DROUGHT MITIGATION EFFECTS
OF MICROIRRIGATION IN ORCHARDS

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Abstract

In a large number of cases plants react rather passively to moderate changes in climatic variables, particularly when provided with enough water by irrigation or rainfalls. However, extreme temperatures, wind, and drought can suppress growth causing dramatic losses of crop production. Temperatures above 30°C combined with drop in relative air humidity below 30% are known to suppress the physiological processes in temperate zone fruit trees causing internal water deficits, sunburn damages, reduced growth, sparse differentiation of reproductive buds, and, often, high respiration rates resulting in small-size fruit and decreased yields.

The effect of microirrigation on air temperature and relative air humidity was studied in a peach orchard during several hot and dry summer days, characteristic of the vegetation period for most peach-growing regions in Bulgaria. Three microirrigation treatments were replicated four times in a random block design: microsprinklers with overlapping areas of surface wetting, microsprinklers wetting half of the soil surface, and drip irrigation. Microsprinkling was used also for maintaining of sod mulch in interlines. In the treatment with drip irrigation, interlines were cultivated periodically. Pairs of mercury thermometers - dry and wet measured air temperature and relative air humidity in tree crowns. Thermometer pairs were installed at three heights - 1.00m, 1.75m, and 2.50m above the ground. Data from a standard meteorological cell were used as reference. Readings were taken in 15-minute intervals, simultaneously in all treatments and the meteorological cell.

Microsprinkler irrigation was found to increase substantially air humidity and to decrease air temperature. There was no significant difference between both treatments of microsprinkling or when the regime for realization of the daily application rate was changed. The effect on microclimate was positively related to the magnitude of the meteorological factors and to the duration of irrigation. However, it was completely lost on the day after irrigation. The investigated drip-irrigation method had no direct effect on air temperature and air humidity.

Key words: microirrigation, microclimate, and peach orchard

1. Introduction

Many climatic variables have direct or indirect effect on plant development although in a large number of cases plants react rather passively to the living environment, particularly when provided with enough water by irrigation or rainfalls. However, extremities regarding temperature, wind, and drought can suppress growth causing dramatic losses of crop production. In general, warming stimulates plant development only to a given temperature threshold, specific for each species. Temperatures above 30°C combined with drop in relative air humidity below 30% are known to suppress the physiological processes in temperate zone fruit trees causing internal water deficits, sunburn damages, reduced growth, sparse differentiation of reproductive buds, and, often, high respiration rates resulting in small-size fruit and decreased yields. Even under optimal temperature and soil-moisture conditions in the root zone, high ambient temperature and low air humidity favor development of transient water stress as transpiration exceeds the supply of water from the roots (Denmead and Show, 1962; Even-Chen et al., 1981; Kramer and Boyer, 1995). In an experiment with non-bearing prune trees, Even-Chen et al. (1981) found that the assimilation of carbon dioxide by well-watered plants decreased by 80% when the air temperature was increased from 30°C to 48°C. Moreover, about 50% of the CO_2-assimilation-drop occurred before the ambient temperature had reached 40°C and the rate of photosynthesis showed no substantial decline before the leaf temperature had exceeded 35°C. Thus, in the very important range from 35°C to 40°C every 1°C-change in the ambient temperature corresponded to about 10% of the total drop of carbon dioxide assimilation. Principally similar results were obtained in experiments with apple (Seeley and Kammereck, 1977; Lakso and Seeley, 1978), sour cherry (Sams and Flore, 1982), rose (Bozarth et al., 1982), and raspberry (Fernandez and Pritts, 1994). Hence, technical and technological solutions for lowering critical temperatures and increasing air humidity during vegetation can provide a pronounced beneficial effect on crop production.

Irrigation systems have been successfully used for decades to regulate microclimate in crop plantations. Actually, the cooling effect of water evaporation from the wetted foliage ("evaporative cooling") is most pronounced and well known (Bible et al., 1968; Gilbert et al., 1970). In the orchards it is achieved by systems for overhead sprinkling, microsprinkling, or misting (Miller et al., 1963; Unrath, 1972a,b; Unrath and Sneed, 1974; Hamer, 1987; Sneed et al., 1988; Dochev, 1990; Southwick et al., 1991). Some systems for under-tree microsprinkling are also used for evaporative cooling, the emitters being adjusted to wet part of the crown (Klassen, 1986). However, most microirrigation systems operate under trees keeping the foliage dry. They have the important advantage of preventing the intrinsic to the evaporative cooling disease problems (Wilson, 1968; Videnov and Doichev, 1973; Olcott-Reid et al., 1981) and damages caused by eventual contact with saline irrigation water (Dochev, 1968 and 1983; Bernstain and Francoas, 1975; Bresler, 1977). Still, the question is whether, loosing the effect of the evaporative cooling, the microirrigation systems keep potentialities to affect the microclimate in an orchard. Although microsprinkler irrigation is supposed to influence beneficially the ambient temperatures, there is scarce information about the quantitative estimation of such an effect.

This study was initiated to determine the effect of three microirrigation treatments, two of microsprinkling and one of drip irrigation, on air temperature and air humidity in a peach orchard during several hot and dry summer days, characteristic of the vegetation period for most peach-growing regions in Bulgaria. It was part of a larger investigation project on microsprinkler irrigation of peach.

2. Materials and methods

The investigation was carried out in the summer of 1993, in a four-year-old peach orchard on the territory of the Institute of Fruit Growing - Plovdiv, a region in Southern Bulgaria where air temperature often reaches 35-40°C for extended periods of the day and relative air humidity drops below 30%. The experimental trees were of "Glohaven" variety on "GF-677" rootstock, planted 3.0x5.5m apart. Peach trees were about 3.00m high and the coefficient of shading was $K_s = 0.50$.

Three micro-irrigation treatments were replicated four times in a random block design. *Treatment 1 (T.1):* Microsprinklers with rotating head, applying irrigation water over the whole soil surface; operating pressure 0.25MPa; discharge 80 l/h; effective radius - 4m; arranged in a triangle scheme, 6m away (one per two trees) along the rows (Fig. 2); fixed on stake piles 0.20m above the ground, and connected by 6mm PE-tubules to 32mm PE-laterals put on the terrain. *Treatment 2 (T.2):* Microsprinklers with static head (deflectors), applying irrigation water over 50% of the soil surface; operating pressure 0.25MPa; discharge 35 l/h;

spreading irrigation water in sectors of 180°, semieliptic pattern of surface wetting with length of the shorter axis 2.0-2.4m and radius of the longer one 1.2-2.3m; operating in pairs with eliptic pattern of surface wetting; placed 3m apart along the rows, midway between every two trees (Fig. 2); fixed directly to 32mm PE-laterals hung on a wire-construction 0.40m above the ground. *Treatment 3 (T.2):* Drippers (point sources); operating pressure 0.1MPa; discharge 4.6 l/h; two emitters per tree, placed bilaterally at 0.75m from the tree trunk (1.5m apart along the rows), Fig. 2; fixed to 20mm PE-laterals hung on a wire-construction 0.60m above the ground. In the first two treatments (T.1 and T.2), microsprinkler irrigation was used also for maintaining of perennial sod mulch (*Lolium Perenne*) in the interlines. In the drip irrigation treatment (T.3), interlines were cultivated periodically. In all treatments, row strips were maintained free of weeds by periodical treatments with herbicides. Each replication block was 50m long and 16.5m (three tree-rows) wide.

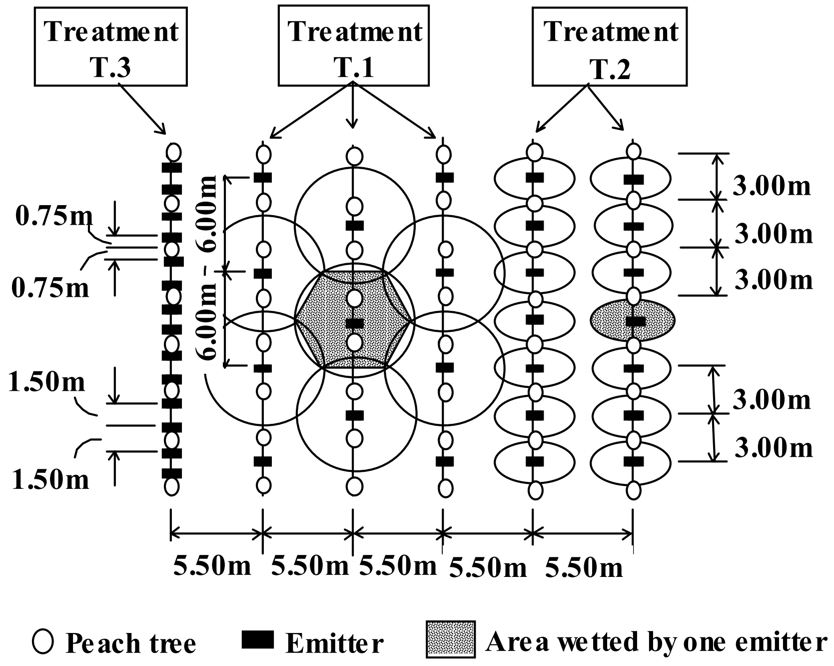

Fig. 1. Scheme of emitter placement in the treatments investigated.

Pairs of mercury thermometers - dry and wet measured air temperature and relative air humidity. In each treatment, measurements were done at three heights - 1.00m, 1.75m, and 2.50m above the ground, respectively at the bottom, in the center, and at the top of the tree crown, under provided shading for the thermometers and free air circulation. Readings from a standard meteorological cell were used as reference. The cell was placed nearby the experimental plot, but far enough to prevent any influence of the irrigation. Readings were taken in 15-minute intervals, simultaneously in all treatments and the reference.

Three different experiments were set in order to determine the effect of each treatment on the investigated meteorological variables, the optimal daily regimes for the application rate realization, and the persistence of the obtained microclimatic effect. First experiment was conducted on August 23, 1993 - calm, sunny, and hot day, intrinsic to the larger part of peach vegetation. Readings were taken from 12:00 to 16:00 astronomic time, when the meteorological variables reached their extreme values for the day. In all treatments, the irrigation was started at 12:00 and ceased at 16:00, i.e. it was irrigated during the whole period of observation. The preceding application rate was delivered three days before, on August 20, 1993. The role of the daily irrigation regime was investigated during two other days in which the course and the extreme values of the meteorological variables were similar - temperature reached 32°C and relative air humidity declined to 35-40%. Readings were taken from 7:00 to 18:00 and the irrigation in each treatment was operated according to the schedule shown in Table 1. During the first day (August 5, 1993) - regime "A", the commonly used irrigation regimes were applied. During the second day (August 17, 1993) - regime "B", the two microsprinkling treatments were alternated with each other in two 150-minute cycles, each cycle including 90-minute irrigation in T.1 followed by a 30-minute irrigation in T.2 and a pause of 30 minutes. Irrigation regimes were scheduled to provide approximately equal application rates in each of the microsprinkler-irrigation treatments, per cycle and per day respectively. The application rates in T.2 and T.3 were calculated over 70% of the total area (K_r=0.7), taking in account the localized water application in these treatments. The persistence of the obtained effect was estimated on August 06, 1993, i.e. on the next day after the effect of commonly used daily irrigation regimes was estimated. In the absence of irrigation, readings in all treatments were taken in one-hour intervals from 7:00 to 16:00 using the experimental set-up described earlier in this article.

Table 1. Irrigation schedules used in the experiment on the regimes for realization of the daily application rates, conducted on August 5 and August 17, 1993.

Regimes and dates	Treatments		
	T.1	T.2	T.3
Regime "A" (August 5)	7:30-11.00 13:00-15:00	11:00-13:00	7:30-15:00
Regime "B" (August 17)	7:00- 8:30 9:30-11:00 12:00-13:30 14:30-16:00	8:30- 9:00 11:00-11:30 13:30-14:00 16:00-16:30	7:00-16:30

The effect on air temperature and relative air humidity was expressed as a difference between the values measured in the orchard and those measured in the meteorological cell (the reference). Obtained differences were compared statistically by levels of measurement for each microirrigation treatment and by treatments for each level, independently for the three experiments. The analyzed samples included the observations over representative time-intervals, specific for each experiment. As the reference values of air temperature and relative air humidity also changed during the day, the relative differences were used instead of the absolute ones in order for experimental results to be comparable.

3. Results and discussion

The effect of microirrigation treatments on air temperature and air humidity is illustrated respectively on Figures 2, 3, and 4. For the observation period, the reference values of the temperature varied from 31.6°C to 35.0°C and those of the relative humidity - from 33% to 26%. Statistically analyzed samples embraced 15 observations in the time-interval 12:30-16:00. The 30-minute period of transition after the beginning of irrigation, registered in T.1 and T.2, was excluded.

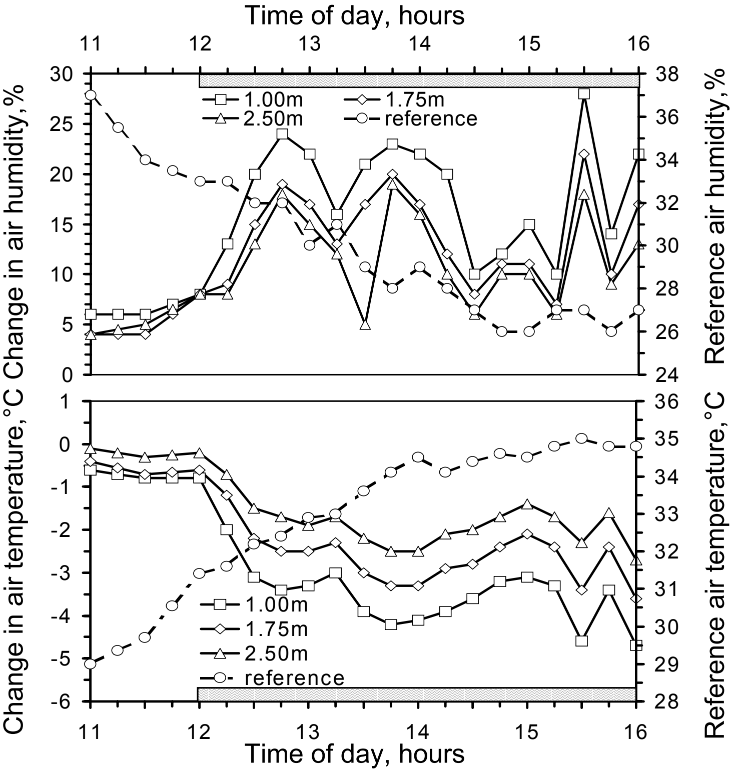

Fig.2. Changes in relative air humidity (above) and air temperature (below) in *Treatment 1* on August 23, 1993. Shaded strips mark the irrigation period.

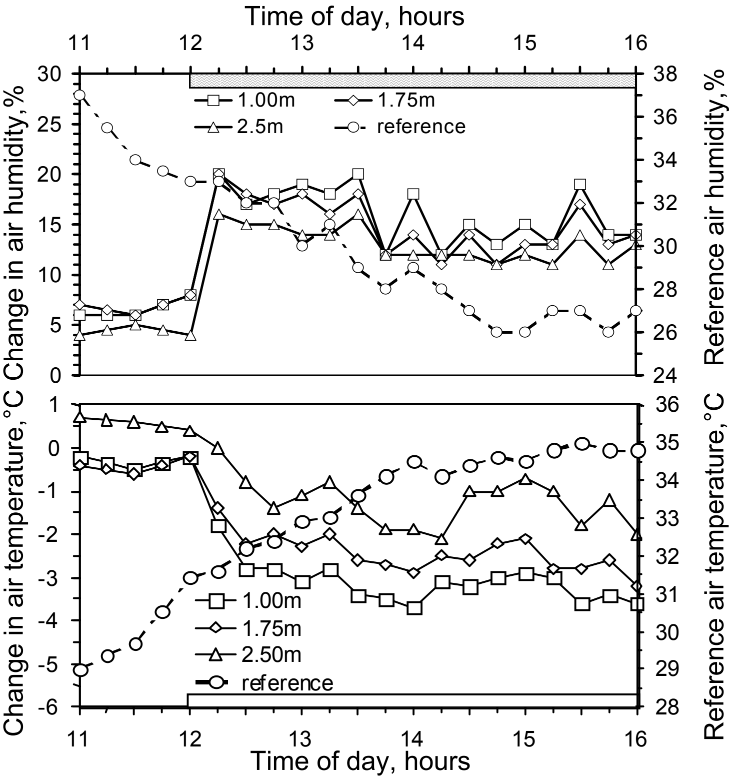

Fig.3. Changes in relative air humidity (above) and air temperature (below) in *Treatment 2* on August 23, 1993. Shaded strips mark the irrigation period.

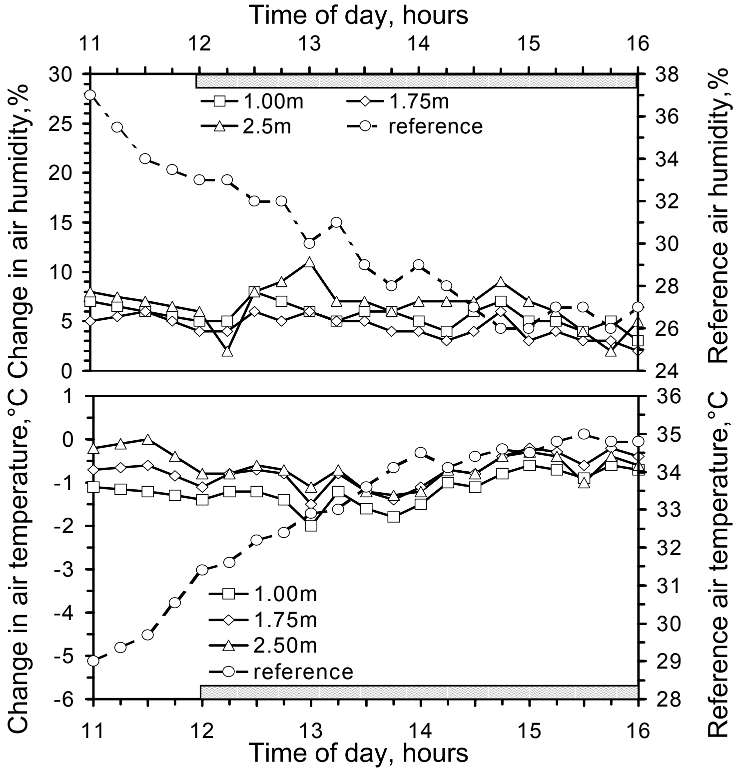

Fig.4. Changes in relative air humidity (above) and air temperature (below) in *Treatment 3* on August 23, 1993. Shaded strips mark the irrigation period.

In Treatment 1, the average decrease in the temperature values by levels of observation, starting from the uppermost, was respectively 1.9°C, 2.6°C, and 3.6°C, and the average raise of relative air humidity was 12%, 14%, and 18%. In some observations, temperature in the lowermost parts of the tree crown was lowered even by 4.7°C and relative air humidity was raised by 28% (by 104% relative to the reference value). The temperature differences registered between the levels of observation (1.00m, 1.75m, and 2.50m) were statistically significant for $P<0.05$ and $P<0.01$. Hence, the cooling effect decreased from the base to the top of the crown. As to air humidity, however, only the difference between levels 1.00m and 2.50m was proven significant for $P<0.05$. In other words, the effect on air humidity was unchanged to a height of 1.75m and then slightly decreased, remaining substantial.

In Treatment 2, the average decrease in temperature values by levels of observation was respectively 1.2°C, 2.4°C, and 3.1°C, and the average raise of relative air humidity was 13%, 15%, and 16%. Again, the maximum departures from the reference values were registered in the lowermost parts of the crown, respectively -3.7°C for the temperature and +20% (+70% relative to the reference) for the relative humidity. The temperature differences among the levels of observation were proven significant for $P<0.05$ and $P<0.01$, as well as for $P<0.001$ except the one between levels 1.00m and 1.75m, i.e. the cooling effect decreased from the base to the top of the crown. As to relative air humidity, the difference between levels 1.00m and 1.75m was not proven significant, between levels 1.75m and 2.50m it was significant for $P<0.05$, and between levels 1.00m and 2.50m it was significant for $P<0.05$ and $P<0.01$. Hence, the effect on air humidity was unchanged to a height of 1.75m and then decreased, remaining substantial.

In Treatment 3, the average decrease in temperature values by levels was respectively 0.7°C, 0.7°C, and 1,1°C, and the average raise of relative air humidity was 6%, 4%, and 5%.

The temperature differences among the three levels of observation were not proven significant, so the registered slight effect might be due rather to other factors than to the drip irrigation. The differences in air humidity between levels 1.00m and 1.75m as well as between levels 1.75m and 2.50m were significant for $P<0.05$. However, as the registered effect was strongest at the top of the tree crown and weakest in its center, it could hardly be considered direct result of the drip irrigation, too.

The comparison by levels of observation showed no significant differences between the treatments of microsprinkler irrigation (T.1 and T.2) regarding the average increase in air humidity. As to the effect on air temperature, only the difference at level 2.50m was proven significant for $P<0.05$. Apparently, the registered cooling effect attenuation, from the base to the top of the crown, was more pronounced under the localized microsprinkler irrigation (T.2). However, the differences between the treatments of microsprinkler irrigation (T.1 and T.2) on one side and the drip irrigation (T.3) on the other side were proven significant for $P<0.05$, $P<0.01$, and $P<0.001$ at almost all levels of observation, related to the effect on both air temperature and air humidity. Only at level 2.50m there was no significant difference between T.2 and T.3. This fact supported the conclusion that the localized microsprinkling cooling effect decreased rapidly above a height of 1.75m.

Generally, the two regimes for realization of the application rate yielded similar microclimatic effects illustrated by the results of regime "B" on Figures 5, 6, and 7. Shaded strips in each graph mark the periods of the irrigation system operation. Apparently microclimate in the peach orchard was affected by the microsprinkler-irrigation only after the ambient temperature had exceeded 28°C and the air humidity had dropped to 45%. Particularly for the days of investigation this happened at about 10:30 as it is clearly seen on the graphs. The ef-

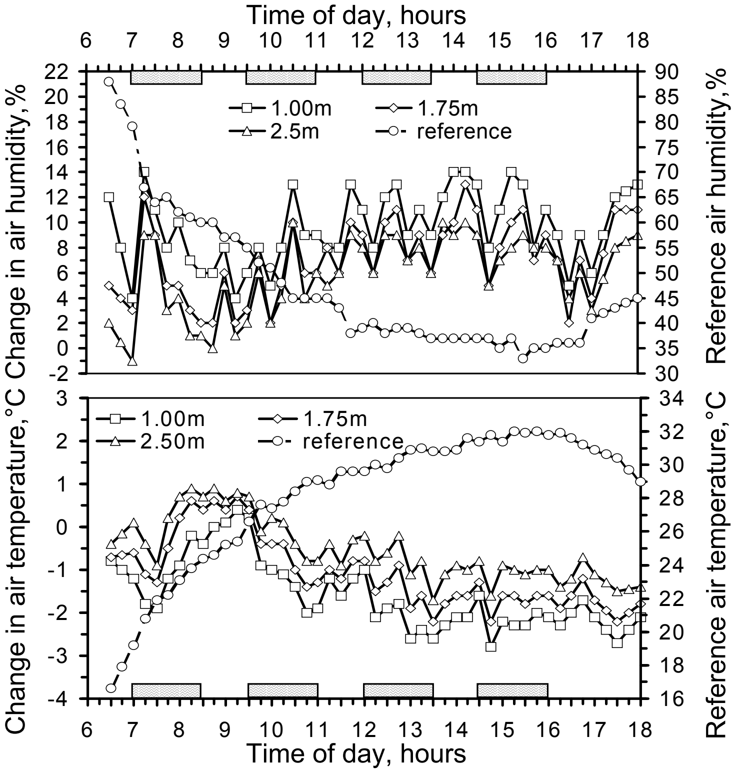

Fig.5. Changes in relative air humidity (above) and air temperature (below) under regime "B" in *Treatment 1* on August 17, 1993. Shaded strips mark the irrigation period.

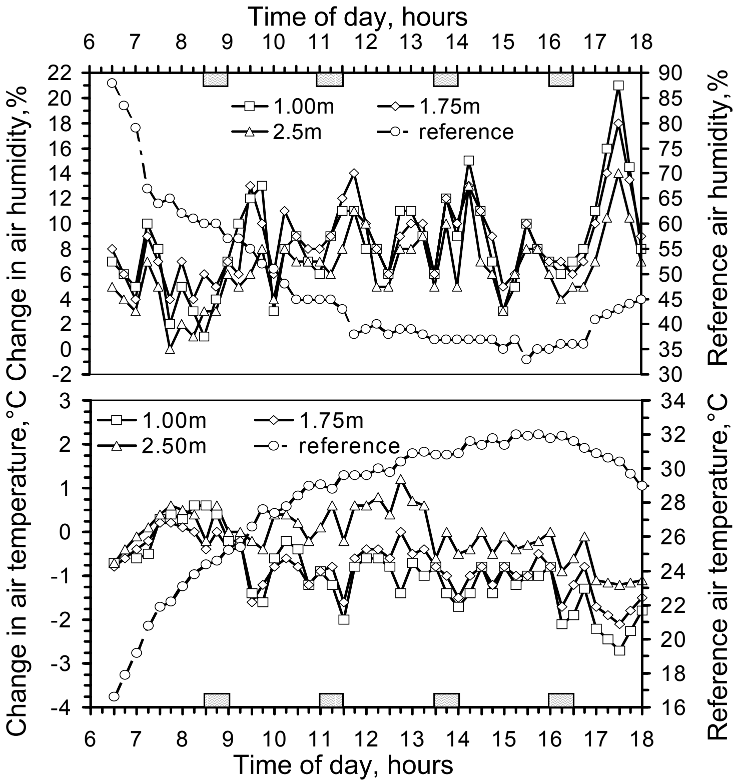

Fig.6. Changes in relative air humidity (above) and air temperature (below) under regime "B" in *Treatment 2* on August 17, 1993. Shaded strips mark the irrigation period.

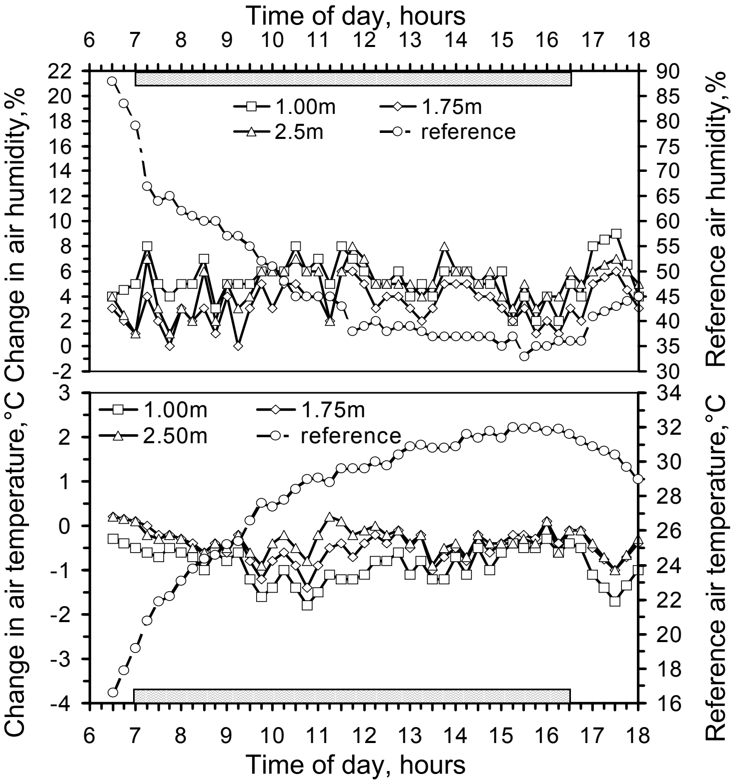

Fig.7. Changes in relative air humidity (above) and air temperature (below) under regime "B" in *Treatment 3* on August 17, 1993. Shaded strips mark the irrigation period.

fect on air temperature and air humidity in all treatments remained unchanged after the irrigation was ceased - to the very end of the observations at 18:00. That is why, the samples for statistical analysis embraced 31 observations done in the time interval 10:30-18:00.

The comparison by levels between the microclimatic effect of each treatment in regime "A" and regime "B", showed that there were no significant differences, i.e. the regimes for realization of the application rates during the two experimental days had not changed significantly the effect on air temperature and air humidity. However, the applied regimes modified the differences between the two microsprinkler-irrigation treatments. For example, the irrigation segmentation in T.2 under regime "B" attenuated the cooling effect of microsprinkling and its performance was closer rather to drip irrigation than to T.1. On the contrary, the effect on air humidity remained significant and was similar to that in T.1. Again, the two microsprinkling treatments had a definitely stronger effect on the meteorological variables investigated than the drip irrigation.

The microclimatic-effect results obtained on the next day after the irrigation showed no statistically significant effect on air temperature and air humidity, notwithstanding the microirrigation treatment, the level above the terrain, or the soil-maintenance system. This observation surprisingly contradicts with the expectations (e.g. Michelet, 1967) that the sod-much transpiration would increase air humidity in the orchard. Apparently, the microclimatic effect is mostly due to the direct contact of the water droplets with air.

4. Conclusions

Under-tree microsprinkler irrigation was found to have a regulative effect on microclimate in the peach orchard increasing substantially air humidity and decreasing air temperature. This effect occurred only after the ambient temperature had exceeded 28°C and the air humidity had dropped to 45%. As a result, the critical threshold of ambient temperatures was shifted almost to 40°C. The effect on microclimate was not affected essentially by the microsprinkler type or by the regime for realization of the application rate. The effect was positively related to the meteorological-factors magnitude and to the duration of irrigation. However, the effect on air temperature and air humidity was completely lost on the next day after irrigation, i.e. an irrigation regime with more frequent applications is preferable. Moreover, in critical for the plants periods of drought, microsprinkling could be operated every day despite of the fact that the applied water amounts would exceed the values of crop water use.

The investigated drip-irrigation method had no direct effect on air temperature and air humidity and it was not proven applicable for microclimate regulation in a peach orchard.

References

Bernstein, L., Francois, L.E., 1975. Effects of frequency of sprinkling with saline waters compared with daily drip irrigation. Agron. J. 67(2), 185-190.

Bible, B.B., Cuthbert, R.L., Corolus, R.L., 1968. Responses of some vegetable crops to atmospheric modifications under field conditions. J. Amer. Soc. Hort. Sci. 92, 590-594.

Bozarth, C.S., Kennedy, R.A., Schekel, K.A., 1982. The effect of leaf age on photosynthesis in rose. J. Amer. Soc. Hort. Sci. 107(5), 707-712.

Bresler, E.B., 1977. Trickle-drip irrigation: principles and application to soil-water management. Advances in Agronomy, 29, 343-393.

Denmead, O.T., Shaw, R.H., 1962. Availability of soil water to plants as affected by soil moisture content and meteorological conditions. Agron. J. 54, 385-390.

Dochev, D., 1968. Irrigation of the Perennial Plantations in the Agriculture - Review, II part (in Bulgarian). Agricultural Academy, Sofia, 240 pp.

Dochev, D., 1983. Irrigation of the Fruit Crops - Review (in Bulgarian). National Agricultural and Industrial Union, Center for Scientific and Technical Information, Sofia, 72 pp.

Dochev, D., 1990. Investigations on the irrigation of peach in PR of Bulgaria (in Bulgarian). Habilitation Thesis, Agricultural Academy, CES Pomorie, 250pp.

Even-Chen, Z., Weinbaum, S.A., Pearcy, R.W., 1981. High temperature effects on leaf resistance, leaf water potential, and photosynthesis of nonbearing prune trees. J. Amer. Soc. Hort. Sci. 106(2), 216-219.

Fernandez, G.E., Pritts, M.P., 1994. Growth, carbon acquisition, and source-sink relationships in "Titan" red raspberry. J. Amer. Soc. Hort. Sci. 119(6), 1163-1168.

Gilbert, D.E., Myer, J.L., Kessler, J.J., La Vine, P.D., Carlson, C.V., 1970. Evaporative cooling of vineyards. Calif. Agric. 24, 12-14.

Hamer, P.J.C., 1987. Irrigation of fruit. 3. Irrigation methods. Irrigation News 11, 23-28.

Klassen, P., 1986. Distribute water effectively. Amer. Fruit Grower, 106, 40;42.

Kramer, P.J., Boyer, J.S., 1995. Water Relations of Plants and Soils. Academic Press, San Diego, 495 pp.

Lakso, A.N., Seeley, E.J., 1978. Environmentally induced responses of apple tree photosynthesis. Hort Science 13, 646-649.

Miller, M.P., Turrel, F.M., Austin, S.W., 1963. Cooling avocado trees by sprinkling. Calif. Aric. 17, 4-5.

Olcott-Reid, B., Sutton, T.B., Unrath, C.R., 1981. Evaporative cooling irrigation influences disease, insect and mite pests of "Delicious" apples. J. Amer. Soc. Hort. Sci. 106(4), 469-474.

Sams, C.E., Flore, J.A., 1982. The influence of age, position, and environmental variables on net photosynthetic rate of sour cherry leaves. J. Amer. Soc. Hort. Sci. 107(2), 339-344.

Seeley, E.J., Kammereck, R., 1977. Carbon flux in apple trees: the effect of temperature and light intensity on photosynthetic rates. J. Amer. Soc. Hort. Sci. 102(6), 731-733.

Sneed, R.E., Perry, K.B., Sanders, D.C., Unrath, C.R., 1988. Using sprinkler irrigation for evaporative cooling. Conserving Energy, Water and Other Resources Trough Irrigation, pp.114-119.

Southwick, S.M., Schakel, K.A., Yeager, J.T., Asai, W.K., Katacich Jr., M., 1991. Over-tree sprinkling reduces abnormal shape in "Bing" sweet cherries. Calif. Agr. 45, 24-26.

Unrath, C.R., 1972a. The evaporative cooling effects of overtree sprinkler irrigation. J. Amer. Soc. Hort. Sci. 97(1), 55-58.

Unrath, C.R., 1972b. The quality of "Red Delicious" apples as affected by overtree sprinkler irrigation. J. Amer. Soc. Hort. Sci. 97(1), 58-61.

Unrath, C.R., Sneed, R.E., 1974. Evaporative cooling of "Delicious" apples - the economic feasibility of reducing environmental heat stress. J. Amer. Soc. Hort. Sci. 99(4), 372-375.

Videnov, B., Doichev, K., 1973. Apple scab and apple russeting as affected by irrigation method (in Bulgarian). Ovoshtarstvo 52, 9-12.

Wilson, D.E., 1968. Effects of sprinkler irrigation on disease outbreaks. Proc. Intern. Congr. Plant Pathol. 1:219 (Abstr.).