ISSN 1413-7895

PLASTIC TUNELL ORIENTATION AND IRRIGATION MANAGEMENT OF PEPPER (*Capsicum annuum*, L.)

Marcos Brandão Braga
Antonio Evaldo Klar*
Department of Agricultural Engineering, College of Agricultural Sciences, State University of São Paulo, P.O. 237, CEP 18603-970, Botucatu – SP. E-mail: klar@fca.unesp.br
**Scientific Researchist of CNPq.*

1 ABSTRACT

The main purpose of this study was to measure spatial distribution of evaporation and pepper plant (*Capsicum annuum*, L.) behavior under five minimum soil water potentials (-10, -20, -30, -40 and –50 kPa) in two arch roof plastic tunnels (20m length x 5m width x 4m height in the center), oriented to North/South and East/West. Small evaporimeters were installed in each tunnel, with intervals of 1.2m in the width and 3.0m in the length directions and 0.5 and 1.0m from the soil surface. Thermohygrographes and Class A Pans were used in both tunnels and outside. The best fruit yields were obtained from the highest soil water potentials and for plants from East/West tunnel (1.62 kg/plant) while North/South produced only 1.42 kg/plant. Consequently, tunnels constructed on the East/West direction are indicated for higher pepper yield and it also showed more homogeneous spatial evaporation distribution than the North/South one. The geostatistical studies did not showed spatial dependency of the evaporation from microevaporimeters in both tunnels. The evaporation averages of Class A Pan in the North/South and East/West tunnels were 32.02 and 36.46% lower than outside, respectively. The minimum and maximum temperature averages were not significantly different in both tunnels, but the minimum external temperature average were higher and the maximum average was lower than that obtained in the tunnels. Air relative humidity averages in both tunnels were 9,1% higher than outside.

KEYWORDS: plastic tunnels; pepper; evaporation.

BRAGA, M. M.; KLAR, A. E. INFLUÊNCIA DA ORIENTAÇÃO DE ESTUFAS E MANEJO DE IRRIGAÇÃO NA CULTURA DE PIMENTÃO (*Capsicum annuum*, L.)

2 RESUMO

O principal objetivo deste estudo foi medir a distribuição espacial da evaporação dentro de duas estufas tipo túnel com posições geográficas Norte/Sul e Leste/Oeste e também a produção de pimentão (*Capsicum annuum*, L.) irrigado por gotejamento. O delineamento estatístico foi em blocos casualizados e cinco tratamentos de potencial mínimo de água no solo (-10, -20, -30, - 40 e -50 kPa). Microevaporímetros foram instalados em cada estufa em intervalos de 1,2m no sentido da largura e

Recebido em 10/11/2002 e aprovado para publicação em 26/01/2003

DOI: http://dx.doi.org/10.15809/irriga.2003v08n1p69-77

3m no sentido do comprimento da estufa e em duas alturas 0,5 e 1m do solo, formando uma rede de 24 evaporímetros por estufa. Termigrógrafos e tanques Classe A foram usados dentro e fora das estufas. A melhor produção foi obtida no manejo feito com o maior potencial de água no solo em ambas as estufas, com as medias de produção de 1,62 kg/planta na estufa com orientação Leste/Oeste e de 1,42kg/planta no Norte/Sul, estatisticamente diferentes, mostrando que o pimentão produzido na estufa instalada na posição Leste/Oeste seria a indicada para produção comercial nas condições estudadas. As médias de evaporação nos tanques Classe A nas estufas Norte/Sul e Leste/Oeste foram 32,02 e 36,46%, respectivamente, menores que a evaporação do instalado externamente. As médias das mínimas e máximas temperaturas não foram significativamente diferentes entre estufas, mas as mínimas temperaturas externas foram mais altas e as máximas mais baixas que as obtidas dentro das estufas. As médias da umidade relativa em ambas estufas foram 9,1% maiores que as externas. Os resultados mostraram maior homogeneidade na distribuição espacial da evaporação na estufa Leste/Oeste que na Norte/Sul. Os estudos de geoestatística não mostraram dependência espacial entre os pontos de evaporação medidos em ambas as estufas.

UNITERMOS: Estufas, Pimentão, Evaporação.

3 INTRODUCTION

Plastic tunnels are important tools for modern agriculture, mainly for increasing crop yields. Harnett et al. (1979), in a review, concluded that East/West greenhouse orientation was more efficient for radiation transmissibility than the North/South one. On the other hand, the reflection of plastic cover is resulted from the type and conditions of the material, solar position and geographic orientation of the structure (KLAR & ALVES, 1996). However, there are few studies about the distribution and spatial variability of micrometeorological elements on different greenhouse types and their influence on plants.

According to Prados (1986), plastic cover changes radiation balance and Bourland et al (1990) affirmed that evaporation produces condensation and has direct influence in greenhouse microclimate. Several studies showed that evapotranspiration in greenhouses is lower than outside due to wind reduction, decreased radiation transmissivity by plastic cover and higher relative humidity (KLAR & ALVES, 1996). These authors showed that the evaporation values in greenhouses were significantly lower than those occurred outside and Teodoro et al. (1993) related a value of 30%, also using the class A pan.

Evaporimeters are the cheapest and easiest method for measuring Reference Evapotranspiration (ETo), because evaporation involves all energetic complex responsible for water evaporation (KLAR, 1988). However, evaporimeters are not frequently used in greenhouses, specially the largest ones, as the Class A Pan.

Water application must be carefully studied, mainly when applied on plants under protected environment. Caixeta et al. (1981) showed that drip irrigation allowed better pepper fruit size uniformity and higher fruit productivity than other irrigation methods. Borrely & Zerbi (1973), comparing drip and sprinkler irrigation, observed similar conclusion. This last method produced the highest percentage of non-commercial pepper fruits in relation to drip irrigation (BERNSTEIN & FRANCOIS, 1973; PUGLIA & CASCIO, 1979).

Wierenga & Saddig (1985) obtained the highest yield (38 ton/ha) using a –15 to –20 kPa minimum soil water potential (Ψs), while Sirjacobs & Slama (1981) showed the best yields between –15 and –35 kPa and Giardini & Pimpini (1971), -60 kPa. Obviously, there are several factors to consider, which involve the climate, the soil and, of course, the plant.

The highest plant growth and yield under greenhouse conditions have to consider two basic conditions: the best energy balance in relation to evapotranspiration and the correct plant water and nutrition needs (MOSS et al. 1985). The purpose of this study was to estimate the evaporation distribution inside two plastic tunnel directions (North/South and East/West) and the minimum soil water potential for the best pepper fruit yield.

4 MATERIAL AND METHODS

The experiment was set up at the Agricultural Engineering Department, FCA/UNESP, Botucatu – SP, Brazil, Latitude 22° 51' S and 786m altitude

The soil was classified as Utisol; the bulk density was 1.45 to 1.48 g/cm^3 and the soil water characteristic curves were based in 7 points per depth (Table 1).

Table 1. Values of soil water potential (Ψs) vs. soil water content (a%, volume basis) at 0-15 and 15-30 cm depth.

Depth (cm)	Ψs (kPa)						
	- 5	- 10	- 30	- 50	- 100	- 500	- 1500
a% (0-15)	0.290	0.254	0.212	0.196	0.189	0.168	0.161
a% (15-30)	0.320	0.306	0.265	0.247	0.233	0.190	0.166

The climate of Botucatu region, according to Köepen, is mesotermic, humid; the rainfall and evapotranspiration averages are 1546.8mm and 692mm per year, respectively. The annual temperature average is 20.6 °C, and the maximum and minimum averages are, respectively, 23.5 and 17,4 °C.

Two arched roof tunnels (20m length, 5m width, 3,5m height in the center) were constructed, one directed to North/South and other to East/West and covered with 0,15mm thickness plastic sheet. The lateral walls had 2m height and were covered with "sombrite" screen curtains. A mobile plastic curtain was placed on the lateral walls only for using during rainfall.

Pepper plants (*Capsicum annuum* L. cv. Magali-R) were planted and received fertilizers according to recommendations of IAC Bulletin number 100 (1996). The experiment included five soil water treatments (-10, -20, -30, -40 and –50 kPa minimum soil water potential) and four replicates distributed in randomized complete block design. Each plot had 15 plants that were sown on 07/30 and transplanted on 11/09 with spacing of 0.30 and 0.40m among plants and rows, respectively.

In order to estimate the soil water potential, tensiometers were set up at 0.15m and 0.30m depth. Together with the tensiometers, the soil water content was controlled by neutron probe.

The irrigation was done by Trickle Irrigation System, with 0.30cm between emitters, 1.4 L/h discharge per emitter and 70kPa pressure. A control system was set up with: non-return valve, air release valve, automatic metering valve, fertilizer tank, rings and sand filters, pressure and flow regulators.

A thermohygrograph and Class A Pan were set up in the center of each tunnel. Climatic data outside tunnels were obtained from automatic meteorological station about 200 m from the experiment. Twenty-four small evaporimeters (1.50 liter volume, 0.07m height and 0.18 diameter) were set up 0.50m from the soil surface and uniformly spaced until the plants start to shade them. Then, the evaporimeters were raised to 1.0m from the soil surface. The evaporation from evaporimeters was measured three times a week in the morning.

Several plant parameters were observed and measured: commercial fruit yield.

5 RESULTS AND DISCUSSION

5.1 Yield Factors

According to the analysis of variance, the soil water potential treatments affected fruit yield but did not influence number of fruit per plant and the tunnel direction influenced fruit yield and also number of fruit per plant (Table 2). There were significant variations for the fruit production within the blocks, which can be explained by the different energy availability in the tunnel (Figure 2 and 3).

In relation to the yield, while the plants from the tunnel North/South showed statistical differences (410 g/pl) for fruit yield between the treatments –10 and –50 soil water potentials, the East/West tunnel did not show significant variations among irrigation treatments for this factor. Sijacobs & Slama (1983) showed the highest pepper fruit yield between –15 and –50 kPa and, according to Wierenga & Saddig (1985), the best minimum Ψs interval was from –15 to –20 kPa. On the other hand, the fruit yield averages in both tunnels were significantly different, 1,620 and 1,490 g/pl, respectively for East/West and North/South tunnels and the variation coefficient (CV%) was lower for East/West tunnel than for the North/South one. These results can be explained by the different energy distribution in the tunnels (Figure 2 and 3), because the other factors applied (soil, fertilization, etc.) were the same.

The results of Teodoro & Oliveira, 1991, were similar to those from North/South tunnel for pepper fruit yield, but they did not indicate the greenhouse direction. The fruit yield data for both tunnels were much higher than those obtained by Caixeta (1978) and Correia (1984) under field and non-protected conditions. The different results can be explained by the much higher long wave radiation inside than outside tunnels (RICIERE, 1995).

Table 2. Means of yield (Y-kg/plant) and number of fruits (N) related to North/South (N/S) and East/West (E/W) tunnels, and soil water potential (Ψs-kPa) treatments. Variation Coefficients (CV%) and Standard Deviations (S. D.)

Ψs	-10	-20	-30	-40	-50	Mean	CV%	S. D.
Y-N/S	1.80aA	1.58abA	1.47abA	1.40abA	1.19bB	1.49B	14.53	0.2153
Y-E/W	1.64aA	1.59aA	1.69aA	1.65aA	1.53aA	1.52A	6.47	01047
N-N/S	13aA	11aA	11aB	11aB	12aB	12B	13.12	1.00
N-E/W	14aA	13aA	14aA	14aA	15aA	14A	11.96	1.00

Small letters in horizontal direction mean 5% significant by Test Tukey and capital letters in vertical direction mean statistical differences between tunnels by Variance Analysis (F)

The fruit number per plant was not statistically different within each tunnel, but significant differences occurred between tunnels for this factor. It is interesting to note that variation coefficient (%CV) was lower in the East/West than in the North/South tunnel for fruit yield and fruit number per plant.. The energy distribution can explain these results, because its is more uniform in the East/West than in the North/South tunnel (Figure 2 and 3).

5.2 Air Relative Humidity and Temperature

The air relative humidity values inside the tunnels were higher than those outside perhaps due to the lateral screen (sombrite) of the tunnels, which attenuates the wind speed, beyond the presence of the evaporimeters, including the Class A Pan. The lower temperatures inside the tunnels in relation to outside also increase the relative humidity, which averages were 84.4% and 86.8% for East/West and North/South, respectively, and 76.5% outside for a 150 days period. During this period, the outside values were always lower than those inside the tunnels.

The air temperature is very important for vegetables, because affects germination, diseases incidence, as well as, all plant development. There were no differences between minimum and maximum air temperatures comparing both tunnels, but significant differences were obtained between tunnels and the meteorological station data. The minimum temperature averages for 150 days were 17.4, 17.3 and 19.0 °C, respectively for East/West, North/South and outside, and in the same order, the maximum air temperature means were 29.0, 28.9 and 28.1 °C. It is necessary to point out that the minimum temperature is close to the values recommended by Tivelli (1998) for the crop, in opposite to the maximum values, which were higher than those indicated by the same author. It is easily to deduce that the tunnel temperatures were not affected by the tunnel direction.

5.3 Evaporation

Figure 1 shows the class A pan evaporation values. The minimum total water used during the experiment occurred on the driest treatment (484.18 mm) and the maximum (754mm) on the most frequent irrigated treatment of the East/West tunnel. This maximum value is similar to recommendation of Doorenbos & Kassan (1979) for the same crop. The daily averages were 3.94, 3.76 and 5.73 mm, respectively for East/West, North/South and the meteorological station located about 200m from the experiment. Therefore, the last value is 34.24% higher than those from protected environments. The Table 3 shows the regression equations from Class A Pan evaporation values in and outside the tunnels with significant correlation coefficients. These values are roughly similar to those observed by Montero et al. (1985), Prados (1986), Teodoro et al. (1993) and Klar & Alves (1996). The evaporation differences observed by these authors come from the very low wind speed and less direct solar radiation inside the tunnels (RICIERI, 1995). The Class A Pan is important to measure evaporation for several reasons: its use is universal; it is easy to construct it; and it integrates all energetic complex responsible for evaporation (KLAR, 1988).

The evaporation and energy distribution inside the tunnels are difficult to study, because there is not a suitable, easy and cheap technique. However, a simple methodology, with several small evaporimeters or microevaporimeters uniformly distributed inside each tunnel showed to be an important tool for energy evaluation, because evaporation can be transformed in energy and, easily, it makes possible to study the energy distribution.

Table 3. Regression equations of Class A Pan evaporation values between out and inside tunnel East/West (Out x E/W); out and inside tunnel North/South (out x N/S); and inside tunnels East/West and North/South (E/W x N/S).

Relationships	Equations	Correlation coefficients (r)
(Out x E/W)	E/W = 0.4934 Out + 1.1134	0.77**
(Out x N/S)	N/S = 0.4421 Out + 1.2241	0.77**
(E/W x N/S)	N/S = 0.8490 E/W + 0.410	0.95**

** Significant 1% probability by F and T tests.

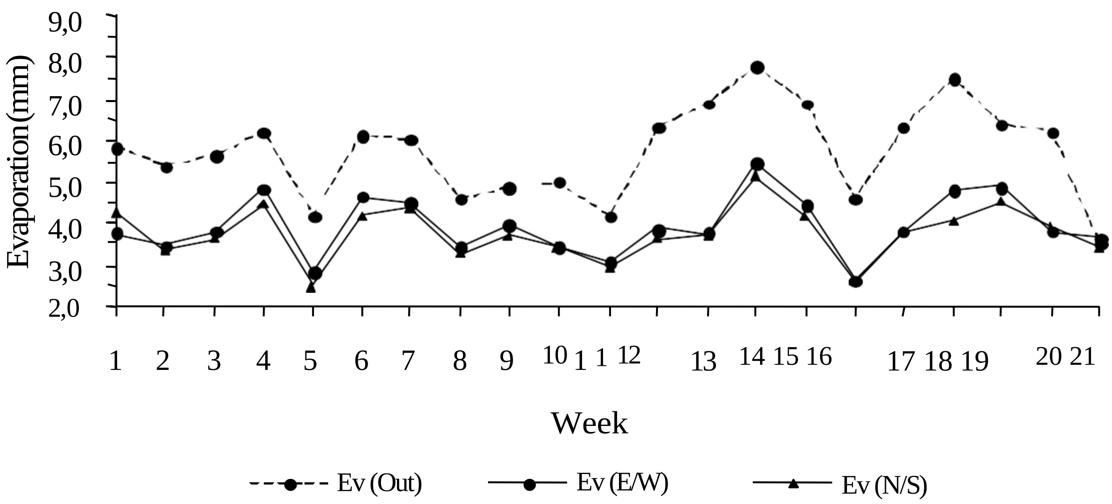

Figure1. Week evaporation average obtained from Class A Pan installed out and inside the tunnels.

Figure 2 shows the spatial evaporation in both tunnels from 11/07 to 12/06, when the plants were about 50cm height. Some climatic elements obtained from the meteorological station showed the averages: 464 $calcm^{-2}day^{-1}$ solar flux radiation; 138.3 $km.day^{-1}$ wind speed and 5.4 hours solar brightness. The evaporation distribution was more uniform in the East/West than in the North/South tunnel. In this one, the highest evaporation occurred in the south side and a possible explication would be the predominance of the Southwest wind. Perhaps, the good evaporation distribution inside the E/W tunnel is related to the flux radiation distribution, comparing to the other tunnel. But, for more correct conclusion, a set of instruments for measuring temperature, flux radiation, etc. would have to be installed at the same points were the evaporation was determined. On the other hand, it is possible to observe peaks and depressions where the evaporation is higher or lower, mainly along the center of tunnels. This behavior certainly comes from the plastic sheet superposing, with double sheet producing small evaporation, and higher values occurred where the sheet is not superposed. This evaporation behavior shows the sensibility of the method applied in this study.

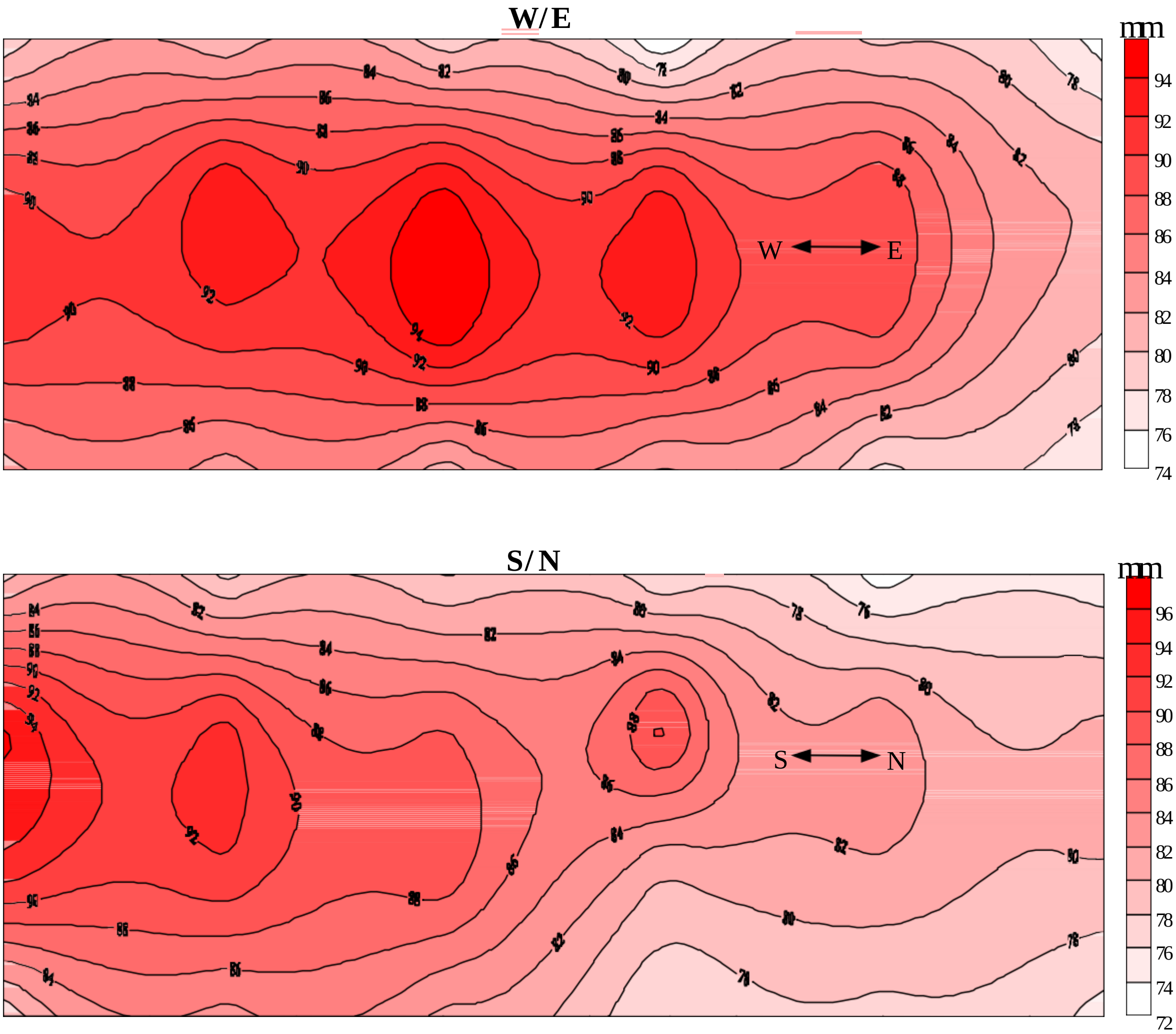

Figure 2. Spatial evaporation average in evaporimeters set up at 0.50m from soil surface (period at 11/07 to 12/06/97)

The Figure 3 shows the evaporation behavior with the evaporimeters installed 1,00m from the soil surface. The evaporation distribution was more uniform in the East/West than in the North/South tunnel, as occurred in the previous periods and evaporimeters 0.50m from the soil. The explanation for this behavior is the same used before.

The evaporation values from 01/16 to 02/14 were lower than those from the previous period due to lower values of the main climatic factors occurring in this period whose averages were: 466 cal.cm^{-2}.day^{-1}, 126.7 km.day^{-1} and 6.7 hour/day for solar flux radiation, wind speed and daily solar brightness, respectively. The means were 496 cal/cm^{2}.day, 133.3 km/day and 7.5 hours, from 12/15/97 to 01/15/98, in the same order.

The evaporation averages obtained from microevaporimeters (0.50m), from (10/08 to 12/16/97) were 2.84 for East/West and 2.83 mm/day for North/South. For evaporimeters set up at 1,00m from soil surface (12/17/1997 to 02/17/1998) the evaporations were 3.18 and 3.11 mm/day, respectively. These differences came from the higher values of outside flux radiation and solar brightness from the last period.

This study clearly showed that the tunnel direction must be carefully designed for the best plant growth and yield.. This conclusion is obvious because water needs heat (energy) for evaporation and, consequently, evaporation date can be transformed in energy (589 calorie are necessary for evaporating 1 gram of water at 25ºC), which is the base for this assertion and conclusion.

6 CONCLUSIONS

The tunnel direction must be carefully designed for the best plant growth and yield, and this study showed the advantages of East/West plastic tunnel direction for the best yield of pepper plants.

Microevaporimeters are good tool for evaluating energy distribution in greenhouses.

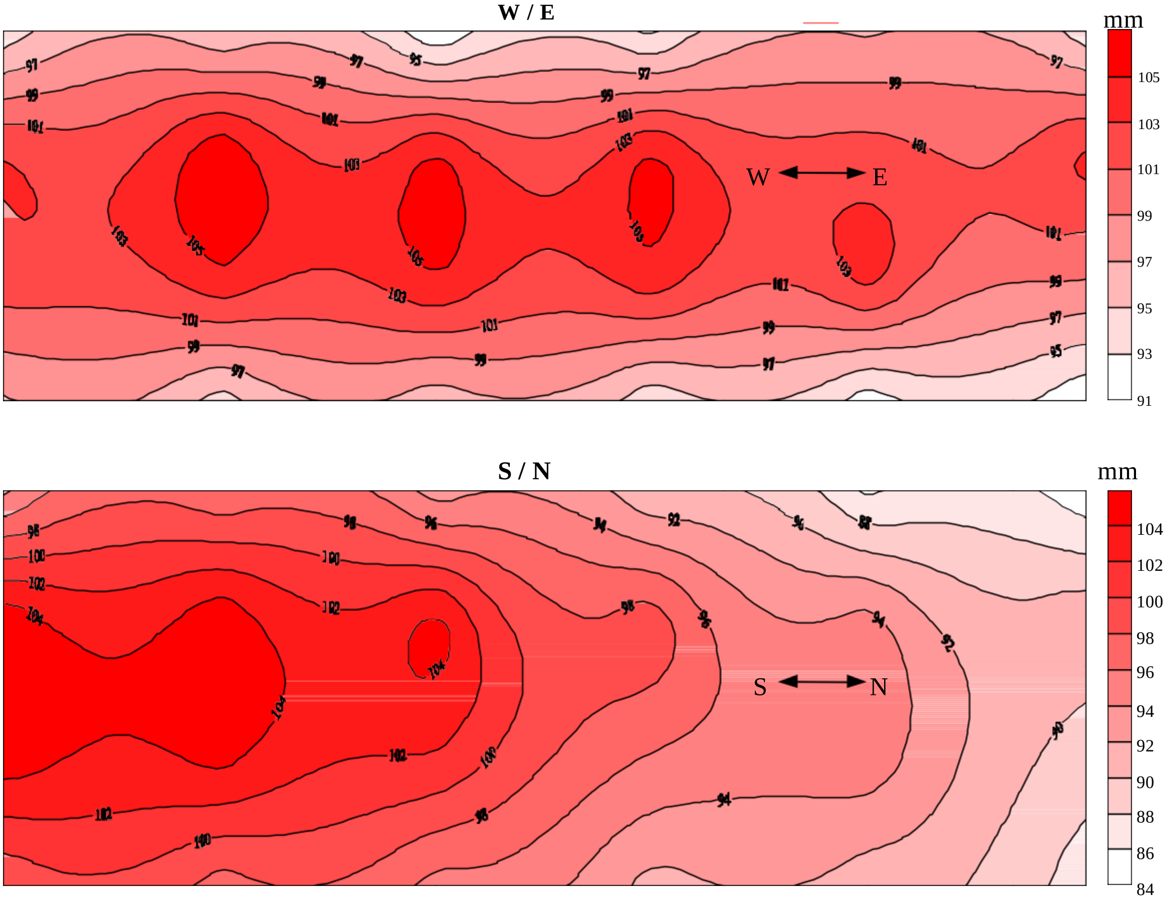

Figure 03. Spatial evaporation distribution measured in evaporimeters placed 100 cm from soil surface (period at 12/17/97 to 01/15/98).

7 REFERENCES

ASSIS, S.V. **Radiação solar em estufas de polietileno, nas orientações norte-sul e leste-oeste**. 1998. 109 f. Tese (Doutorado em agronomia / Energia na agricultura) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, 1998.

BERSTEIN, L.; FRANCOIS, L.E. Comparisons of drip, furrow and sprinkler irrigation. **Soil Science**, v. 115, n. 1, p. 73-86, 1973.

BORRELLI, A.; ZERBI, G. La irrigacione a goccia (Esoerienze in serra su perperone e malanzana). **Annali de la Facalta de Sciencia Agrararia Universita Studi Napoli Porticci**, Napoli, v. 7, n. 2, p. 209–218, 1973.

BOULAND, T. et al. Performance of greenhouse heating system with a phase change material. **Agricultural and Forest Metereology**, Ámsterdam, v. 52, n. 3, p. 303-318, 1990.

CAIXETA, T.J. **Estudo comparativo entre sistemas de irrigação por sulco e gotejamento, e efeito da lâmina de água e freqüência de irrigação por gotejamento na cultura do pimentão**. 1978. 60 f. Dissertação (Mestrado em Engenharia Agrícola) - Universidade Federal de Viçosa, Viçosa, 1978.

CAIXETA, T.J. et al. Efeito da lâmina de água e frequência de irrigação por gotejamento na cultura do pimentão II- Produção de sementes**.** **Revista Ceres**, Viçosa, v. 278, n. 155, p. 52-59, 1981.

CORREIA, L.G. Colheita, rendimento, classificação embalagem e comercialização de pimentão e pimenta. **Informe Agropecuário**, Belo Horizonte, v. 10, n. 113, p. 70-72, 1984.

DOORENBOS, J.; KASSAM, A.H. **Yield response to water.** Roma: Food and Agriculture Organization of the United Nations, 1979. 193 p. (FAO Irrigation and Drainage Paper, 33).

GIARDINI, L.; PIMPINI, F. Acrescimento, produtividá ed evapotranspirazione nel peperone in funzione dell umitá del terreno all' internvento irriguo. **Revista Agronomica**, Lisboa, v. 5, n. 1, p. 99-114, 1971.

HARNETT, R.F.; SIMS, T.V.; BOWMAN, G.E. Comparison of glasshouse types and their orientation. **Experimental Horticulture**, London, v. 31, n. 1, p. 59-66, 1979.

KLAR, A.E. **A água no sistema solo-planta-atmosfera**. 2.ed. São Paulo: Nobel, 1988. 408p.

KLAR, A.E.; ALVES, D.R.B. Evapotranspiração de referência em um túnel plástico. In: SIMPÓSIO BRASILEIRO DE RECURSOS HÍDRICOS, 12., 1997, Vitória. **Anais...** São Paulo: Sociedade Brasileira de Recursos Hídricos, 1996, v.2, p.179-83, 1996.

MONTERO, J.I. et al. Climate under plastic un the almeira. **Acta Hortiulturae**, Wageningen, v. 170, n. 2, p. 227-234, 1985.

MOSS, G. I. et al. Techniques for accurately measuring water use by entire greenhouse crops. **Horticultural Science**, Alexandria, v.20, n. 6, p. 887-889, 1985.

PRADOS, N.C. **Contribuición al estudio de los cultivos enarenados en almeria: necessidades hídricas y extración del nutrientes del cultivo de tomate de crescimento indeterminado em abrigo de polietileno**. 1986. 195 f. Tesis (Doctoral en Agricultura), Almeiria, 1986.

PUGLIA, S.D.; CASCIO, B.L. The production effects of various methods of irrigation on peppers. **Irrigazione**, Bologna, v. 2, n. 1, p. 47-50, 1979.

RICIERI, R.P. **Transmissão da radiação solar global e difusa em estufas plásticas e nebulizadora**. 1995. 91 f. Dissertação (Mestrado em Agronomia / Energia na Agricultura) - Faculdade de Ciências Agronômicas, Universidade Estadual Paulista, Botucatu, 1995.

SIRJACOBS, M.; SLAMA, D.O. Irrigation localiseé d'une culture de proivona sours serre en región aride. **Farham Royal**, London, v. 11, n. 1, p. 21, 1985.

TEODORO, R.E.F.; OLIVEIRA, A.S. Efeito da irrigação na produção de pimentão (Capsicum annuum L.), conduzido em casa de vegetação e em condições de campo. In: CONGRESSO BRASILEIRO DE ENGENHARIA AGRÍCOLA, 20., 1991, Londrina. **Anais...** Londrina: Sociedade Brasileira de Engenharia Agrícola, 1991 p. 676-691.

TIVELLI, S.W. A cultura do pimentão. In: GOTO, R.; TIVELLI, S.W. (Org.) **Produção em ambiente protegido***:* condições subtropicais. Botucatu: Universidade Estadual Paulista, 1998, p. 225-256.

WIERENGA, P.J.; SADDIQ, M.H. Optimum soil water tension for trickle irrigated chile peppers. In: INTERNATIONAL DRIP/TRICKLE IRRIGATION CONGRESS, 3., 1985, Fresno. **Proceedings**, Fresno: American Society Agricultural Engineering, 1985. p. 193-197.