Revista Brasileira de Agrometeorologia, Santa Maria, v. 4, n. 1, p. 15-20, 1996.
Recebido para publicação em 04/10/95. Aprovado em 09/02/96.

EFFECT OF BLACK POLYETHYLENE MULCH ON THE THERMAL REGIME OF A SOIL[1]

EFEITO DA COBERTURA COM POLIETILENO PRETO SOBRE O REGIME TÉRMICO DE UM SOLO

Nereu Augusto Streck[2], Flavio Miguel Schneider[2], Galileo Adeli Buriol[2,3], Arno Bernardo Heldwein[2]

SUMMARY

Two experiments were carried out at Santa Maria, Central Region of the Rio Grande do Sul State, Brazil, in order to measure the effect of black polyethylene mulch on soil temperature. One experiment was installed in an open field from March 24, 1993 to May 17, 1993. The other experiment was performed inside a plastic greenhouse from August 21, 1994 to December 01, 1994. Daily measurements of soil temperature in both mulched and bare soil were taken in the two experiments. Highest estimated values of soil heat flux were obtained in mulched soil. In general, minimum, mean, and maximum soil temperatures were higher in mulched soil. Black polyethylene decreased the maximum amplitude of soil temperature wave.

Key words: mulching, soil temperature, thermal properties of soil.

RESUMO

Foram instalados dois experimentos em Santa Maria, RS, Brasil, com o objetivo de quantificar o efeito da cobertura do solo com polietileno preto sobre a temperatura do solo. Um experimento foi realizado em condições de campo, de 24 de Março a 17 de Maio de 1993 e outro no interior de uma estufa plástica, de 21 de Agosto a 01 de Dezembro de 1994. A temperatura do solo foi medida diariamente no solo com cobertura e no solo desnudo. Os valores estimados de densidade de fluxo de calor no solo foram

[1] Research supported by FAPERGS (Fundação de Amparo à Pesquisa do Rio Grande do Sul) and PETROQUÍMICA TRIUNFO S.A.

[2] Professor of the Departamento de Fitotecnia, Centro de Ciências Rurais, Universidade Federal de Santa Maria. 97119-900, Santa Maria, RS, Brazil. Internet:nereu@super.ufsm.br.

[3] CNPq Fellowship.

maiores no solo com cobertura de polietileno preto. A temperatura mínima, média e máxima do solo foi maior no solo com cobertura. O polietileno preto diminuiu a amplitude máxima da onda diária de temperatura do solo.

Palavras-chave: cobertura, temperatura do solo, propriedades térmicas do solo.

INTRODUCTION

Soil temperature is an important edaphic factor that can influence many processes such as evapotranspiration, growth and development of plants, biological activity and others. Mulches are most commonly used in horticulture to suppress weeds, reduce water loss from soil surface, increase nutrient availability, and modify soil microclimate.

Changes in soil temperature due to black plastic mulches have been reported by several researchers. Recently, STRECK et al. (1994) reviewed the effects of various mulches on soil microclimate. The damping of the soil temperature wave is the primary effect of opaque mulches.

Black polyethylene (PE) is highly opaque to solar and terrestrial radiations (ROSENBERG, 1974; LIAKATAS et al., 1986), thus the minimun and mean temperatures are increased by the black PE as compared to bare soil (STRECK et al., 1994). A review of the effect of black PE on maximum soil temperature, however, shows that is a controversial issue. Although a greater number of papers report that maximum soil temperature is increased by black PE because of heat conduction from the hot sheet to the soil (GLINIECKI, 1959; TAKATORI, et al., 1964; COUTER & OEBKER, 1964; PENDLETON et al., 1966; EKERN, 1967; KNAVEL & MOHR, 1970; INADA, 1973; MAURYA & LAL, 1981; GURNAH & MUTEA, 1982; TRIPATHY & KATIYAR, 1984; LIAKATAS et al., 1986; HAYNES, 1987; SALMAN et al., 1990; TRUAX & GAGNON, 1993) some results of soil temperature decrease by black PE have been found (HOPEN, 1965; BENNET et al., 1966; DECICO & SANTOS, 1976; CHOPRA & CAUDHARY, 1980; SILVA, 1980; BERTON, 1981). STRECK et al. (1994) attributed these divergences to climatic factors, mode of mulch use, quality and thickness of mulch material, mulch width, and mainly, the soil moisture conditions of bare soil during the measurements. Mulch materials block the transport of vapor out of the soil, and consequently, reduce water losses from the soil. In contrast, in a bare soil with high soil moisture a large fraction of the net radiation is consumed as latent flux. Consequently, the bare soil dries quickly. Thus, if the soil moisture of the bare soil is not controlled, the temperature difference between mulched and bare soil can not be attributed only to the mulch material.

The purpose of this study was to measure the alterations in the thermal regime of a soil by black PE mulch, in the Central Region of the Rio Grande do Sul State, Brazil.

MATERIAL AND METHODS

Two experiments were carried out at the Experimental Field Station of 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 95 m altitude). The texture of the soil is loam, with 36% sand, 38% silt, and 26% clay.

The first experiment was installed in an open field. A 8mx15m area was plowed and disced in order to bring the soil to a good tillage condition. One 1.5m x 15m plot was mulched with black PE 30µm thikness from March 24, 1993 to May 17, 1993, and another plot (same size) was kept without covering, as a control (bare soil).

The soil was moistened (field capacity) to a depth of 50cm one day before mulching. No additional water was applied to the mulched plot during the experimental period. The control plot was irrigated daily at about 10 o'clock, except in rainy days, in an attempt to maintain its soil moisture similar to the covered one. The quantity of water applied was estimated according to atmospheric conditions.

Soil temperature was measured throughout the experimental period using mercury-in-glass geothermometers at 2 cm and 5 cm depth. Daily measurements of soil temperature were taken at 15h30min and 16h00min, local standard time (LST). On 05/06/93, a clear day, soil temperature was recorded between 6h00min and 21h00min, every hour. Near to the time of occurence of minimum and maximum temperatures at each depth, the reading interval was reduced to 15min. The soil moisture content was measured by the gravimetric method on 05/06/93 at 16h00min. Six samples per treatment were colected in a 0-5 cm layer. Thermal properties of mulched and bare soil were estimated on 05/06/93. Soil heat capacity (C) was calculated according to De VRIES (1963).

$$C = 0.44 \; X_m + 0.6 \; X_0 + X_w \qquad (1)$$

Where X_m, X_0, and X_w denote the volumetric fraction of minerals, organic matter, and water of the soil, respectively.

The thermal diffusivity (D) of the soil was calculated after (DECICO, 1974; SCHNEIDER, 1979).

$$D = \frac{w}{2}\left[\frac{z_j - z_i}{l\,n\left(\frac{\Delta T_i}{\Delta T_j}\right)}\right]^2 \qquad (2)$$

Where ù = angular velocity of the earth [(7.272)10^{-5} rad.s^{-1}], z_i and z_j are the soil depths (cm), and

ΔT_i = $Tmax_i$ - _(z_i);

ΔT_j = $Tmax_j$ - _(z_j); Tmax and _ are the maximum and mean soil temperatures at *i* and *j* depths (z), respectively. Mean soil temperature (_$_z$) was calculated by:

$$\overline{T}_z = \frac{(Tmin_z + Tmax_z)}{2} \qquad (3)$$

The thermal conductivity (K) was obtained from the relation between C and D (DECICO, 1974; SCHNEIDER, 1979):

$$K = C\,.D \qquad (4)$$

The soil heat flux (S) was estimated on 05/06/93 according to the Fick's law:

$$S = -K\left(\frac{\_T}{\_X}\right) \qquad (5)$$

Where K = thermal conductivity (cal.cm^{-1}.°C^{-1}.s^{-1}) and ÄT/ÄX = temperature gradient (°C.cm^{-1}).

The second experiment was performed inside a 10m x 25m nonheated plastic greenhouse. Four 5.2m x 2m plots were covered with black PE 30ìm thickness from August 21, 1994 to December 01, 1994. Seedlings of "Monte Carlo" tomato, an indeterminated growth variety, was planted on August 22, 1994 using 0.40 m x 1.00 m plant spacing. Each plot had two rows with tomato plants (13 plants/row). Plants were irrigated by drip irrigation lines under the mulch. Water was applied through the irrigation lines as needed to keep tensiometer readings below 80 kPa. One tensiometer was placed at the 10cm depth within a row of tomato plants in the plot where soil temperature was measured. Geothermometers were buried at 2 cm, 5 cm, 10 cm, and 20cm depths within a row of tomato plants in one mulched plot. The control plot was composed of a 1 m^2 noncropped area (unmulched bare soil) at the center of the greenhouse. Geotermometers were installed at the same depths of the mulched plot. Control plot was not cropped during the experiment and irrigated as described in first experiment.

Daily measurements of soil temperature in both mulched and control plots were taken at 9h00min, 15h30min, 16h00min, 17h30min, and 21h00min (LST). At Santa Maria, Rio Grande do Sul State, Brazil, the minimum soil temperature at the 20 cm depth occurs near to 9h and the maximum soil temperatures at 2 cm, 5cm, 10 cm, and 20 cm depths occur near the afternoon measurements mentioned above, respectively (SCHNEIDER, 1979). Thus, the mean soil temperature at 20 cm depth ($\_{20}$) was calculated according to equation (3).

According to DECICO (1974) and SCHNEIDER (1979) if the mean soil temperature at a given depth is known, it can be assumed as being the mean temperature of the soil profile. Assuming that the waves of soil temperature follow a sinuosidal model, regardless of the depth, the maximum amplitude of the soil temperature wave (T_0) at each depth (i) can be estimated by:

$$T_0 = Tmax_i - \overline{T}_{20} \qquad \textbf{(1)}$$

Equations (3) and (6) were used to estimate the mean temperature of soil and the maximum amplitude of each soil depth in mulched and bare soils.

RESULTS AND DISCUSSION

Soil moisture was somewhat higher in the mulched than the bare soils on the measurement day: 05/06/93 (Table 1). Consequently, thermal properties of the soil, mainly volumetric heat capacity (C) and thermal conductivity (K), were higher for the mulched soil. Although the bare soil was irrigated one day before the measurements, the water loss from the soil was very intense for the bare soil as compared to the mulched soil. Similar results were obtained by DECICO & SANTOS (1976). Soil mulching reduce soil evaporation and improve water conservation.

Soil heat flux was higher in soil under black mulch than in bare soil, particularly at the early afternoon and the early evening of 05/06/93 (Figure 1). This result is in conflict with other reports that show a decreasing of soil heat flux by black PE (ROSENBERG, 1974; TRIPATHI & KATIYAR, 1984; LIAKATAS et al., 1986). LIAKATAS et al. (1986) reported values of maximum heat into the soil of up to 48% smaller in mulched soil with black PE as compared to the bare soil. As explained previously, the large number of papers which describe the effect of black PE on soil temperature do not present a control of the soil moisture in both treatments. Thus, it is probable that a greater quantity of net radiation was used as latent heat flux and litle remained to be used as sensible heat and soil heat flux in the bare soil.

Table 1 - Moisture content and thermal properties of soil mulched with black polyethylene and bare soil on 05/06/93. Santa Maria, RS, Brazil.

Treatment	θ	C	K	D
Mulched	0.262	0.51	4.62	9.3
Bare soil	0.222	0.45	4.08	9.1

θ=volumetric wetness ($cm^3.cm^{-3}$), C=volumetric heat capacity ($cal.cm^{-3}.°C^{-1}$), K=thermal conductivity ($cal.s^{-1}.cm^{-1}.°C^{-1}$)x$10^{-3}$, D=thermal diffusivity ($cm^2.s^{-1}$)x10^{-3}.

The highest soil heat flux under black PE mulch resulted in higher values of the soil temperature wave on 05/06/93 as compared to the bare soil (Figure 2). During the early morning and the early evening, soil temperature diferences between mulched and bare soil were larger then near noon. Similar results were reported by MAURYA & LAL (1981) and LIAKATAS et al. (1986). Differences of minimum, mean, and maximum soil temperatures between mulched and bare soil were similar on cloudy and clear days. In general, minimum, mean, and maximum soil temperatures were high in the mulched soil in both experiments, regardless the depth (Table 2). These results are similar to those reported in many papers including INADA (1973), ROSENBERG (1974), LIAKATAS et al. (1986), HAYNES (1987), and STRECK et al. (1994)

A particular response was observed in the greenhouse experiment: maximum soil temperature on clear days was higher in the bare soil at 2cm depth (Table 2). DECICO & SANTOS (1976) reported similar results: on a clear day, the maximum soil temperature was higher in the bare soil at 1cm depth, similar to the mulched soil at 9 cm depth, and higher in the mulched soil at 27 cm depth. Two causes can explain these results: (i) inside a plastic greenhouse SCHNEIDER et al. (1993) demonstrated that soil temperature is increased compared to the outside. According to the authors a decrease in latent and sensible fluxes is caused by a poor exchange of air between inside and outside the plastic greenhouse.

Thus, a greater soil heat flux into the bare soil can be expected inside the plastic greenhouse. (ii) clear days used in this experiment were distributed throughout the tomato growing period. Thus, days with litle and greater shading of soil surface by plants were included. The effect of soil mulching decreased as the crop developed and shaded the surface (COUTER & DEBKER, 1964; ROSENBERG, 1974). The average of minimum, mean and maximum soil temperature during the 10 first days of the greenhouse experiment, when crop shading was small, showed the same trend of the noncropped field experiment

Table 2 - Average values of minimum (Min), mean, maximum (Max) temperatures, and maximum amplitude of temperature (T_0) of soil mulched with black polyethylene and bare soil. Santa Maria, RS, Brazil.

Experiment	Depth (cm)	Mulched soil				Bare soil			
		Min	Mean	Max	T_0	Min	Mean	Max	T_0
.... Average of the experimental period									
1993	2	-	-	29.6	-	-	-	26.9	-
	5	-	-	27.1	-	-	-	24.5	-
1994	2	-	24.2	29.0	4.8	-	22.0	28.8	6.8
	5	-		28.2	4.0	-		27.6	5.6
	10	-		26.7	2.5	-		26.6	4.6
	20	23.4		24.9	0.7	20.3		23.7	1.7
.... 10 first days of experimental period									
1994	2	-	20.0	25.0	5.0	-	17.7	23.8	6.1
	5	-		24.4	4.4	-		22.5	4.8
	10	-		22.5	2.5	-		21.9	4.2
	20	19.2		20.8	0.8	16.2		19.2	1.5
.... 5 clear days ($n/N > 0.9$)									
1993	2	-	-	31.1	-	-	-	28.2	-
	5	-	-	27.4	-	-	-	25.5	-
1994	2	-	24.4	29.9	5.5	-	22.0	31.2	9.2
	5	-		29.5	5.1	-		29.5	7.5
	10	-		27.5	3.1	-		27.0	5.0
	20	23.4		25.5	1.1	20.1		23.9	1.9
.... 5 cloudy days ($n/N < 0.1$)									
1993	2	-	-	23.8	-	-	-	21.5	-
	5	-	-	22.9	-	-	-	20.5	-
1994	2	-	23.0	25.0	2.0	-	21.0	23.6	2.6
	5	-		24.7	1.7	-		23.0	2.0
	10	-		23.7	0.7	-		22.8	1.8
	20	22.8		23.2	0.2	19.4		22.5	1.5

n = sunshine duration (hours.day^{-1})
N = day length (hours.day^{-1})

(Table 2).

The results reported in this paper sustain the controversial issue of the effect of black PE on maximum soil temperature. As indicated in the Table 3, although the greater number of days the maximum soil temperature was higher in mulched soil during the experiment 1993 (noncropped soil), the cropping modified this behavior particullarly in upper layers. However, at 20 cm depth in the experiment 1994 the behavior was similar to the experiment 1993. Thus, an additional factor should be considered in studies of soil temperature modifications by black PE, i.e., the crop shading. However, if considering only the experiment 1993 where the soil moisture in both treatments was as similar as possible and the soil was not cropped, than the results are in agreement with the papers that report an increase in maximum soil temperature by black PE.

Table 3 - Percentage of days at which the maximum soil temperature was greater in mulched than bare soil. Santa Maria, RS, Brazil.

Experiment	Depth (cm)	% mulched > bare soil
1993	2	94.2
	5	90.4
1994	2	56.0
	5	64.0
	10	70.0
	20	92.0

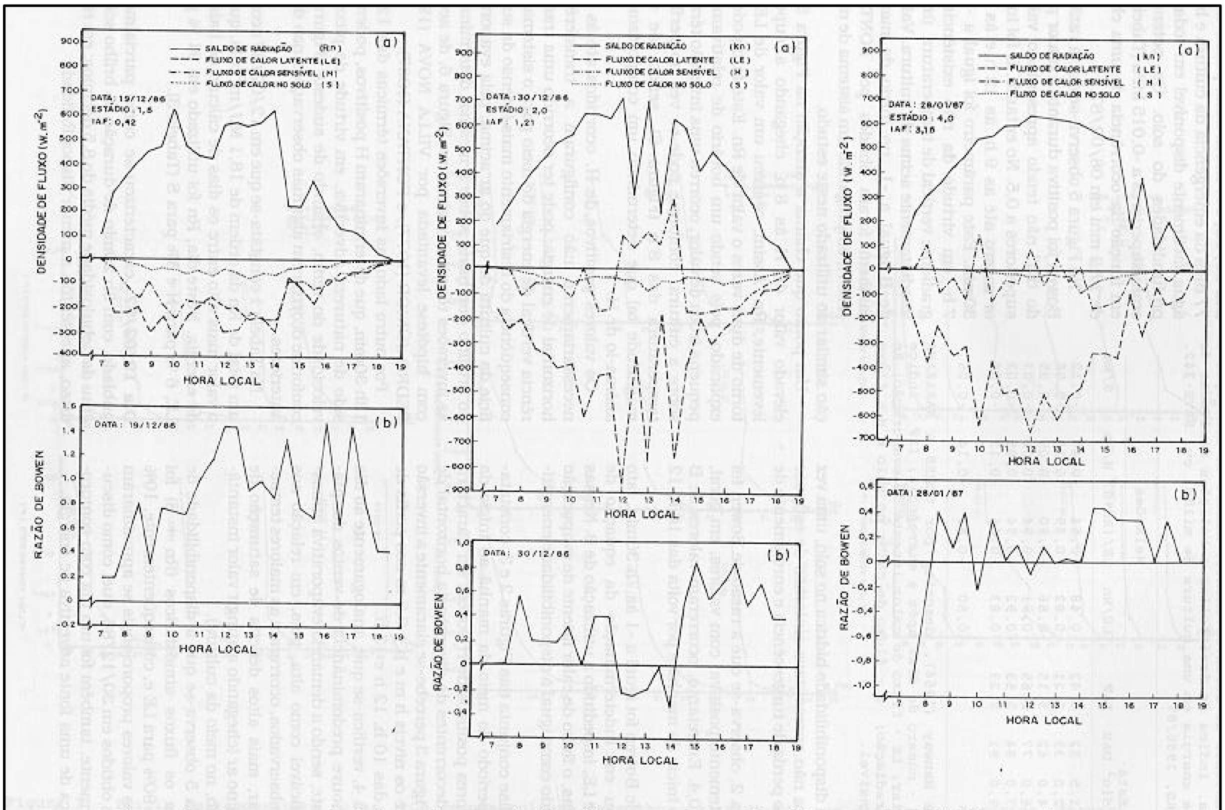

Figura 2 - Componentes do balanço de energia (W.m^{-2}) em uma cultura de milho, cv. SAVE-342(a) e razão de Bowen(b). Taquari, RS, 19/12/86, 30/12/86 e 28/01/87.

The maximum amplitude of soil temperature was decreased by black PE (Table 2). This decrease was larger on clear days. These results are in agreement with those reported by other researchers (ROSENBERG, 1974; DECICO & SANTOS, 1976; LIAKATAS et al., 1986; STRECK et al., 1994). Opaque mulches damp the wave of soil temperature as a consequence of their high opacity to solar and terrestrial radiations. Therefore, the most important thermal effect of soil mulching with opaque materials is the decrease of the variation of the daily soil temperature.

REFERENCES

BENNETT, O. L., ASCHLEY, D. A., DOSS, E. D. Cotton responses to black plastic mulch and irrigation. **Agronomy Journal**, Madison, v. 58, p. 57-60, 1966.

BERTON, R. S. **Efeito da cobertura de polietileno na temperatura do solo e na produção do feijoeiro (*Phaseolus vulgaris* L.) Carioca**. Piracicaba, SP. 1981. 83 p. Dissertação (Mestrado em Agrometeorologia), Escola Superior de Agricultura "Luiz de Queiróz", 1981.

CHOPRA, U. K., CHAUDHARY, T. N. Effect of soil temperature alterations by soil covers on seedling emergence of wheat (*Triticum aestivum* L.) sown on two dates. **Plant and Soil**, Den Haag, v. 57, p. 125-129, 1980.

COURTER, J. W., OEBKER, N. F. Comparison of paper and polyethylene mulching on yields of certain vegetable crops. **Proceedings of American Society for Horticultural Science**, St Joseph, v. 85, p. 526-531, 1964.

DECICO, A. **A determinação das propriedades térmicas do solo em condições de campo**. Piracicaba, SP. 1974. 91 p. Tese (Docente-Livre), Escola Superior de Agricultura "Luiz de Queiróz", 1974.

DECICO, A., SANTOS, J. M. Comportamento térmico do solo sob diferentes condições de cobertura. In: CONGRESSO BRASILEIRO DE CIÊNCIA DO SOLO, X, Campinas, 1975. **Anais...**, Campinas: Sociedade Brasileira de Ciência do solo, 1976. 616 p. p. 55-62.

De VRIES. D. A. **Thermal properties of soil**. In: Van VIJK, W.R. **Physics of plant environment**. Amsterdan: North-Holland Publiscihng, 1963. p. 210-235.

EKERN, P. C. Soil moisture and soil temperature changes with the use of black vapour-barrier mulch and their influence on pineapple (*Ananas comosus* (L.) Merr.) growth in Hawwai. **Soil Science Society of America Proceedings**, Houston, v. 31, n. 2, p. 270-275, 1967.

GLINIECKI, V. L. Polyethylene films for agriculture. **Down to Earth**, Midland, p. 7-9, 1959.

GURNAH, A. M., MUTEA, J. Effects of mulches on soil temperatures under *Arabica* coffee at Kabete, Kenya. **Agricultural Meteorology**, Amsterdam, v. 25, p. 237-244, 1982.

HAYNES, R .J. The use of polyethylene mulches to change soil microclimate as revealed by enzyme activity and biomass nitrogen, sulphur and phosphorus. **Biology and Fertility of Soil**, v. 5, n. 3, p. 235-240, 1987.

HOPEN, H. J. Effects of black and transparent polyethylene mulches on soil temperature, sweet corn growth and maturity in a cool growing season. **Proceedings of American Society for Horticultural Science**, St Joseph, v. 86, p. 415-420, 1965.

INADA, K. Photo-selective plastic film for mulch. **Japan Agricultural Research Quartery**, Tokyo, v. 7, p. 252-256, 1973.

KNAVEL, D .E., MOHR, H. C. Distribution of roots of four differents vegetable under paper and polyethylene mulches. **Proceedings of American Society for Horticultural Science**, St Joseph, v. 91, p. 589-597, 1970.

LIAKATAS, A., CLARK, J. A., MONTEITH, J. L. Measurements of the heat balance under plastic mulches. **Agricultural and Forest Meteorology**, Amsterdam, v. 36, p. 227-239, 1986.

MAURYA, P. R., LAL, R. Effects of different mulch materials on soil properties and on the root growth and yield of maize (*Zea mays*) and cawpea (*Vigna unguiculata*). **Field Crops Research**, Amsterdam, v. 4, p. 33-45, 1981.

PENDLETON, J. W., PETERS, D. B., PEEK, J. W. Role of reflected light in the corn ecosystems. **Agronomy Journal**, Madison, v, 58, p. 73-74, 1966.

ROSENBERG, N. J. **Microclimate: the Biological Environment**. New York: John Wiley & Sons, 1974. 315 p.

SALMAN, S. R., BAKRY, M. O., ABOU, A. F., et al. The effect of plastic mulch on the microclimate of plastic greenhouse. **Acta Horticulturae**, Den Haag, n. 287, p. 471-425, 1990.

SCHNEIDER, F. M. **Comportamento e propriedades térmicas do solo Santa Maria**. Piracicaba, SP, 1979. 77 p. Dissertação (Mestrado em Agrometeorologia), Escola Superior de Agricultura "Luis de Queirós", 1979.

SILVA, L. M .P. **Efeito da cobertura de polietileno sobre o crescimento do feijoeiro (*Phaseolus vulgaris* L.) variedade Carioca**. Piracicaba, SP. 1980. 107 p. Dissertação (Mestrado em Agrometeorologia), Escola Superio de Agricultura "Luiz de Queiróz", 1980.

STRECK, N. A., SCHNEIDER, F. M., BURIOL, G. A. Modificações físicas causadas pelo mulching. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 2, p. 131-142, 1994.

TAKATORI, F. H., LIPPERT, L. F., WHITING, F. L. The effect of petroleum mulch and polyethylene films on soil temperature and plant growth. **Proceedings of American Society for Horticultural Science**, St Joseph, v. 85, p. 532-540, 1964.

TRIPATHI, R. P., KATIYAR, T. P. S. Effect of mulches on the thermal regime of soil. **Soil and Tillage Research**, Amsterdam, v. 4, p. 381-390, 1984.

TRUAX, B., GAGNON, D. Effects of straw and black plastic mulching on the initial growth and nutrition of butternut, white ash and bur oak. **Forest Ecology and Management**, Amsterdan, n. 57, p. 17-27, 1993.