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TEMPERATURE AND MOISTURE REGIME OF A SOIL COVERED WITH TRANSPARENT MULCHES[1]

TEMPERATURA E UMIDADE DE UM SOLO COBERTO COM PLÁSTICOS TRANSPARENTES

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SUMMARY

Three field experiments were carried out at Santa Maria, Central Region of the Rio Grande do Sul State, Brazil, in order to measure the effect of transparent plastic mulches on soil temperature and moisture conservation during the cold months on 1992 and 1993. Treatments were: perforated transparent polyethylene, transparent polypropylene, and bare soil. Tobacco was sown in one of the experiments. Plastic mulches improved soil moisture conservation. Highest values of soil heat flux were observed in soil mulched with perforated polyethylene. Soil and minimum air temperatures were increased by transparent mulches. Tobacco seedlings emergence was faster under perforated polyethylene but seedling growth was improved by polypropylene.

Key words: mulching, soil temperature, soil moisture, tobacco.

RESUMO

Foram instalados três experimentos a campo em Santa Maria, Estado do Rio Grande do Sul, Brasil, com o objetivo de quantificar o efeito da cobertura do solo com plásticos transparentes sobre a tempe-

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ratura e umidade do solo durante os meses mais frios de 1992 e 1993. Os tratamentos foram: polietileno transparente perfurado, polipropileno transparente e solo desnudo. Em um dos experimentos o solo foi cultivado com mudas de fumo. As coberturas plásticas conservaram a umidade do solo por mais tempo do que o solo desnudo. Os valores de densidade de fluxo de calor no solo foram mais elevados no solo coberto com polietileno perfurado. A temperatura do solo e mínima do ar foram maiores no solo com as coberturas plásticas. A emergência das plântulas de fumo foi mais rápida no solo coberto com polietileno perfurado, mas o crescimento das plantas foi maior no solo coberto com polipropileno.

Palavras-chave: cobertura do solo, temperatura do solo, umidade do solo, fumo.

INTRODUCTION

Soil mulching decreases water loss from soil surface to the atmosphere and conserves soil moisture (LIPPERT et al., 1964; ROSENBERG, 1974; MAHRER et al., 1984; STRECK et al., 1994; STRECK et al., 1996a). Weed control, increase in nutrient availability, and modification in soil microclimate have been also reported when soil was mulched (GLINIECKI, 1959; HOPEN, 1965; BRUNINI et al., 1976; HAYNES, 1987; STRECK et al., 1994). The modification in soil microclimate by plastic mulches depends of optical properties of the sheet and type of soil. In general, transparent mulches are more effective to increase soil temperature than opaque mulches (ROSENBERG, 1974; LIAKATAS et al., 1986; STRECK et al., 1994; STRECK et al., 1996b).

Because its high transmissivity to solar radiation, soil covering with transparent sheets can be used in agriculture for heating soil during the cold season and promote earlier yields (TRIPATHI & KATIYAR, 1984; LAMONT Jr., 1993; TABER, 1993; FARIAS-LARIOS et al., 1994; STRECK et al., 1994a). KATAN et al. (1976) demonstrated that mulching a moistened soil with transparent polyethylene during the hot season in Israel controlled soilborne pathogens as well as weeds. This physical method of soil disinfestation is known as soil solarization and practiced in many hot countries including Brazil (KATAN, 1981; KATAN & DEVAY, 1991; SCHNEIDER et al., 1993; STRECK et al., 1995).

Soil mulching is an agricultural practice that is increasing in Southern Brazil and some papers have been reported results of mulches on soil temperature and tomato yield (STRECK et al., 1996a; STRECK et al., 1996b). These results have shown that opaque mulches (white, black, and co-extruded white-on-black) are more effective than transparent mulch for increasing yield of protected tomato.

Perforated transparent polyethylene mulch however, is very used in field conditions for tobacco seedling production during the winter months. Recently, the transparent polypropylene mulch have

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been introduced in an attempt to be an alternative mulch to the polyethylene. Growers have empirically reported that tobacco emergence is earlier under perforated transparent polyethylene, but seedling growth is enhanced by transparent polypropylene. The field observations are certainly related to differences in soil microclimate under both mulches. This study was made in order to measure the effect of perforated transparent polyethylene and transparent polypropylene mulches on soil temperature and moisture in the Central Region of the Rio Grande do Sul State, Brazil.

MATERIAL AND METHODS

Three field 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. Treatments were: soil covered with perforated transparent polyethylene 50 μm thickness (the orifices had 1cm diameter and the perforated area of the sheet was about 1%), transparent polypropylene 50 μm thickness, and uncovered bare soil as a control. The soil was plowed and disked before the mulching in order to bring the soil to a good tillage condition. The plots had 2 m x 15 m size.

The Experiment-I was conducted from October 16, 1992 through November 26, 1992. Mulched and control plots were not irrigated during the experimental period. Soil and minimum air temperatures were measured from October 21 through November 26. The soil temperature was measured using mercury-in-glass geothermometers at the 2 cm depth. Daily measurements of soil temperature were taken at 07 o'clock and 15 o'clock, local standard time (LST). Minimum air temperature was measured by alcohol-in-glass thermometers located at 2cm above soil surface under the mulches and on uncovered soil. On October 21 and October 22, clear days, soil temperature was recorded between 07 o'clock and 17 o'clock (LST), every hour.

The transmissivity of mulches to solar radiation was measured on October 21 and October 22 using LICOR pyranometers. Measurements were made between 07 o'clock and 17 o'clock, every hour. On each hour the measurements were replicated three times. The transmissivity (T) was calculated by:

$$T(\%) = \frac{Rs_{in}}{Rs_{out}} \, x\, 100 \qquad \mathbf{1}$$

where $\mathbf{Rs_{in}}$ and $\mathbf{Rs_{out}}$ are the incoming solar radiation measured under the mulch and 5 cm above the uncovered bare soil, respectively.

The soil moisture content was measured after a rainfall from October 20 through October 23 by the gravimetric method. Four samples per treatment were collected in a 0-5 cm layer at 17 o'clock every day. The rainfall finished on October 20 at about 13 o'clock.

The Experiment-II was installed from March 24, 1993 through May 17, 1993. The soil was moistened (field capacity) to a depth of 50cm one day before mulching. No additional water was applied in 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 soil moisture similar among the treatments. The quantity of water applied was estimated in an attempt to supply the atmospheric demand of the day.

Soil temperature was measured throughout the experimental period using mercury-in-glass geothermometers at 2 cm and 5 cm depths. Daily measurements of soil temperature were taken at 15:30 and 16 o'clock, LST. On May 06, a clear day, soil temperature was recorded between 5:30 and 21 o'clock, every hour. Near to the time of occurence of minimum and maximum temperatures at each depth, the reading interval was reduced to 15 minutes.

The soil moisture content was measured by the gravimetric method on May 06 at 16 o'clock. Six samples per treatment were colected in a 0-5cm layer. Thermal properties (soil heat capacity, thermal conductivity, and thermal diffusivity) of mulched and bare soils were estimated on May 06 according De VRIES (1963), DECICO (1974), SCHNEIDER (1979), and STRECK et al. (1996c).

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

$$S = - K \left(\frac{\Delta T}{\Delta X} \right) \qquad 2$$

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

The Experiment-III was performed from July 01, 1993 through October 07, 1993. No additional water was applied in the mulched and control plots during the experimental period, as described in the first experiment. Tobacco was sown on July 01. Tobacco seedlings were sampled weekly from August 08 through October 01. A 20 cm x 20 cm area composed the samples. Three samples per treatment were collected. The plant number/samples were counted and dried. Soil temperature was measured from July 07 through October 07 using mercury-in-glass geothermometers at 2 cm and 5cm depths. Daily measurements of soil temperature were taken at 09 o'clock, 15 o'clock, and 15:30, LST.

Temperature data were analysed on each time in the three experiments. The values of temperature measured every hour on clear days were analysed separately. Plant growth was analysed as weight of total dry matter sampled throughout the Experiment-III.

RESULTS AND DISCUSSION

The changes in soil moisture for the upper 5 cm layer of mulched and bare soils during a natural drying cicle of the Experiment-I are shown in Figure 1. The soil drying trend was markedly reduced by plastic mulches. Similar results were obtained in Experiment-II on May 06.

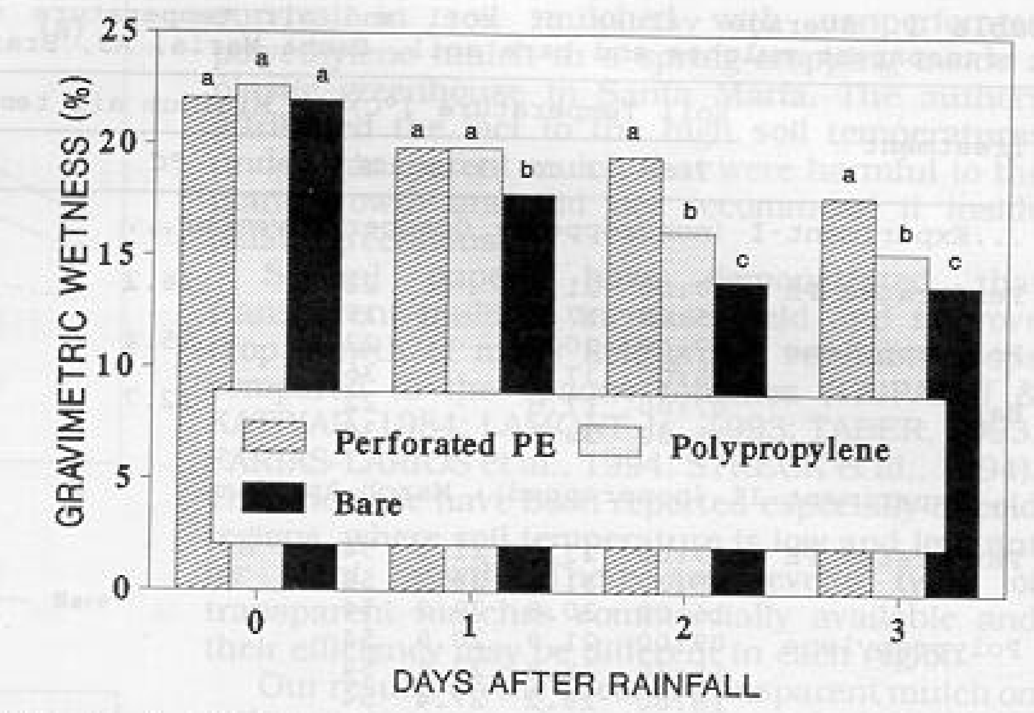

Figure 1. Moisture content for the upper layer (0-5cm) of soil mulched with transparent plastics and bare soil from October 20, 1992 through October 23, 1992. Groups with same letter within each sampling day are not significantly different at the 5% level according to Duncan's test. Santa Maria, RS, Brazil.

Moisture conservation by mulching has been reported by many authors including LIPPERT et al. (1964), ROSENBERG (1974), MAHRER et al. (1984), STRECK et al. (1994), and STRECK et al. (1996a). This occur due to the fact that in the mulched soil the evaporated soil moisture condenses on the sheet and drips down again to the soil surface. On the other hand, the water loss from bare soil to the atmosphere is very intense and it is a function of net radiation at soil surface. Comparing the two plastics materials, the polypropylene sheet has higher permeability to water vapour diffusion than perforated polyethylene sheet. As a consequency, soil moisture was significantly less conserved under polypropylene mulch than perforated polyethylene mulch two days after rainfall (Figure 1). As a consequence of moisture conservation by mulches, thermal properties of the soil, mainly volumetric capacity (C) and thermal conductivity (K) were higher in the mulched soils.

Soil heat flux was higher in mulched soils (Figure 2), resulting greater soil heating under the transparent plastics, particularly the perforated polyethylene (Table 1). Soil temperature differences between mulched and bare soil ranged from 1.0 to 3.6 and 0.1 to 3.4°C in the morning measurements and 2.0 to 4.7°C and 0.1 to 4.1°C in the afternoon measurements, respectively under perforated polyethylene and polypropylene mulches. In addition, soil temperature waves had higher values in mulched soils as compared to the bare soil, mainly under perforated polyethylene sheet (Figure 3).

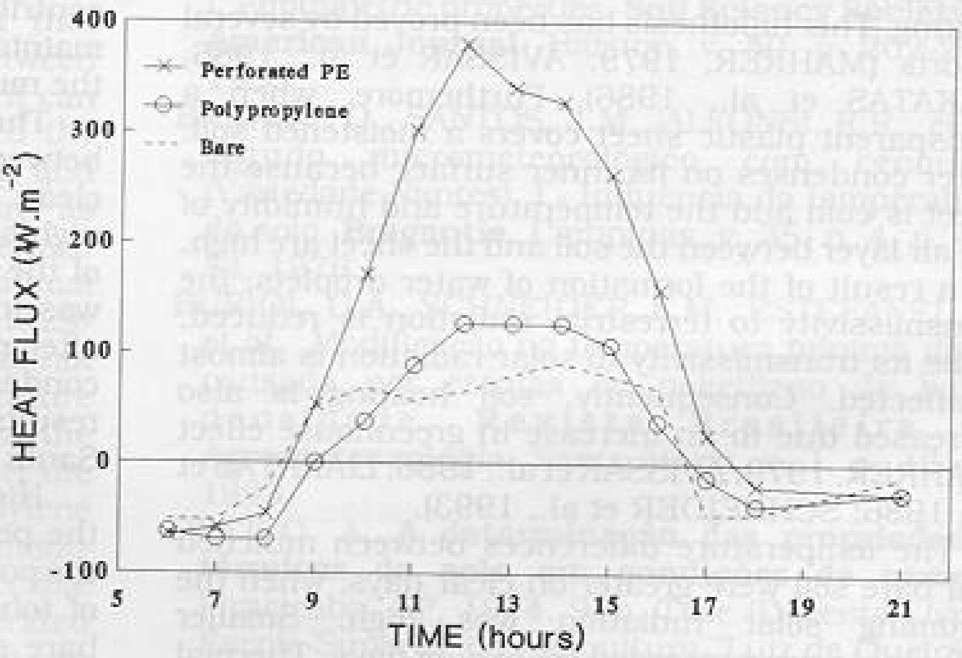

Figure 2. Diurnal variation of soil heat flux in soil mulched with transparent plastics and bare soil on May 06, 1993. Santa Maria, RS, Brazil.

The increase in soil temperature by transparent mulches during the daytime is due to a decrease in sensible and latent heat fluxes, and thereby increases the amount of heat available 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 because the sheet is cold and the temperature and humidity of the air layer between the soil and the sheet are high. As a result of the formation of water droplets, the transmissivity to terrestrial radiation is reduced, while its transmissivity to solar radiation is almost unaffected. Consequently, soil heating is also increased due to an increase in greenhouse effect (MAHRER, 1979; AVISSAR et al., 1986; LIAKATAS et al., 1986; SCHNEIDER et al., 1993).

The temperature differences between mulched and bare soil were greater on clear days, when the incoming solar radiation was high. Smaller differences were recorded on cloudy days. Thermal storage in the soil from past clear days have contributed to temperature differences on cloudy days as reported previously by LIAKATAS et al. (1986).

The transmissivity to solar radiation by perforated polyethylene and polypropylene mulches were, on average, 82.6% and 74.2%, respectively. The greater solar radiation availability and mainly the lower energy used as latent flux due to the water conservation contributed to the very higher values of soil heat flux under perforated polyethylene mulch as compared to the polypropylene (Figure 2). Consequently, soil heating was greater under perforated polyethylene at 2 cm and 5 cm depths, regardless the time of measurements in the three experiments (Table 1).

Table 1. Average values of soil and air temperature under the transparent mulches and bare soil. Santa Maria, RS, Brazil.

Treatment	Soil Temperature (°C)				Minimum air temperature	
	Time	2 cm	5 cm	N*	°C	N*
...Experiment-I (noncropped): October/November...						
Perforated PE	07:00	21.1	-	22	16.2	24
	15:00	37.6	-	36		
Polypropylene	07:00	20.9	-	22	15.4	24
	15:00	37.0	-	36		
Bare	07:00	17.5	-	22	12.7	24
	15:00	32.9	-	36		
...Experiment-II (noncropped): March-April...						
Perforated PE	09:00	23.2	21.4	54	-	-
	15:30	31.3	28.9	54		
	16:00	30.8	29.2	54		
Polypropylene	09:00	21.9	20.9	54	-	-
	15:30	28.8	27.1	54		
	16:00	28.2	27.4	54		
Bare	09:00	21.2	19.6	54	-	-
	15:30	26.9	25.0	54		
	16:00	26.1	24.5	54		
...Experiment-III (cropped): July-October...						
Perforated PE	09:00	15.2	14.2	91	-	-
	15:30	23.4	20.8	91		
	16:00	23.5	20.9	91		
Polypropylene	09:00	14.3	13.4	91	-	-
	15:30	20.1	18.9	91		
	16:00	20.8	19.2	91		
Bare	09:00	14.2	13.2	91		
	15:30	19.7	18.8	91		
	16:00	19.7	18.8	91		

*N=number of observations

As a consequence of the increase in soil temperature, the minimum air temperature near the soil surface followed the order: perforated polyethylene mulch > polypropylene mulch > bare soil (Table 1). The lower value of minimum air temperature on the bare soil was measured on November 05, 1992 (5.6°C). In mulched soils, minimum air temperatures in the same day were 10.8°C and 10.1°C under perforated polyethylene and polypropylene, respectively. The minimum air temperature differences between mulched and bare soil reached up to 5.6°C. In addition to the soil heating, the release of latent heat flux from water condensation on plastic sheet and the greenhouse effect by water droplets have probably also contributed to decrease heat loss from soil and maintain a higher minimum air temperature under the mulches as compared to the bare soil.

The minimum air temperature differences between mulched and bare soil were higher after clear, cold and low-wind speed nights. In those nights, the condensed water layer on inner surface of the plastics was high and the greenhouse effect was increased. Smaller diferences were registered after nights with high-north-wind speed when the condensed water layer was not formed. Similar results were observed inside plastic greenhouse at Santa Maria by BURIOL et al. (1993).

Higher values of soil and air temperature under the perforated polyethylene mulch as compared to the polypropylene mulch had an effect on the growth of tobacco seedlings (Figure 4). Tobacco seeds in bare soil treatment were carried by run-off of an intense rainfall before its emergence and thus, only mulch treatments were cropped. Comparing the mulched treatments, seedling emergence was faster under perforated polyethylene mulch. The seedling growth was improved however, by polypropylene mulch. This behavior is probably related to the higher permeability of polypropylene sheet that promoted a more intense air exchange between inside and outside the mulch. Consequently, it can be infered that polypropylene sheet improved the aeration, which increased plant transpiration and decreased diurnal soil and air temperature as compared to the perforated polyethylene sheet. According HAWKS & COLLINS Jr. (1983) the optimal diurnal temperature for tobacco plant growing is 29-32°C. Air temperature under the mulches was not measured in our experiments. But, soil temperature at 2 cm depth often exceeded 32°C under the perforated polyethylene from the 56th day after the planting while soil temperature under polypropylene mulch did not exceed 30°C during the Experiment-III. In addition, it was observed a considerable number of killed plants under the perforated polyethylene mulch in the last sampling, which can to confirm the hipothesis above mentioned. STRECK et al. (1996b) also reported a reduced tomato plant survival in soil mulched with nonperforated polyethylene mulch in a spring-cropping inside a plastic greenhouse in Santa Maria. The authors attributed the fact to the high soil temperatures under transparent mulch that were harmful to the plant growth and did not recommend it inside plastic greenhouse.

Several papers have demonstrated that transparent mulches increase yield and improve crop growth of many field-grown vegetable crops compared to the opaque mulches (TRIPATHI & KATIYAR, 1984; LAMONT Jr., 1993; TABER, 1993; FARIAS-LARIOS et al., 1994; STRECK et al., 1994). This increase have been reported especially in cold regions, where soil temperature is low and limitant for plant growth. There are several types of transparent mulches commercially available and their efficiency may be different in each region.

Our results on the effect of transparent mulch on soil temperature and moisture conservation are in agreement with other reports. The use of transparent mulches in open fields during the cold months in South Brazil has a good potential. The weed growth however, is an important disadvantage of its use and reported by several papers including TABER (1993), LAMONT Jr. (1993) and STRECK et al. (1996b). The microclimate under the two transparent mulches verified in this study confirm the empirical field observations by growers about the growth of tobacco seedlings. Polypropylene sheet should be used as mulch for tobacco seedling production when compared to the perforated polyethylene. The behavior of other important field-crops (lettuce and strawberry) protected by transparent mulches during the cold season are needed and will be the next step of our program.

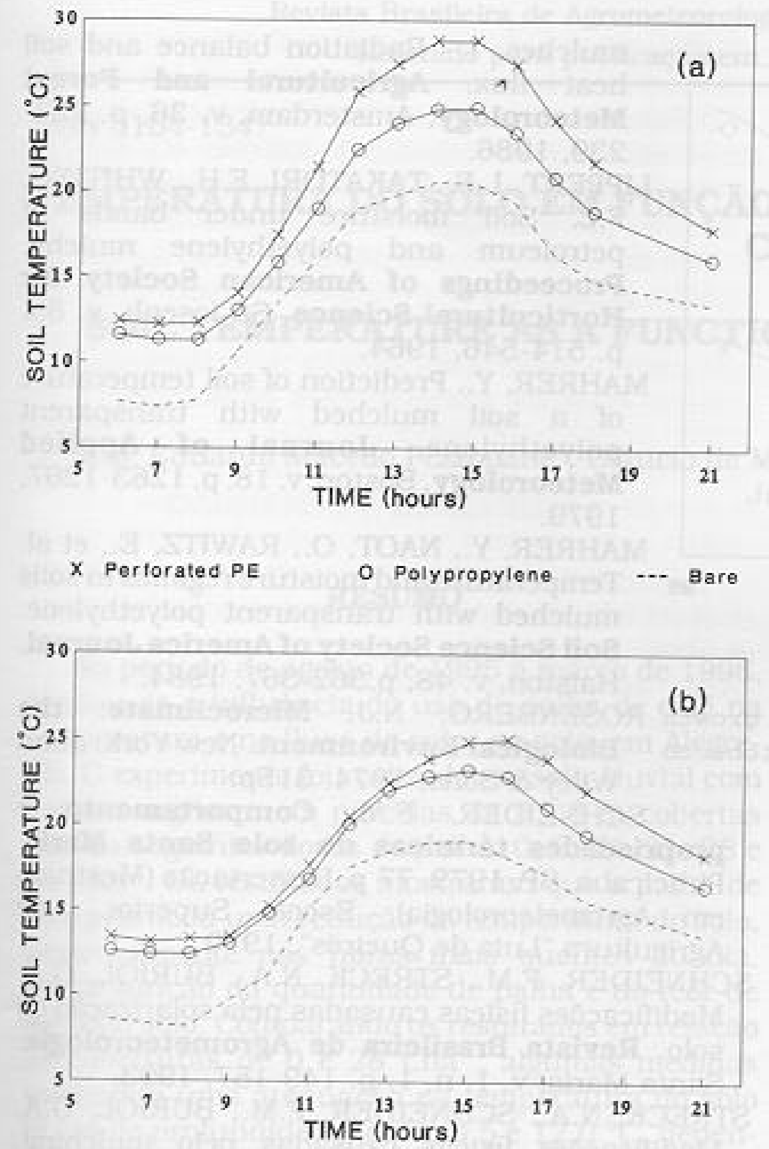

Figure 3. Diurnal variation of soil temperature at 2 cm (a) and 5 cm (b) depths in soil mulched with transparent plastics and bare soil on May 06, 1993. Santa Maria, RS, Brazil.

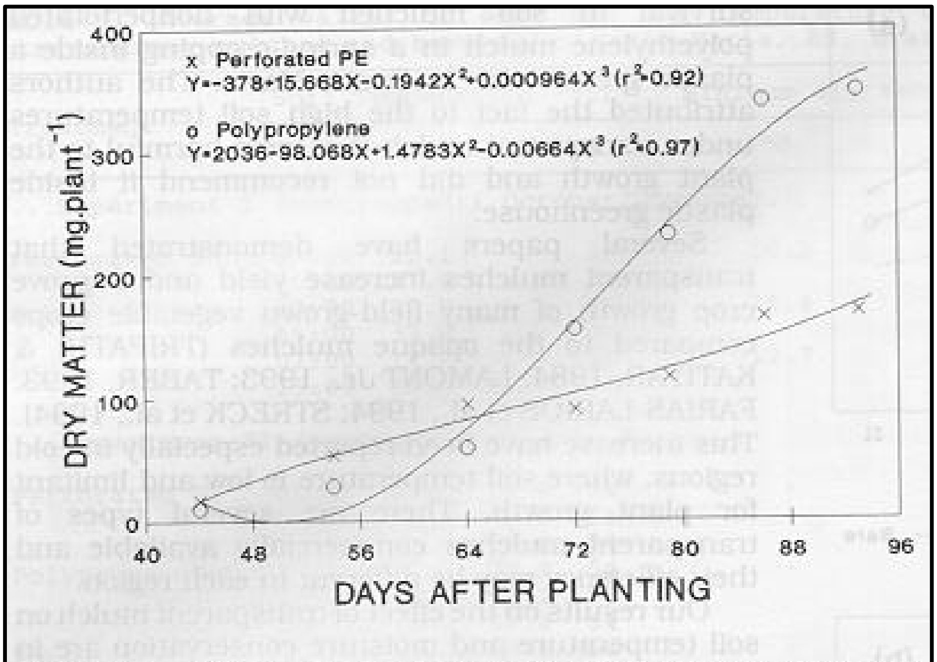

Figure 4. Effect of transparent mulches on plant growth expressed as weight of total dry matter of tobacco seedlings. Santa Maria, RS, Brazil, 1993.

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