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INTENSIFIED SOIL SOLARIZATION WITH LOW TUNNEL: EFFECTS ON SOIL TEMPERATURE AND CARROT YIELD

AUMENTO NO AQUECIMENTO DO SOLO SOLARIZADO COM COBERTURA DE TÚNEL BAIXO E SEU EFEITO SOBRE A PRODUTIVIDADE DE CENOURA

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SUMMARY

Soil solarization has been used in regions and periods with high temperature and solar radiation availability. In cooler periods, however, this method is not effective in the open field, but may be improved inside closed glass and plastic greenhouses. In this study, the raise in soil temperature by using a low plastic tunnel to cover solarized soil to intensify soil heating was evaluated in the Central Region of the Rio Grande do Sul State, South Brazil. The effect of soil solarization on carrot yield was evaluated as well. On the average, maximum temperature in solarized soil under low tunnel was 5.2°C and 4.1°C in Summer and 5.3°C and 5.1°C in Fall, higher than usually solarized soil at 2 cm and 5 cm depths. A significant increase in carrot yield resulted by solarization, even in the absence of known pathogens.

Key words: solar heating, soil temperature, carrot.

RESUMO

A técnica da solarização é usada em regiões e períodos quentes e de elevada disponibilidade de radiação solar. Em períodos menos quentes a técnica não tem eficiência suficiente em condições de campo mas pode ser usada no interior de estufas, mantendo-as fechadas durante o tratamento. O objetivo do trabalho foi determinar o aumento do aquecimento do solo com o uso de um túnel baixo, cobrindo a parcela solarizada, em Santa Maria, RS. Foi ainda medida a produtividade da cenoura em área solarizada

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convencionalmente, com cobertura de túnel e em solo sem solarização. A temperatura máxima do solo foi, em média, 5,2°C e 4,1°C no verão e 5,3°C e 5,1°C no outono maior no solo solarizado com a cobertura de túnel em relação ao solo solarizado conven-cionalmente. A produtividade de cenoura nas áreas solarizadas foi significativamente superior à das áreas sem solarização.

Palavras-chave: solarização, temperatura do solo, cenoura.

INTRODUCTION

Soil solarization is a field pre-planting soil disinfestation method conceived and developed by KATAN et al. (1976) in Israel. The soil previously moistened is covered with transparent polyethylene mulch during the hot season, when the solar radiation is of high intensity. Many papers have shown the effectiveness of soil solarization as a method for controlling soilborne plant pathogens and weeds. Increase in plant growth and yield of field and protected crops was also refered in different countries over the world (KATAN, 1981; KATAN et al., 1987; KATAN & DEVAY, 1991; SCHNEIDER et al., 1993; STRECK et al., 1995).

In cooler regions or periods when solar radiation is of relatively low intensity, this method is not effective in the open field because maximum soil temperatures in the mulched soil are not high enough to reach lethal levels for soil pathogens. Under these especific climatic conditions however, soil solarization may be still effective in closed greenhouses, as demonstrated by GARIBALDI & TAMIETTI (1984) and MAHRER et al. (1987). On the other hand, even when solarization is effective in the open field, the period of treatment may be reduced by using closed greenhouse (MAHRER et al., 1987). As the method of soil solarization is dependent on solar radiation availability, its evaluation in different countries is an important approach that should be encouraged.

The purpose of this study was to evaluate the raise in solarized soil temperature by using a low tunnel cover in order to intensify soil heating. The effect of soil solarization on carrot yield was also evaluated.

MATERIAL AND METHODS

Two field experiments were carried out at the Crop Production Department of the Federal University of Santa Maria, Rio Grande do Sul State, Brazil (29°43'S latitude, 53°48'W longitude, and 95m altitude). Experiment-I was conducted in the Fall of 1993, from March 23rd through May 17th and

Experiment-II was performed in the Summer of 1994, from December 30th, 1993 through February 15th, 1994. The soil is loam, with 36% sand, 38% silt, and 26% clay. A 8m x 15m area was plowed and disked in order to bring the soil to a good tillage condition for both experiments.

Individual plots of 5m x 2m were used. Treatments were: soil covered with transparent mulch (T1), soil covered with transparent mulch plus a transparent low tunnel covering its, 0.5 height in the center (T2), and control bare soil (T3). Transparent polyethylene used for mulching and low tunnel covering had 100µm thickness. Soil water contents were maintained high in solarized and control plots throughout the experimental periods.

Soil temperature was measured daily at 9:00, 15:30 and 16:00, local standard time (LST), at 2cm and 5cm depths by using mercury-in-glass geothermometers burried in the center of each plot. Afternoon measurements corresponded to the time of maximum temperature at 2cm and 5cm depths (SCHNEIDER, 1979; STRECK et al., 1996).

On May 06th, 1993, a clear day, soil temperature was recorded from 5:30 through 21:00, every hour. Near the time of occurence of minimum and maximum soil temperatures at both depths, readings were done every 15 minutes. Thermal properties (soil heat capacity, thermal conductivity, and thermal diffusivity) of mulched and bare soil were estimated on May 06th according De VRIES (1963), DECICO (1974), SCHNEIDER (1979), and STRECK et al. (1996). The soil heat flux (S) was estimated on May 06th according to the Fick's law:

$$S = -K\left(\frac{\Delta T}{\Delta X}\right) \qquad (1)$$

where K = thermal conductivity of the soil ($W.m^{-2}.°C^{-1}$) and $\Delta T/\Delta X$ = temperature gradient.

"Nantes" carrot was sown on May 19th, 1993 (after solarization period of Experiment-I) in rows (2cm depth and 25cm between rows) and harvested in October 15th. Each treatment had three replications. The most common recommended agronomic practices for carrot crop were followed throughout the investigation. The yield parameters were weight and number of marketable and nonmarketable harvested roots. Root yield was sampled in a 1m x 0.25m area and replicated five times inside each plot. Nonmarketable yield was roots less than 12cm in lenght. Yield data were submitted to analysis of variance and differences among means were performed by using Duncan's test.

RESULTS AND DISCUSSION

Soil heat flux was higher in solarized soils, resulting greater soil heating (Figure 1). There was an increase in soil heat flux during the daytime in solarized soil covered with a low tunnel. This technique promoted higher values of soil temperature as compared to the uncovered solarized soil, particularly at the time of the day when solar radiation reached maximum values.

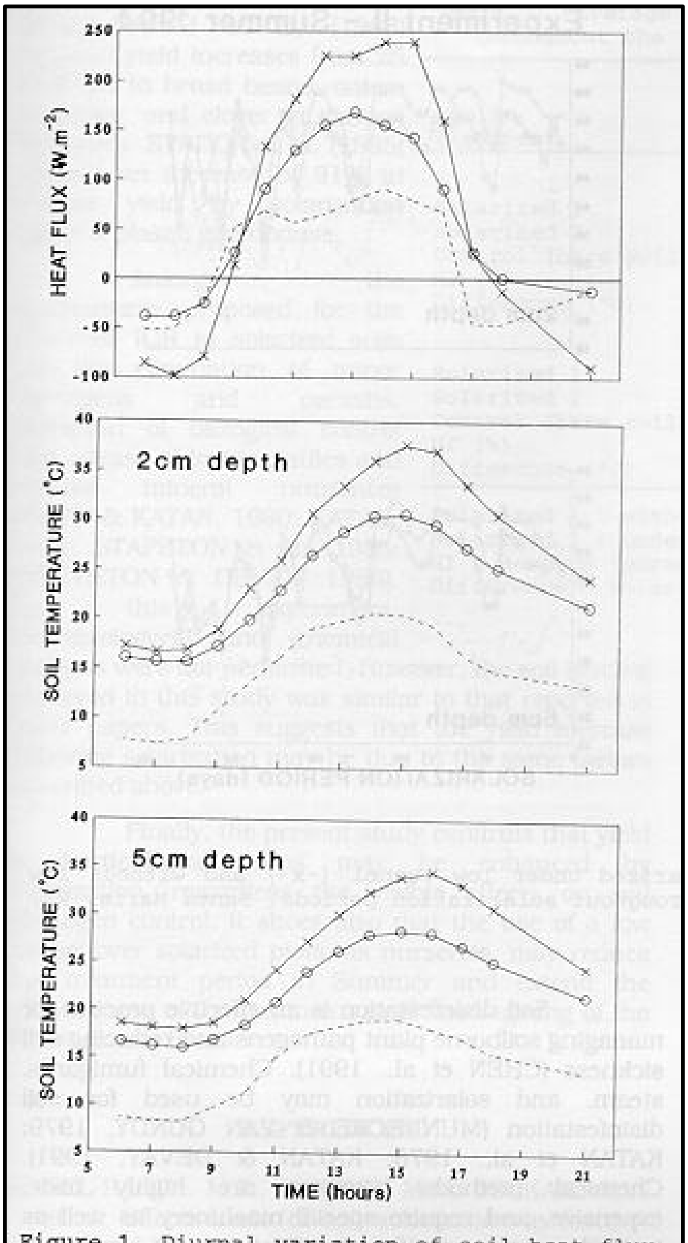

Figure 1. Diurnal variation of soil heat flux and soil temperature in soil solarized under low tunnel (-x-) and without low tunnel (-o-) and in control bare soil (---) on May 06th, 1993. Santa Maria, RS, Brazil.

Daily values of maximum temperature and the average temperature at the measured times in solarized and control soils throughout the experimental periods are presented in Figure 2 and Table 1. The maximum temperatures were always higher in solarized soils than in bare soil at the two depths, and differences between solarized treatments were observed. The low tunnel (T2) promoted higher temperature values and mulching the soil only with one transparent sheet was also higher than bare soil. The temperature differences among the solarized and bare soils and between the solarized soils were greater on clear days than on cloudy days. In addition, soil temperature was higher in Summer than in Fall. During the Summer, soil temperature at 5cm depth often exceeded 50°C in the solarized soil only with transparent mulch and 55°C under low tunnel. In Fall however, the soil temperature did not reach 45°C or 50°C in both treatments, respectively. On the average, maximum temperatures in solarized soil covered with low tunnel were 5.3°C and 5.1°C higher than in usually solarized soil at 2 cm and 5 cm depths, respectively in Experiment-I and 5.2°C and 4.1°C in Experiment-II.

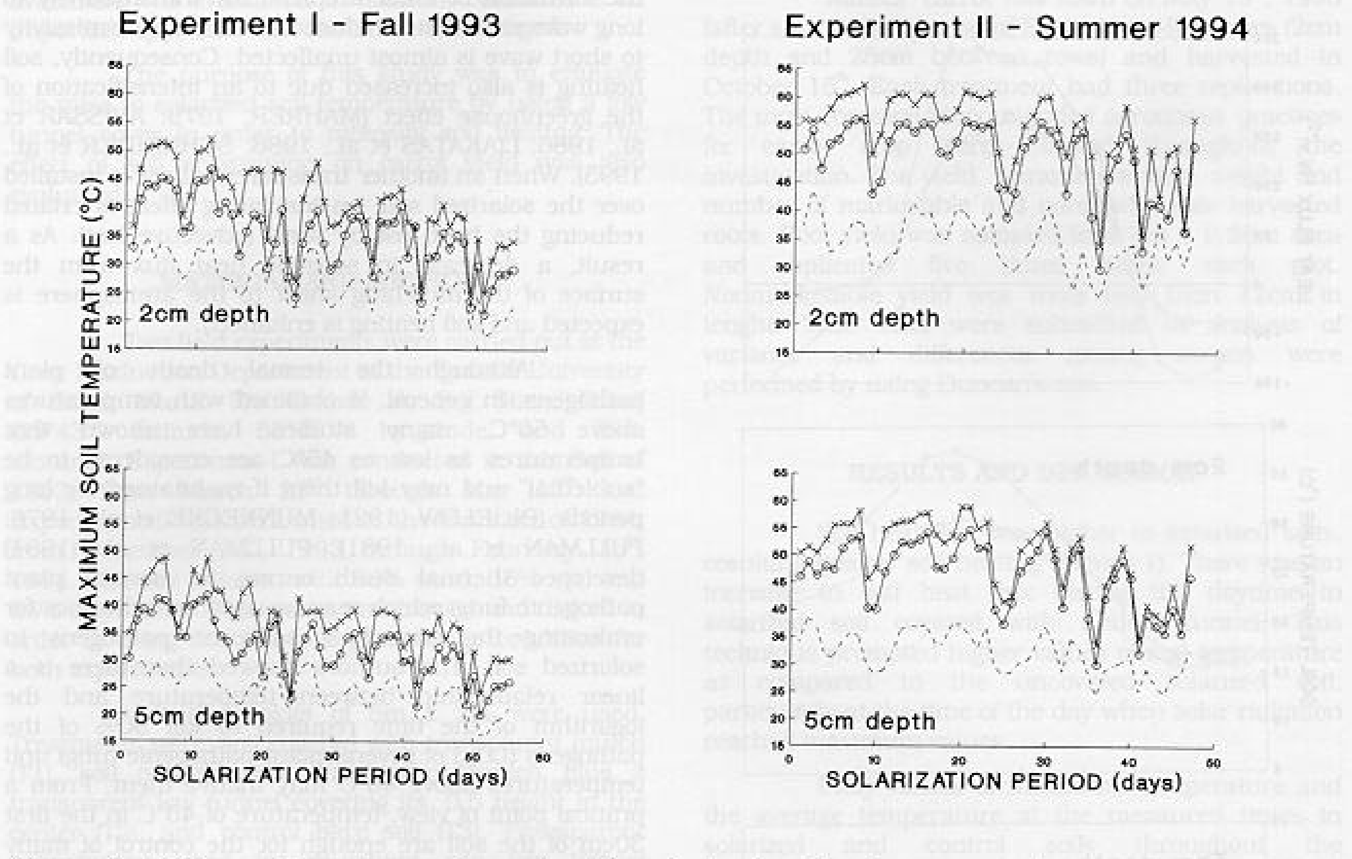

Figure 2. Daily maximum temperature of soil solarized under low tunnel (-x-) and without low tunnel (-o-) and in control bare soil (---) throughout solarization periods. Santa Maria, RS, Brazil, 1993/94.

Similar differences were observed at the other measured times, but temperature differences between the two solarized treatments were greater for morning measurements during Summer than Fall. This occured certainly because the night lenght is shorter in Summer and consequently, the net radiation at night is not significantly lower. In general, the use of a low tunnel covering the solarized soil promoted a heating increase of 5-13% in the morning and 8-15% in the afternon.

The increase in soil temperature by transparent mulches during the daytime is due to a decrease in sensible and latent heat fluxes, and thereby increasing the amount of available heat for soil heating. This hipothesis has been proved by several reports (MAHRER, 1979; AVISSAR et al., 1986; LIAKATAS et al., 1986). Furthemore, when a transparent plastic sheet covers a moistened soil, water condenses on its inner surface and as a result of the formation of water droplets, the transmissivity to long wave radiation is reduced, while its transmissivity to short wave is almost unaffected. Consequently, soil heating is also increased due to an intensification of the greenhouse effect (MAHRER, 1979; AVISSAR et al., 1986; LIAKATAS et al., 1986; SCHNEIDER et al., 1993). When an another transparent sheet is installed over the solarized soil, an insulating effect is criated reducing the heat lost by wind (advective lost). As a result, a decrease in sensible heat flux from the surface of the mulching sheet to the atmosphere is expected and soil heating is enhanced.

Although the termal death of plant pathogens, in general, is obtained with temperatures above 50°C, many studies have shown that temperatures as low as 45°C are considered to be "sublethal" and may kill them if maintained for long periods (BIGELOW, 1921; MUNNECKE et al., 1976; PULLMAN et al., 1981). PULLMAN et al. (1981) developed thermal death curves for several plant pathogenic fungi which may be used as indicators for evaluating the control of soilborne pathogens in solarized soil. The authors showed that there is a linear relationship between temperature and the logarithm of the time required to kill 90% of the pathogens (LD_{90}) of several plant pathogenic fungi and temperatures above 40°C may inative them. From a pratical point of view, temperature of 40°C in the first 30cm of the soil are enough for the control of many soilborne pest (KATAN, 1981). Although the soil temperature was measured only until 5cm depth, some inferences may be made. In the Summer experiment, soil temperature at 5cm depth reached 54.4°C and 58.2°C during January and in the Fall experiment 41.8°C and 48.6°C during March, respectively in soil solarized only with transparent mulch and under low tunnel. In addition, temperatures above 40°C at 5cm depth were observed in 36 and 41 days in Summer and 5 and 12 days in Fall for soil solarized only with transparent mulch and under low tunnel, respectively. These temperatures were observed until April 06th, in solarized soil with transparent mulch while in solarized soil under low tunnel the temperature reached 40°C until April 16th. These temperatures are similar to those reported in other countries where soil solarization is an effective method for controlling soilborne pathogens, as Israel (KATAN et al., 1976; MAHRER, 1979), Iraque (HASSON & HUSSAIN, 1986), Italy (GARIBALDI & TAMIETTI, 1984), USA (STAPLETON et al., 1985) and Spain (MELERO et al., 1988). Thus, it is hoped that if 40°C had occurred until 30cm depth including in Fall by using the low tunnel. From a practical point of view, these results allow to infer that solarization period may be extended until the begining of the Fall, which may be a potentially important information for the planning of local growers.

Marketable yield of carrot was significantly greater in solarized plots as compared to bare soil (Table 2). Root weight increased 36% and 39%, respectively in solarized soil only with transparent mulch and under low tunnel. There were no significant differences between the solarized treatments. Nonmarketable yield was significantly greater for the control bare soil, because carrot roots were larger in solarized soil.

Repeated planting of the same crop on the same soil is particularly common in horticulture crops usually providing optimum conditions to enhance inoculum potencial and diseases. As a result, soilborne plant diseases are often a great problem in many countries (MUNNECKE & VAN GUNDY, 1979). In addition, monoculture intensifies the accumulation of deleterious fators which may cause growth retardation of crops. In modern plant pathology, soil sickness is a term which describes the poor plant growth and yield decline of field crops under continuous cropping sistems and monoculture (sewell, 1984 apud CHEN et al., 1991). The term is also known as soil fatigue, replant disease, and tired soil. Plants growing in these soils show growth retardation, delayed flowering, and reduced yield (CHEN et al,. 1991).

Table 1. Average soil temperature of solarized and bare soils throughout the two experiments. Santa Maria, RS, Brazil.

Soil Treatment	9:00		15:30		16:00	
	2cm	5cm	2cm	5cm	2cm	5cm
			Experiment I - Fall 1993			
Solarized 1	25.3	23.4	35.0	31.9	34.2	32.2
Solarized 2	26.6	25.7	40.3	36.9	39.5	37.3
Control (bare soil)	21.2	19.6	26.9	24.5	26.1	25.0
HI (%)	5.3	9.8	15.1	15.6	15.5	15.8
Difference (°C)	1.3	2.3	5.6	5.0	5.3	5.1
			Experiment II - Summer 1993/94			
Solarized 1	34.5	33.0	49.0	46.4	48.3	46.0
Solarized 2	39.2	37.1	54.2	49.9	53.1	50.1
Control (bare soil)	26.5	25.1	34.2	32.4	33.3	32.2
HI (%)	13.6	12.4	10.6	7.5	9.9	8.0
Difference (°C)	4.7	4.1	5.2	3.5	4.8	4.1

Solarized 1 = without low tunnel
Solarized 2 = under low tunnel
HI = Heating increase of solarized 2 over solarized 1
Difference = Solarized 2 - Solarized 1

Soil disinfestation is an effective practice for managing soilborne plant pathogens and reducing soil sickness (CHEN et al., 1991). Chemical fumigants, steam, and solarization may be used for soil disinfestation (MUNNECKE & VAN GUNDY, 1979; KATAN et al,. 1976; KATAN & DEVAY, 1991). Chemical methods however, are highly toxic, expensive, and require special machinery as well as trained personnel for application. In addition, pesticide-free agriculture has become very popular in recent years with increased demand for "health products". Thus, soil solarization has shown be a potentially "ecological" usefull practice against soil sickness.

In addition, to reduce soil pathogens and weeds, soil solarization often results in increased plant growth and yield response (IGR). This may be observed even when no major plant pathogens or pests are isolated from soil or plant roots (CHEN & KATAN, 1980; KATAN, 1981, STAPELTON et al., 1985; ABDEL-RAHIM et al., 1988; KATAN & DEVAY, 1991; STRECK et al., 1995). The results obtained in this experiment on crop yield are in agreement with other reports. STAPLETON et al. (1985) found dry weight increases from 66% to 450% in radish when grown in solarized soils. ABDEL-RAHIM et al. (1988) reported yield increases from 25 to 432% in broad beans, onion, tomatoes, and clover in varions soil types. STRECK at al. (1995) showed an increase of 91% in tomato yield by solarization inside a plastic greenhouse.

Among the mechanisms proposed for the observed IGR in solarized soils are the elimination of minor pathogens and parasits, induction of biological control and release of toxic volatiles and soluble mineral nutrientes (CHEN & KATAN, 1980; KATAN, 1981, STAPETON et al., 1985; STAPLETON & DEVAY, 1986). In this experiment, microbiologycal and chemical analysis were not performed. However, the soil heating observed in this study was similar to that reported in other papers. This suggests that the yield increase following solarization may be due to the same factors described above.

Finally, the present study confirms that yield of horticultural crops may be enhanced by solarization, regardless the visible effects on soil pathogen control. It shoes also that the use of a low tunnel over solarized plots, as nurseries, may reduce the treatment period in Summer and extend the effectiveness of the treatment until the begining of the Fall in South Brazil.

Table 2. Effect of soil solarization on marketable and nonmarketable yield of carrot. Santa Maria, RS, Brazil, 1993.

Soil Treatment	Marketable			Nonmarketable		
	$kg.m^{-2}$	$number.m^{-2}$	average weight ($g.root^{-1}$)	$kg.m^{-2}$	$number.m^{-2}$	average weight ($g.root^{-1}$)
Solarized 1	2.122a	54.0b	38.93a	0.232b	12.8b	13.9a
Solarized 2	2.176a	64.8a	33.97a	0.197b	19.6b	11.0a
Control (Bare soil)	1.569b	61.2ab	26.07b	0.646a	81.2a	9.5a

Means within each colunn not followed by the same letter are significantly different at the 5% level according to Duncan's test.
1 = without low tunnel
2 = with low tunnel

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