.0 statistical package, SPSS , USA).

3. Results

3.1. Soil temperature

Soil temperature was greatly increased in solarized soil treatments compared with the control (Table 2 and Figure 4,5). The means of absolute maximum soil temperatures (°C) recorded during the solarization period were 31.1, 37.4, 41.5 and 46.3 °C during the 2011 solarization season and 31.4, 40.6, 43.9 and 47.8°C during the 2012 season under the control, PE, DPE, and DPE+ OM treatments, respectively (Table 3). The means of absolute maximum soil temperatures increased by 6.3, 10.4 and 15.2 °C under the solarized treatments, compared to the control for 2011 and by 9.2, 12.5, and 16.4°C for 2012, respectively. The double polyethylene layer and organic matter treatment (DPE + O.M) increased the mean of absolute maximum temperature by 4.8 and 3.9°C during 2011 and 2012 seasons, respectively, compared to the double polyethylene layer sheet alone (DPE). In addition, DPE + OM treatment increased the mean of absolute maximum temperature by 8.9°C and 7.2°C during 2011 and 2012, respectively, compared to the common solarization treatment using single layer of polyethylene sheet (PE). Furthermore, the number of hours recorded under the lethal temperature class (≥45°C) were 28 and 235 h recorded under the DPE +OM treatments during 2011 and 2012 solarization seasons, respectively. The absolute maximum soil temperatures measured during the two solarization periods were 46.3°C and 47.8°C obtained under the treatment (DPE+OM) in the summers of 2011 and 2012, respectively.

Table 2. Number of hours for different temperature classes recorded under solarization treatments, during July10- August 27, 2011 and July 17-August 27, 2012 in Al- Aroub Agricultural Research Station, South of the West Bank.

Temperature class	2011				2012			
	CK	PE	DPE	DPE+O.M	CK	PE	DPE	DPE+O.M
≤ 25 ^{o}C	123	0	0	0	0	1	0	0
26 - 30 ^{o}C	915	55	26	17	788	11	0	3
31 - 35 ^{o}C	118	729	258	211	216	419	139	18
36 - 40 ^{o}C	0	372	764	483	0	535	550	232
41 - 45 ^{o}C	0	0	108	417	0	34	316	516
≥ 45 ^{o}C	0	0	0	28	0	0	0	235
Total hours	1156	1156	1156	1156	1004	1004	1004	1004

CK = non solarized soil
PE = polyethylene sheet
DPE = double polyethylene layer
DPE+O.M = double polyethylene layer +chicken manure

Table 3. Means of absolute minimum and maximum temperatures recorded under the various treatments during 2011 and 2012 solarization seasons.

Temperature class	**2011**				**2012**			
	CK	PE	DPE	DPE+O.M	CK	PE	DPE	DPE+O.M
Minimum (^oC)	23.2	25.9	26.3	26.7	25	24.8	28.6	32.3
Maximum (^oC)	31.1	37.4	41.5	46.3	31.4	40.6	43.9	47.8

CK = non solarized soil

PE = polyethylene sheet

DPE = double polyethylene layer

DPE+O.M = double polyethylene layer +chicken manure

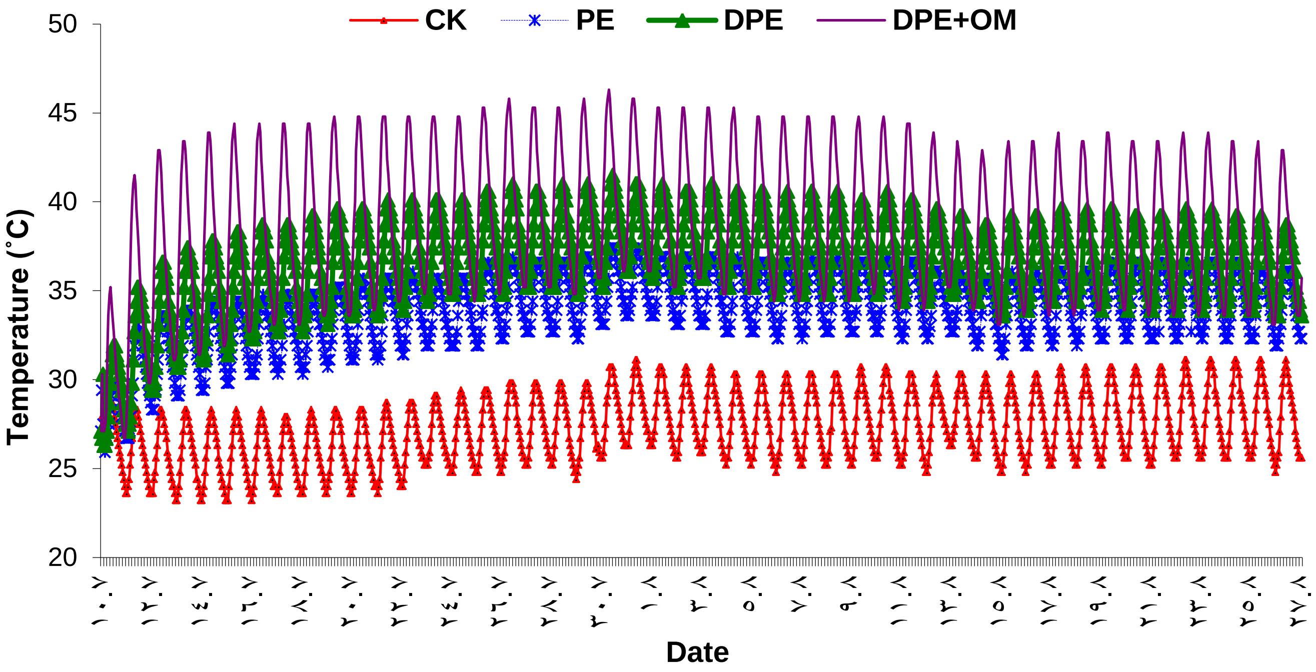

Figure 2. Absolute maximum temperatures data under solarization treatments, during July 10- August 27, 2011 in Al- Aroub Agricultural Research Station, South of the West Bank.

CK: non-solarized soil;

PE: polyethylene sheet;

DPE: double polyethylene layer;

DPE+O.M: double polyethylene layer +chicken manure

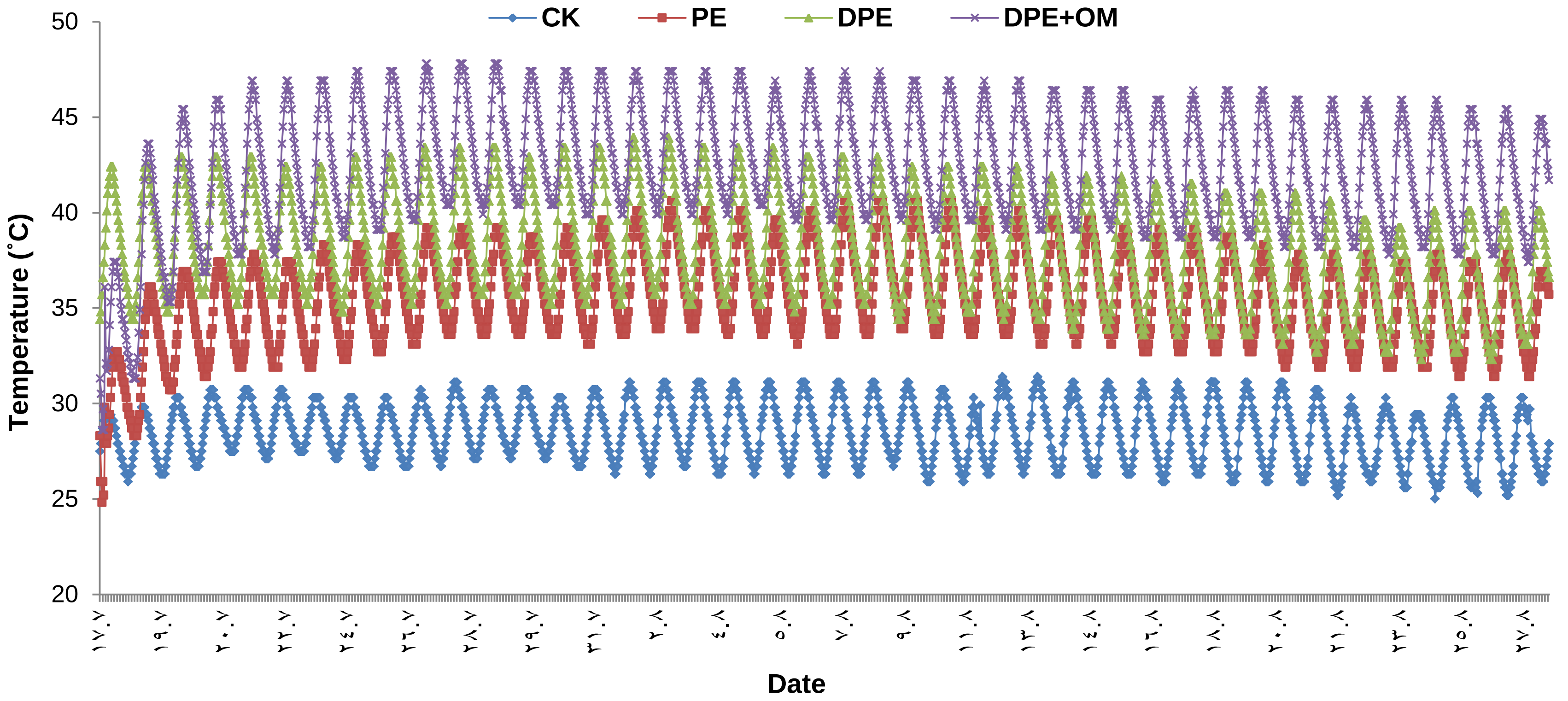

Figure 3. Absolute maximum temperatures data under solarization treatments, during July 17- August 27, 2012 in Al- Aroub Agricultural Research Station, South of the West Bank.

CK: non solarized soil;

PE: polyethylene; sheet;

DPE : double polyethylene layer;

DPE+O.M: double polyethylene layer +chicken manure

3.2. Disease Severity

Results indicated that disease severity was significantly reduced with the use of different soil solarization techniques using the PE sheets compared to control (Table 4). In **2011**, the infections induced by both FOL and FORL was completely suppressed (100%) in the DPE and the DPE+OM treatments compared to the control at both soil depths. No significant differences in severity were noticed in general between soil depths (20 cm vs. 30 cm). In the 2011 solarization season, the PE treatment reduced the disease by 66% at the 20 cm depth for FOL and by 71% for FORL at same depth. Compared to the control, PE treatment has also reduced the disease by 100% at the 30 cm depth for FOL and by 70.7% for FORL at the same depth. In the **2012** solarization season, the PE treatment reduced the disease by 56.9% at the 20 cm depth for FOL and by 76.3% for FORL at the same depth. Compared to the control, PE treatment has also reduced the disease by 62.3% at the 30 cm depth for FOL and by 58% for FORL at the same depth. In addition, the DPE and the DPE+ OM had completely suppressed both diseases in both solarization seasons 2011 and 2012 regardless of the soil depth.

Table 4. Effect of soil solarization treatments in 2011 and 2012 on disease severity (%) of Fusarium wilt (FOL)and Fusarium crown and root rot disease (FORL) of tomato plants under greenhouse conditions.

Treatment	**2011**				**2012**			
	FOL (%)		FORL (%)		FOL (%)		FORL (%)	
	20cm	30cm	20cm	30cm	20 cm	30 cm	20cm	30 cm
Control	38a	42a	100a	75b	51a	53a	93a	100a
PE	13b	0b	29c	22c	22 b	20b	22c	42b
DPE	0b	0b	2 d	0d	2c	0 c	0d	0d
DPE+OM	0b	0b	0d	0d	0c	0 c	0d	0d
LSD	21.7		15.02		14.8		17.3	

Means of the data followed by the same letters within columns and rows for each year and depth are not statistically different according Fisher LSD test at $p \leq 0.05$.
CK: non solarized soil;
PE: polyethylene sheet;
DPE: double polyethylene layer;
DPE+O.M: double polyethylene layer +chicken manure

3.3. Estimation of Pathogen's Population

The population of the two tested pathogens (FOL and FORL) was dramatically declined in soil due to solarization treatments of seven weeks at the two soil depths (Table 5). In the 2011 solarization season, the regular PE treatment reduced the population of FOL by 20 and 27% and of FORL by 75 and 61% at 20 and 30 cm soil depths, respectively. However, the substantial decline was witnessed under DPE and DPE + OM treatments for both solarization seasons and at both soil depths. The population decline in FOL ranged from 73- 98% and in FORL from 76 - 97% after the 2011 solarization treatments of DPE and DPE+OM. There was no significant differences between soil depths.

In the 2012 solarization season, the regular PE treatment reduced the population of FOL by 40and 37% and of FORL by 43 and 55% at 20 and 30cm soil depths, respectively. However, the substantial decline was witnessed under DPE and DPE + OM treatments for both solarization seasons and at both soil depths. The population decline in FOL ranged from 92- 98% and in FORL from 73 - 91% after the 2012 solarization treatments of DPE and DPE+OM. There was no significants differences between soil depths.

Table 5. Effect of soil solarization treatments, on the population of *F.oxysporium* f. sp. *lycopersici* and *F. oxysporium* f. sp. *radicus-lycopersici* in 2011 and 2012.

Treatments	**2011**				**2012**			
	FOL (CFU x 10^2)		**FORL** (CFU x 10^2)		**FOL** (CFU x 10^2)		**FORL** (CFU x 10^2)	
	20 cm	**30 cm**	**20cm**	**30 cm**	**20 cm**	**30 cm**	**20 cm**	**30 cm**
CK	392 ab	532 a	225 b	428 a	683 a	650 a	437 a	552 a
PE	313 b	386 b	56 cd	165 c	405 b	413 b	248 b	248 b
DPE	40 c	143 c	13 d	103 d	15 c	57 c	117 c	52 c
DPE+OM	10 c	12 c	11d	27d	22 c	18 c	82 c	62 c
LSD	145.16		138.7		144.3		120.6	

* Means of data followed by the same letters within columns and rows for both years and depths are not statistically different according Fisher LSD test at $p \leq 0.05$.

CK: non solarized soil;
PE: polyethylene sheet;
DPE: double polyethylene layer;
DPE+O.M: double polyethylene layer +chicken manure

3.4. Chemical Analysis of soil

Results showed that soil solarization didn’t affect the soil pH levels under all treatments compared with the control in both 2011 and 2012 solarization seasons. However, both the EC and Organic matter (OM) have significantly escalated with the addition of the organic matter (more than 6 fold for EC and more than 67% for OM) compared with the control in 2011 and very close to that in 2012 season (Table 6). Solarization of soil using DPE in addition to organic matter (DPE +OM) increased the NH_4 availability in soil dramatically (>6 fold). However, the rest of the solarization treatments (PE + DPE) increased the available NH_4 but to a lesser amounts but were not significantly different from the control treatment. The NO_3 availability was increased significantly as well compared to the control by all solarization treatments, but the peak was recorded by the DPE+OM treatment (>14 fold). Furthermore , the solarization treatments in 2011 increased available phosphorus in soil from 36% (PE) to more than 100% (DPE+OM), compared to the control . However , potassium levels were increased to a lesser extent (8%-30%) under solarization treatments, compared to the control in 2011season. In 2012 solarization season, almost similar trends were recorded for increased levels of nutrients associated with solarization treatments especially with DPE and in particular with the addition of the organic manure.

Table 6. Effect of soil solarization on soil chemical properties

Parameter	2011					2012				
	CK	PE	DPE	DPE+O.M	LSD	CK	PE	DPE	DPE+O.M	LSD
pH	7.2a	7.2a	7.2a	7.2a	0.36	7.1a	7.1a	7.1a	7.1a	0.36
EC (ms cm^{-})	0.4 b	0.9 b	0.8 b	3 a	0.66	0.3c	0.6 bc	1 b	2 a	0.42
O. M (%)	2.1b	2.7ab	2 b	3.5 a	1.09	2.3 c	2.5 bc	3.4 b	4.6 a	0.91
N (%)	0.15c	0.17 b	0.14c	0.28 a	0.012	0.16 c	0.19bc	0.25ab	0.31a	0.06
NH4 mg/kg	41b	46.3 b	62.9 b	311.2a	114.4	41 b	65.2 b	50.2 b	335.8 a	71.1
NO_3 mg/kg	4.7 c	16 bc	31.5 b	70.5 a	19.6	5 d	17.5 c	33.2 b	75.2 a	12.4
P mg/kg	27b	36.7 b	37.5 b	79.4 a	18.6	35 b	36.7 b	38.2 b	80.5a	12.1
K+ mg/kg	174 b	189b	206ab	227a	33.4	155 c	196 b	215ab	233a	33.4

Means of data followed by the same letters in rows are not significantly different according Fisher LSD.
CK: non solarized soil;
PE: polyethylene sheet;
DPE: double polyethylene layer;
DPE+O.M: double polyethylene layer +chicken manure.

3.5. Plant's Growth

Soil solarization significantly stimulated tomato plant's growth parameters in both solarization seasons (Tables 7, 8 & 9; Figures 6 & 7). In 2011, fresh weights of tomato plants growing in solar treated soils increased significantly by 83, 133 and 600% under PE, DPE and DPE+O.M treatments , respectively compared with the control. In 2012, almost similar trends were recorded with slight variations. No significant differences between soil depths in general, were noticed in both seasons (Table 7). As for dry weights, significant increase was noticed with the use of solarization treatments similar to fresh weights under all solarized treatments in both seasons with some variation, compared with the control (Table 8). The heights of tomatoes grown in solarized soils covered with PE, DPE and DPE+OM were significantly increased by 242, 286 and 700% respectively during the 2011season and almost in the same trend, during the 2012 season, compared to the control. The DPE+OM treatment has induced the highest values of plant height compared to the control (Table 9).

Table 7. Effect of soil solarization treatments on tomato fresh weights (g/plant)

Treatments	Fresh weights (gm/plant)			
	2011		2012	
	20cm	30cm	20cm	30cm
Control	6 c	5 c	4 c	3 cd
Polyethylene	11c	7c	10 bc	11 b
Double polyethylene	14 c	10 c	15 b	16 b
Double polyethylene + organic manure	42 a	29 b	28 a	26 a
LSD	11.5		6.7	

Table 8. Effect of soil solarization treatments on tomato dry weights (g/plant)

Treatments	Dry weights (gm/plant)			
	2011		2012	
	20cm	30cm	20cm	30cm
Control	1 c	0.2 c	1 de	0.6 f
Polyethylene	0.8 c	0.8c	2 c	0.8 ef
Double polyethylene	1.6 bc	1c	2 c	1.2 d
Double polyethylene + organic manure	3.6 ab	5.4 a	5.6 a	4.2 b
LSD	2.6		0.203	

Table 9. Effect of soil solarization treatments on tomato plant heights (cm/plant).

Treatments	Plant heights (cm/plant)			
	2011		2012	
	20cm	30cm	20cm	30cm
Control	7d	7d	8e	15de
Polyethylene	24 bc	23 c	25cde	27bcd
Double polyethylene	27 bc	33b	33b	43b
Double polyethylene + organic manure	56 a	51a	41bc	61a
LSD	9.4		12.5	

Figure 4. Effect of soil solarization treatments (2011) on tomato plants growth**.**
CK: non solarized soil;
PE: polyethylene sheet;
DPE: double polyethylene layer;
DPE+O.M: double polyethylene layer + chicken manure

Figure 5. Effect of soil solarization treatments (2012) on tomato plants growth.

CK: non solarized soil;
PE: polyethylene sheet;
DPE: double polyethylene layer;
DPE+O.M: double polyethylene layer + chicken manure

4. Discussion

Enhancement of soil solarization in the uplands using a double layer of polyethylene sheets separated with 2 cm alone or in combination with 10% organic manure soil amendment had demonstrated effective disease control treatment against *Fusarium* diseases of tomato plants. Results revealed that soil temperatures were greatly increased in solarized soil compared with the control. Clearly, the use of double polyethylene layer and organic matter treatment (DPE+OM) increased the means of absolute maximum temperatures by 8.9 and 7.2°C during 2011 and 2012, respectively, compared to the common solarization treatment using a single layer of polyethylene sheet (PE). The number of hours recorded under the lethal temperature class (≥45°C) were 28 and 235 h recorded under the DPE +OM treatments during 2011 and 2012 solarization seasons, respectively. The use of double polyethylene layer alone however, increased the means of absolute maximum temperatures by 4.1°C and 3.3 °C during 2011 and 2012, respectively, compared to the common solarization treatment (PE). This was enough to reduce both diseases effectively and enhance other positive changes in nutrients availability and plants health. Similar results were obtained by Barakat and Al-Masri, (2012) in which significant reduction in Fusarium wilt of tomato (*Fusarium oxysporum* f. sp. *lycopersici*) was negatively correlated with the number of hours of soil temperatures above 45 °C. Elmore et al, 1997 indicated that the heating effect of soil solarization is greatest at the surface of the soil and decreases with depth. They further showed that the maximum temperatures recorded under solarized soil ranged from 42 to 55°C at a depth of 5 cm and from 32 to 37°C at 45 cm. Higher soil temperatures and deeper soil heating may be achieved inside greenhouses or by using a double layer of plastic sheeting. Mauromicale et al , (2010) indicated, however, that soil solarized in greenhouses may reach 60°C at a depth of 10 cm and 53°C at 20 cm. In another study, Mauromicale, et al, (2005) showed that solarization increased the maximum soil temperature by 9–10 °C in the first, and by 13–15 °C in the second solarization season. Solarization of field soil with two layers of (25 µm thick) PE film, separated by a 6-cm air layer, caused soil temperatures at 15cm depth to rise by 12.7°C and 3.6°Cover those in no covered soil or soil covered by one layer of film, respectively (De Vay et al, 1987). In addition to that, the researchers showed that the number of hours recorded for temperatures above 45° C under PE, and DPE was 0 and 108 hours for the 2011 season and 34 and 316 hours, for the 2012 season, respectively. Similar results were obtained by Tamietti and Valentino (2006). This study showed that disease severity was significantly reduced with the use of different soil solarization treatments compared to the control in both seasons. The *Fusarium* wilt and *Fusarium* crown and root rot infections were completely suppressed (100%) in the DPE and the DPE+OM treatments compared with the PE and control in both seasons. Disease suppression can be correlated with the reduction of pathogen populations under the solarization treatments. The population decline in FOL ranged from 73- 98% and in FORL from 76 - 97% in 2011, and very much similar in 2012. Several investigators have documented that soil solarization fortified with organic amendment reduced and/or suppressed several diseases and reduced populations of soil borne pathogens (Hampton et al, 2004; Wang et al. 2006; Saremi et al, 2010; Mauromicale et al, 2011 and Klein, et al. 2011). Furthermore Klein et al (2007) showed that the reduction of *Fusarium* crown and root rot of cucumber seedlings artificially inoculated with *F. oxysporum* f. sp. *radicis-cucumerinum* was evident when they were planted in solarized soil previously amended with plant residues. In addition, it was demonstrated that organic amendments exert a protective role keeping soil microbial biomass and enzymatic activities protected from the detrimental effect of heating (Duff and Connelly, 1993; Saremi et al., 2010). In the same direction De Vay et al, (1987) showed that the viability of propagules (mainly chlamydospores) of *Fusarium oxysporum* f. sp. *vasinfectum* that had been buried at 30 cm depth, was reduced after 31 days of solarization by 97.5, 58%, and 0% under a double film layer, a single layer, and in non-covered soil, respectively. The insulation effect of a double layer of PE film improved heat retention in soil and the solarization effect. In the same direction Saremi et al (2011) showed that *F. oxysporum* f.sp. *lycopersici* within the 30 cm soil depth was exposed to lethal temperatures, and complete disinfestation was successfully achieved leading to the effective suppression of the wilt disease. Concerning both pathogens population under solarizaton, results showed that the population of FOL and FORL was significantly reduced under DPE+OM treatment (98 and 97%) and DPE (73 and 76%) compared with the regular PE treatment (20 and 75%) and the control (97 and 98%) during 2011, respectively. In 2012 solarization season the population of FOL and of FORL were reduced under DPE+OM by (98 and 91%), DPE by (92 and 73%) while under regular PE treatment reduction was (40 and 43%). This reduction in pathogens population can be related to lethal temperatures recorded under solarization treatments of DPE and DPE+OM. High temperatures weakened both pathogens and reduced the infections on tomato plants, or may have directly killed both pathogens Barakat and Al-Masri,(2012). In this direction, Saremi et al (2011)showed that soil solarization greatly reduced the population densities of *Fusarium* species and other major soil borne pathogens. Population density (CFU g $^{-1}$ soil) of *Fusarium* species decreased quickly after application of two weeks soil solarization. Means of population densities were reduced from 1833 CFU g^{-1} soil to 900 CFU g^{-1} soil after two weeks and to 500 CFU g^{-1} soil after four weeks, and finally dropped down to 100 CFU g^{-1} soil after six weeks. In the same direction Ashrafi et al, (2010) .showed that soil solarization reduced the population density of *F. oxysporum* from 1800 CFU–g^{-1} soil to 700 after 4 weeks of solarization and to 300g^{-1} soil after 6 weeks. Melero-Vara and López-Herrera , (2012) reported that the viability of soil borne plant pathogens has shown to be compromised by N-rich organic amendments of solarized soil , such as poultry manure, through the liberation of toxic volatiles, including ammonia (NH_3) and nitrous acid (HNO_2).

Furthermore, solarization treatments varied in their effect on soil nutrients; solarization using DPE sheets in addition to organic matter (DPE+OM) increased the NH4 availability in soil dramatically (>6 fold) and NO3 (>14 fold). Available Phosphorus (P+) and Potassium (K+) increased significantly as well in both seasons but to lesser extent. Similarly, Stapleton and DeVay, (1995) reported that the concentrations of NH_4 and NO_3 in the top 15-20 cm of solarized soil were increased and the concentration of other soluble mineral nutrients, including nitrogen, phosphorus, potassium were enhanced. In the same direction, Mauromicale et al (2011), reported that solarization combined with organic matter increased soil fertility, and the highest increase was recorded on K_2O and exchangeable K^+, NH_4 and NO_3. In this study, solarization treatments increased significantly the EC values compared with the control. Similarly, Gelsomino and Cacco (2006), showed that the values of EC increased with solarization treatments by decomposition of organic matter and the release of organic acids and nutrients. Furthermore, Candido et al, (2010) and Matheron and Porchas (2008), showed that solarization improved soil structure and increased soil content of soluble nutrients, particularly dissolved organic matter, inorganic nitrogen forms, and available cations, and shifted composition and richness of soil microbial communities, with a marked increase of plant growth beneficial's and plant pathogens antagonists. As a consequence of these effects, soil solarization was largely documented to increase plant growth and crop yield and quality.

Furthermore, it was evident in this study that solarization stimulated fresh, dry weights and heights of tomato plants in both seasons. Fresh weights of tomato plants growing in solar treated soil increased significantly by 83, 133 and 600% under PE, DPE and DPE+OM treatments, respectively, compared with the control in 2011, and, almost with similar trends in 2012. As for dry weights and plant heights , significant increase was noticed as well with the use of solarization treatments similar to fresh weights in both seasons. The stimulation of tomato plants growth parameter is related to the decomposition of organic matter, the increase of available nutrients (ammonium , nitrate and potassium) and the reduction in pathogens population in solarized soils.. Similarly, Ashrafi et al, (2008) reported that soil solarization improved cucumber plant growth and consequently fruit yield . Increase in fruit yield was as high as 232% higher than the control. This remarkable increases in cucumber yield by soil solarization was largely attributed to the absence of Egyptian boromrape infestation , but additional beneficial effects generated by the solarization treatment , such as the control of soil borne diseases, an increased release and uptake of macro and micronutrients, the release of plant growth regulator , the enhancement of mycorrhizal growth and an increase in endogenous gibberellin supply cannot be ruled out.

Furthermore, Gruenzweig et al (1993) reported that the increased growth response and yield quality due to soil solarization may be related to number of physiological changes, as increased photosynthetic activity, consequently protein levels, accelerated tissue development, and delayed senescence occurring in the late developmental stages of plants grown in solarized soil.

In conclusion, this study showed that using double polyethylene sheets (DPE) in addition to organic matter (DPE+MO) greatly enhanced the capacity of soil solarization in increasing soil temperature to more lethal levels, and consequently reducing diseases severity as a result of pathogen population reduction. In addition, it was demonstrated that this technique futher increased soil nutrients and plants growth parameters. However , further studies are still needed in the fields of:

1. Selection of more efficient types of polyethylene with better ability to arrest temperature for longer hours.
2. Testing organic matter from different sources in combination with solarization treatments.
3. Testing the potential of double polyethylene covers with organic matter against other soil borne plant pathogens.
4. Testing the effect of combining soil solarization with other disease control measures (i.e. reduced dose of chemical and/or biological control).
5. Testing the possible interaction of solarization with soil beneficial microflora.

REFERENCES

1. Abd El-Megid, M. S., Ibrahim, A. S., Khalid, S. A., and Satour. M. M. 1998. Studies on vegetable transplants using seed-bed solarization: improvement of onion transplant characters and smut disease control, in soil solarization and integrated management of soil pests: Proceedings of the second conference on soil solarization, Aleppo, Syria (Stapleton, J. J., J. E. DeVay, and C. L. Elmore, Eds.). FAO plant production and protection paper 147:165-174.
2. Abu Irmaileh , Barakat. 2003. Weed Management for Developing Countries, FAO .plant production and protection paper 120.
3. Abu-Gharbieh, W. I., Saleh, H., and Abu-Blan. H. 1991. Use of black plastic for soil solarization and post-plant mulching, in soil solarization: Proceedings of the first conference on soil solarization, Amman, Jordan (DeVay, J. E., J. J. Stapleton, and C. L. Elmore, Eds.). FAO plant production and protection paper 109:229-242.
4. Alkayssi. A.W. and Alkaraghoul .A.A. 1991. Influence of different color plastic mulches used for sol solarization on the effectiveness of soil

heating, FAO Plant Production and protection paper 109, M-53 , ISBN 92-5-103057-X.

5. Ashrafi Z. Y, Alizadeh H. M. and Sadeghi S. 2008, Effect of soil solarization on the control of Egyptian broomrape (orobanche aegyptiaca) and yield improvement of cucumber (Cucumis sativus) grown in greenhouse. Bulg. J. Agric. Sci., 14: 583- 591
6. Barakat R.M., and Al-Masri, M. I. 2012. Enhanced Soil Solarization against *Fusarium oxysporum* f. sp.*lycopersici* in the Uplands, Hebron University, P.O. Box 40, Hebron, Palestine.
7. Barbercheck, M. E., and Von Broembsen, S. L. 1986. Effects of soil-solarization on plant parasitic nematodes and *Phytophthora cinnamomi* in South Africa. Plant Disease 70:945-950.
8. Ben-Yephet, Y., J. M. Melero-Vara and DeVay, J. E. 1988. Interaction of soil solarization and metham-sodium in the destruction of *Verticillium dahliae* and *Fusarium oxysporum f. sp. vasinfectum*. Crop Protect. 7:327331.
9. Ben-Yephet. Y,. Stapleton . J. J, Wakeman. R. J., De Vay. J. E.,1987, Comparative effects of soil solarization with single and double layers of polyethylene film on survival of *Fusarium oxysporum* F.

SP.*Vasinfectum* Phytoparasitica September 1987, Volume 15, Issue 3, pp 181-185.

10. Bonanomi, G., Antignani, V., Pane C., and Scala, F. 2007. Suppression of soilborne fungal diseases with organic amendments. J. Plant Pathol. 89:311-324.
11. Brown, J. Y. Lu ,Stevens C., V.A. Khan., Tang J. E., A.Y., Hiltbold. A.E., M.A. Wilson and Adeyeye. O. 1991. Soil solarization: the effects of organic amendments on growth and fertility.
12. Candido. V,'Addabbo. T . D, Miccolis. V, Basile. M, 2010, Soil Solarization and Sustainable Agriculture,Sociology, Organic Farming, Climate Change and Soil Science, Sustainable Agriculture Reviews Volume 3, 2010, pp 217-274.
13. Cartia, G., 2002. Alternatives to methyl bromide for tomatoes and vegetables. Proceedings of the International Conference on Alternatives to Methyl Bromide, Mar. 5-8, Sevilla, Spain, pp: 366-370.
14. Caussanel J.,A., Trovelot, J., Vivant, G., Gianinazzi, S . 1997. Effects of soil solarization on weed infestation and on mycorrhizas development. Abstracts Second International Conference on Soil Solarization and Integrated Management of Soilborne Pest. ICARDA, Aleppo, Syria.

15. Chase, C. A., Sinclair. T. R., and Locascio. S. J. 1999. Effects of soil temperature and tuber depth on Cyperus spp. control. Weed Science 47:467-472.
16. Chen Y., J. Katan,. Gamliel A.,. Aviad T., and Schnitzer. M. 2000. Involvement of soluble organic matter in increased plant growth in solarized soils. Biology and Fertility of Soils 32, 28-34.
17. Chen, Y., Gamliel. A., Stapleton. J. J., and Aviad. T. 1991. Chemical, physical, and microbial changes related to plant growth in disinfested soils, in Soil solarization (J. Katan and J. E DeVay, Eds.). CRC Press, Boca Raton, Florida. 103-129
18. Claeyd E., Bell C.E., Devay J.E. , and Stapleton J. 1997. Soil Solarization A Nonpesticidal Method for Controlling Diseases, Nematodes, and Weeds, University of California Vegetable Research and Information Center Publication 21377.
19. Clyde. L.,. DeVay. E.,J. Stapleton. E.,J.O. 1991. Soil Solarization CA 95616 USA Proceedings of the First international Conference , Amman, Jordan, 19-25 February .
20. Dahlquist, R, .M ., Prather T., S., and. Stapleton, J.J. 2007. Time and Temperature Requirements for Weed Seed Thermal Death , Weed Science 55:619–625.

21. Davis, J.R. 1991. Soil solarization: Pathogen and disease control and increases in crop yield and quality: Short and long-term effects and integrated control. p. 39-50. In J. Katan and J.E. DeVay (eds.). Soil solarization. CRC Press, Boca Raton, FL.
22. De Vay, J.E. and Katan J. 1991. *Soil solarization*. CRC Press, Inc., Boca Raton, Florida, USA, 267 pp.
23. DeVay, J. E., and Katan. J. 1991. Mechanisms of pathogen control in solarized soils, in Soilsolarization (J. Katan and J. E. DeVay, Eds.). CRC Press, Boca Raton, Florida. 87-101.
24. DeVay, J.E. 1991. Historical review and principles of soil solarization pp 1-6. In Soil Solarization. FAO Plant Production and Protection Paper 109 369pp.
25. DeVay, J.E. 1995. Solarization: An Environmental friendly Technology for pest management. Arab Journal of Plant Protection, 13 (1); 56-61.
26. DeVay, J.E., Stapleton. J. and Elmore. C.L. 1990. Soil solarization FAO Plant Production and Protection Paper 109 369pp.
27. Egley, G. H. 1990. "High-Temperature Effects on Germination and Survival of Weed Seeds in Soil," Weed Science, pp.429-435

28. Elmhirst J. 2006. Crop Profile for Greenhouse Tomato in Canada , Agriculture and Agri-Food Canada 960 Carling Avenue, Building 57 Ottawa, Ontario K1A 0C6.

29. Elmore C.,L., Stapleton, J .,J ., Bell, C.,E .and DeVa y, J. E. 1997. Soil solarization a non-pesticidal method for controlling diseases, nematodes, and weeds. University of California, Publication 21377.

30. Elmore, C. l. Jams S., Bell,C.,E.,James ,D. 1997. Soil Solarization A Non-pesticidal Method for Controlling Diseases, Nematodes, and Weeds , University of California Division of Agriculture and Natural resource publication 21377.

31. Elmore, C.L. 1991. Weed control by solarization. p. 61-72. In J. Katan and J.E. DeVay (eds.). Soil solarization. CRC Press, Boca Raton, FL. Environ. 8 (2): 821-826.

32. Eshel, D.; Gamliel, A.; Grinstein, A.; Diprimo, P. and katan, J. 2000 Combined soil treatments and sequence of application in improving the control of soilborne pathogens. Phytopathology, vol. 90, no. 7, p. 751-757.

33. Gamiel, A., and Stapleton. J.J. 1993. Characterization of antifungal volatile compounds evolved from solarized soil amended with cabbage residue. Phytopathology 83:899-905.

34. Gamlie A. 2010. Application aspects of integrated pest management Journal of Plant Pathology (2010), 92 (4, Supplement), S4.23-S4.26

35. Gasoni, L., Kahn, N., Yossen, V., Cozzi, J., Kobayashi, K., Silvana. B, Barrera, V., and Zumelzú, G. 2008 , Effect of soil solarization and biocontrol agents on plant stand and yield on table beet in Córdoba (Argentina) crop Protection; DOI:10.1016/j.

36. Gelsomino A., Badalucco. L., Landi. L., and Cacco. G. 2006. Soil carbon, nitrogen and phosphorus dynamics as affected by solarization alone or combined with organic amendment. *Plant and Soil* 279, 307-325.

37. Gruenzwieg J.M., Rabinowitch. H.D. and Katan. J. 1993. Physiological and devlopmental aspects of increased plant growth in solarized soils. *Annual Applied Biology* 122, 579-591.

38. Gutkowski D. and Terranova S. 1991. Physical effects of soil solarization, FAO Plant Production and protection paper 109, M-53 , ISBN 92-5-103057-X.

39. Harender R, Sharma SD (2009). Integration of soil solarization andc hemical sterilization with beneficial microorganisms for the control of white root rot and growth of nursery apple Scientia Horticulturae, 119(2): 126-131.

40. Hartz, T.K., DeVay, J.E., and Elmore, C.L. 1993. Solarization is an effective soil disinfestations technique for strawberry production. Hort Science 28:104-106.

41. Hasing J.E,. 2002. Agroeconomic of soil solarization on fall-planted lettuce effect, Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Science in The Department of Horticulture.

42. Hibar, K., Daami-Remadi M., Jabnoun-Khiareddine H. and El Mahjoub M., 2005. *In vitro* and *In vivo* inhibitory effect of *Trichoderma harzianum* on *Fusarium oxysporum* f. sp. *Radicis-lycopersici*. Biotechnol. Agron. Soc. Environ., 9: 163-171.

43. Ioannou, C. A. Poullis, and Heale., J. B. 2000. Fusarium wilt of watermelon in Cyprus and its management with soil solarization combined with fumigation or ammonium fertilizers," OEPP Bulletin, vol. 30, pp. 223–230.

44. Jacobson, R., Greenberger A., Katan J., Levi M. and Alon H., 1980. Control of Egyptian broomrape (Orobanche aegyptiaca) and other weeds by

45.Jury W. A. and Horton, R. 2004. Soil physics. p.176-197. In: Heat flow in Soil. 6th ed. John Whiley and Sons, Hoboken, Jew Jersey.

46.Katan, J. (1980). Solar pasteurization of soils for disease control, status and prospects. Plant Disease, 64: 450-454.

47.Katan, J. 1981. Solar heating (solarization) of soil for control of soilborne pests. Annu. Rev. Phytopathology. 19:211-236.

48.Katan, J. 1987. Soil solarization. In: Chet, I. (Ed.), Innovative Approaches to Plant Disease Control. Wiley, New York, pp. 77:105.

49.Katan, J., Greenberger, A., Alon, H., and Grinstein, A. 1976. Solar heating by polyethylene mulching for the control of diseases caused by soil-borne pathogens. Phytopathology 66:683-688.

50.Katan, J.A., Greenberger, Alon, H. and Grinstein, A. 1976. Solar heating by polyethylene mulching for the control of disease caused by soil-borne pathogens. Phytopathology, 66: 683-688.

51.Khalid ,K.,A. 2012, Soil solarization and its effects on medicinal and aromatic plants , Nusantara Bioscience, Vol. 4, No. 1, Pp. 36-44.

52.Klein, E., Katan, J., Austerweil, M., and Gamliel, A. 2007. Controlled laboratory system to study soil solarization and organic amendment effects onplant pathogens. Phytopathology 97:1476-1483.

53. Lamberti, F., and Basile, M. 1991. Improvement in plastic technology for soil heating, in Soil solarization: Proceedings of the first conference on soil solarization, Amman, Jordan (DeVay, J.E., J. J. Stapleton, and C. L. Elmore, Eds.). FAO plant production and protection paper 109:309-330.
54. Levy, N.O.; Elad, Y. and Katan, J. 2004. Integration of Trichoderma and soil solarization for disease management. In: OILB Meeting of the WGs: Management of plant diseases and arthropod pests by BCAs and their integration in agricultural systems. (9th -13th June, 2004, Trentino, Italy).
55. Mahrer, Y., O. Naot, E. Rawitz and J. Katan. 1984. Temperature and moisture regimes in soils mulched with transparent polyethylene. Soil Sci. Soc. Amer. J. 48:362-367.
56. Mansoori, B. and Jaliani, N.K.H., 1996. Control of soilborne pathogens of watermelon by solar heating. Elsevier Sci., 15: 423-424.
57. Mashingaidze, A.B., Chivinge O.A. and Zishiri C., 1996. The effect of clear and black plastic mulch on soil temperature, weed seed viability and emergence, growth and yield of tomatoes. Journal of Applied Science in Southern Africa: 2(1): 6-14

58. Matheron, M. E., and Porchas, M. 2005. Influence of soil temperature and moisture on eruptive germination and viability of sclerotia of *Sclerotinia minor* and *S. sclerotiorum*. Plant Disease. 89:50-54.

59. Mauromical,G., Angel, M.G and MonacoA.L. 2011. The effect of organic supplemementalation of solarized soil on the quality of tomato . Scientia Hort ., (2): 189-196.

60. Mauromicale . G, Marchese . M,. Restuccia .A,. Sapienza .O,. Restuccia G,. Longo A. M. G, 2005, Root nodulation and nitrogen accumulation and partitioning in legume crops as affected by soil solarization, Plant and Soil ,April 2005, Volume 271, Issue 1-2, pp 275-284.

61. McGovern, R.J., and McSorle R.. 1997. Physical methods of soil sterilization for disease management including soil solarization. p. 283-313. In N.A. Rechcigl and J.E. Rechcigl (eds.). Environmentally safe approaches to crop disease control. CRC Press, Boca Raton, FL.

62. McGovern, R.J., C.S. Vavrina, T.A. Obreza and J.C. Capece, 1996. Reduction of fusarium crown and root rot of tomato by combining soil solarization and metam sodium. Methyl Bromide Alternatives, 2: 8-8.

63. McGovern, R.J., McSorley. R., and Bell. M.L. 2002. Reduction of landscape pathogens in Florida by soil solarization. Plant Disease 86:1388-1395.

64. McSorley, R., Ozores-Hampton M, Stansly., P.A., and Conner., J.M. 1999. Nematode management, soil fertility, and yield in organic vegetable production. Nematropica 29:205-213.

65. Melero-Vara ,J. M. and López-Herrera ,C. J. (2012)Use of Poultry Manure Combined with Soil Solarization as a Control Methodfor Meloidogyne incognita in CarnationInstituto de Agricultura Sostenible, CSIC, Apdo. 4084, 14080 Córdoba, Spain;

66. Nafees B, Najma A, Yasmin A, Muhammad A, Abdul R (2007). Soil Solarization: A safe, affective and practicable technique for the control of soil born fungi and nematodes. Pak. J. Biol. Sci. 10(1): 57-64.

67. Nelson, P. E. T., Tousson, A. and Marasas, W. F. O. 1983. Fusarium Species: An Illustrated Manual for Identification, Pennsylvania State University Press, University Park, Pa, USA,.

68. Nico AI, Jimenez-Diaz RM, Castillio P (2003). Solarization of soil in pilesfor the control of Meloidogyne incognita in olive nurseries in southernSpain. Plant Pathol. 52: 770-778.

69.Noto, G. 1994. Soil solarization in greenhouse: Effects on tomato crop, in III international symposium on protected cultivation in mild winter climates, Buenos Aires, Argentina (Larroque O. R., Ed.). Acta Horticulturae 357:237-242.

70.Patterson, D.T. 1998. Suppression of purple nutsedge (Cyperus rotundus) with polyethylene film mulch. Weed Technology 12:275-280.

71.Robert M. and Harsimran K. G. 2010. Introduction to Soil Solarization, Institute of Food and Agricultural Sciences, University of Florida. ENY 062.

72.Rubin, B., Cohen, O. and Gamliel, A. 2007. Soil solarization an environmentally-friendly alternative , The Volcani Center, P.O.B. 6, Bet Dagan 50250, Israel.

73.Saremi H, Amiri M.E, 2010. Exploration of potato cultivar resistant to the major fungal pathogen on potato wilting disease in Iran. J. F. A.

74.Environ. 8 (2): 821-826.

75. Saremi H, Amiri ME, Mirabolfathi M, (2011).I Application of soil solarizationfor controlling soilborne fungal pathogens in newly established pistachio and olive orchards. International J. Fruit Sci. 10: 143-156.

76. Saremi H, Okhovvat S. M, Ashrafi S. J (2007). Wilting of date palm means of solar heating of the soil by polyethylene mulching. Weed Sci., 28: 312–316.

77. Sesveren, S., Kırda, C., and Kaman, H., 2011. Effects of CO_2 enriched air and soil tillage on greenhouse solarization, Journal of Food, Agriculture & Environment Vol.9 (1): 550-556.

78. Shlevin, E., Mahrer, Y. and Katan. J. 2004. Effect of moisture on thermal inactivation of soilborne pathogens under structural solarization. Phytopathology 92:132-137.

79. Shlevin, E., Mahrer, Y., and Katan, J. 2004. Effect of moisture on thermal inactivation of soilborne pathogens under structural solarization. Phytopathology 94:132-137.

80. Soytong k., Sibounnavong, p. 2012, Genetic variation of *Fusarium oxysporum f. sp. lycopersici* isolated from tomatoes in Thailand using pathogenicity and AFLP markers , African Journal of Microbiology Research Vol. 6(27), pp. 5636-5644 .

81. Stapleton, J.J and DeVay, J.E. 1986. Soil solarization: a non-chemical approach for management of plant pathogens and pests. Crop Protection 5: 190-198.

82. Stapleton, J.J. 1991. Thermal inactivation of crop pests and pathogens and other soil changes caused by solarization pp 37-41. In soil solarization, FAO Plant production and protection paper 109. 396pp.

83. Stapleton, J.J. 1997. Solarization: An implementable alternative for soil disinfestation. In: Canaday, C. (Ed.), Biological and Cultural Tests for Control of Plant Diseases, Vol. 12. APS Press, St. Paul, pp. 1}6.

84. Stapleton, J.J., and C.M. Heald. 1991. Management of phytoparasitic nematodes by soil solarization. p. 51-59. In J. Katan and J.E. DeVay (eds.). Soil solarization. CRC Press, Boca Raton, FL.

85. Stapleton, J.J., and DeVay, J.E., 1995. Soil solarization: A natural mechanism of integrated pest management. In: Reuveni, R. (Ed.), Novel Approaches to Integrated Pest Management. Lewis Publishers, Boca Raton, pp. 309,322.

86. Stapleton, J.J., and DeVay, J.E.. 1984. Thermal components of soil solarization as related to changes in soil and root microflora and increased plant growth response. Phytopathology, 74: 255-259.

87. Stapleton. J.J. 2000. Soil solarization in various agricultural production systems, Kearney Agricultural Center, University of California,9240 S. Crop Protection 19 837-841.

88. Stevens .C., Khan V. A., Brown J. E., 1991, Soil solarization: the effects of organic amendments on growth and fertility of cole crops, in Proceedings of the 23rd National Agricultural Plastics Congress American Society of Plasticulture,vol.23,pp.272–280.

89. Stevens C., V.A. Khan, R. Rodriguez-Kabana, L.D. Ploper, P.A. Backman, D.J. Collins, J.E. Brown, M.A. Wilson, and E.C.K. Igwegbe, 2003. Integration of soil solarization with chemical, biological and cultural control for the management of soilborne diseases of vegetables. Plant and Soil 253, 493-506.

90. Subbarao, B. M, and Liu, Y. B. 2008. Comparative survival of sclerotia of *Sclerotinia minor* and *S. sclerotiorum*. Phytopathology 98:659-665.

91. Tamietti, G. and Valentino, D. 2006. Soil solarization as an ecological method for the control of Fusarium wilt of melon in Italy, Crop Protection, vol. 25, no. 4, pp. 389–397..

92. Tjamos EC, Antoniou P, Tjamos SE (2000). Implementation of soil solarization in Greece: conclusions and suggestions Crop Prot. pp. 843-846.

93. Tjamos, E. C., and D. R. Fravel. 1995. Detrimental effects of sublethal heating and *Talaromyces flavus* on microsclerotia of *Verticillium Dahliae*. Phytopathology, 85:388-392.

94. Yücel, S., and Çali, S. 1998, Studies on the effect of soil solarization including combinations with fumigant and antagonist in greenhouse to control soil borne pathogens in the East Mediterranean region of Turkey, in Soil solarization and integrated management of soil pests:, Aleppo, Syria (Stapleton, J. J., E.DeVay J., and Elmore C. L., Eds.). FAO plant production and protection paper 147:367-375.

95. Zhang ,S., Roberts , P. D., McGovern R. J. and Datnof, L.E. 2011. Fusarium Crown and Root Rot of tomato in Florida , Institute of Food and Agricultural Sciences (IFAS), Publication PP52.

بسم الله الرحمن الرحيم

جامعة الخليل

كلية الدراسات العليا والبحث العلمي

برنامج الوقاية النباتية

زيادة فعالية التعقيم الشمسي لمكافحة امراض الذبول الفيوزارمي على نباتات البندورة في المناطق الجبلية

إعداد: رزق غياضه

إشراف
أ . د رضوان بركات

الملخص

تم دراسة طرق تحسين كفاءة عملية التعقيم الشمسي في المناطق الجبلية من اجل مكافحة مرض الذبول الفيوزارمي (*Fusarium oxysporum* f. sp. *lycopersici* (FOL)) و مرض عفن الجذور الفيوزارمي (*Fusarium oxysporum* f. sp. *radicis lycopersici* (FORL))؛ واستخدمت لذلك طبقتين من ستائر البولي ايثلين يفصل بينهما 2−3 سم مفردة او مع اضافة 10% من مخلفات الدجاج اللاحم. و كذلك استخدم طبقة واحدة من ستائر البولي ايثلين مقارنة مع الشاهد، وذلك لمدة سبعة اسابيع خلال شهري تموز واب في موسمين متتالين(2011 و 2012)، في اراضي محطة العروب الزراعية . ولتقييم كفاءة العملية تم قياس درجات الحرارة وعدد ابواغ الفطريات الممرضة وشدة الاصابة بالمرض ومعدل نمو نباتات البندورة والتغير الكمي في تركيز العناصر الغذائية بالتربة.

واوضحت النتائج بان اضافة السماد العضوي مع تغطية التربة بطبقتين من البولي ايثلين زادت درجات الحرارة في التربة(15.2°م) مقارنة مع عدم اضافة السماد(10.5°م)، والتعقيم العادي(6.3°م) خلال موسم 2011، و بزيادة مماثلة في الموسم التالي. ووجد كذلك بان عدد الساعات المسجلة والتي تزيد فيها درجات الحرارة عن درجة الحرارة القاتلة (45°م) ؛ تراوحت بين 28–235 ساعة على التوالي خلال الموسمين، و كانت الاعلى تحت المعاملة طبقتي الستائر مع اضافة المادة العضوية. هذا وبالإضافة قللت معنويا من المسببات المرضية بنسبة 97%، ومنعت ظهور المرضين كليا، وزادت معدل نمو النباتات بنسبة 600%؛ وذلك يرجع الى زيادة تركيز العناصر المغذية من الامونيوم و النترات و البوتاسيوم والفسفور المنطلقة من تحلل المواد العضوية او من معادن التربة. كما و ادى استعمال الطبقتين من الستائر الى نتائج ايجابية معنوية ومماثلة لحالة اضافة السماد مع بعض الاختلافات المعنوية مقارنة مع طريقة التعقيم العادية والشاهد.