ON THE NECESSITY FOR FURTHER IMPROVEMENT IN MICROIRRIGATION SCHEDULING

Kouman S. Koumanov[1]

(1) Fruit Growing Institute 12 Ostromila, Plovdiv 4004, Bulgaria

Keywords: drip irrigation, microsprinkling, application efficiency, irrigation scheduling

ABSTRACT

In contrast to an intensive technical improvement of microirrigation systems during the last decades, the methods for irrigation scheduling and management have not been essentially changed since the appearance of microirrigation. Currently used approaches originate from those developed for conventional irrigation methods (surface and sprinkler), where soil is considered a water reservoir and water fluxes are predominantly one-dimensional (vertical). Micro-irrigation specificity is introduced by series of empirical coefficients which have to account for the local soil wetting, frequent water applications, and two- or three- rather than one-dimensional water distribution and redistribution in the root zone. It is generally accepted that microirrigation and particularly drip irrigation provides a high application efficiency of 0.90÷0.95, the water losses being associated predominantly with deep percolation. Some authors, however, reported high evaporative losses under microirrigation, which was inconsistent with the current understanding for the processes taking place in the continuum soil-plant-atmosphere. This fact was corroborated by the results of experiments carried out in peach and almond plantations, respectively at the Fruit Growing Institute – Plovdiv, and at the University of California – Davis, USA, in the period 1994-1997. The drip irrigation water distribution in the root zone of peach trees was established in three soils – Luvisol, Fluvisol and Vertisol – through soil sampling at 10, 25, 50, 75 and 100 cm radially from the dripper and by layers of 10 cm in depth down to 80 cm. Water use of an almond tree under microsprinkling was estimated by precise water balance in a quarter of the root system using 25 neutron probe access tubes and eight tensiometer pairs. Obtained results proved water losses by evaporation, which might be significant, depending on soil and climatic conditions. Currently used methods for microirrigation scheduling ignore that fact or take it in account indirectly – through the coefficient of reduction K_r, thus turning that coefficient into a regional variable and loading the procedure with additional empiricism. Hence, crop water use efficiency could be increased and time and labour consumption decreased if coefficients used in that methodology were given their real physical meanings, and evaporation losses were calculated as a function of the soil and climate characteristics.

INTRODUCTION

Microirrigation has been widely used in agriculture and especially for perennial crops because of its possibilities for effective control on the processes in the irrigation system, in the irrigated plantation and even in each plant. In contrast to an intensive technical improvement of microirrigation systems during the last decades, however, methods for irrigation scheduling and management have not been essentially changed since the appearance of microirrigation in the sixties of the past century. Currently used approaches originate from those developed for conventional irrigation methods (surface and sprinkler), where soil is considered a water reservoir and water fluxes are predominantly one-dimensional (vertical). Micro-irrigation specificity is introduced by series of empirical coefficients which have to account for a local soil wetting, frequent water applications, and two- or three- rather than one-dimensional water distribution and redistribution in the root zone. Generally, the application rate *I*, which has to compensate for crop water use in a given period and for eventual water losses associated with the irrigation process, is calculated using the following equation:

$$I = \frac{1}{K_e} K_r K_c ET_0, \tag{1}$$

where ET_o is the reference evapotranspiration, K_c is crop coefficient, K_r is reduction coefficient and K_e is the application efficiency.

The reduction coefficient K_r accounts for eventual decrease in evapotranspiration because of the localized water application and partial soil covering by the crop canopy (Belchev et al., 1979; Fereres et al., 1982); K_r should also account for planting distances differing from these established when crop water use was estimated. Some authors provide the ET_c-decrease by including K_r in the value of the crop coefficient (Allen et al., 1998). Generally, the value of K_r is defined as a function of the coefficient of shadowing K_s, $K_s = F_s : F_t$, where F_t is the soil surface area belonging to one treee and F_s is the area of the vertical projection of the tree crown or the "shadowed area" (Fig. 1). The application efficiency K_e accounts for water losses during water application and is defined as the ratio of water applied that is actually stored in the crop root zone to the total water applied (Bralts, 1986). It is widely accepted that microirrigation and particularly drip irrigation provides a high application efficiency, $K_e = 0.90 \div 0.95$ (Vermeiren and Jobling, 1980; Snyder and Pruitt, 1989). Moreover, evaporation losses are usually accepted minimal and only drainage is considered to limit the application efficiency (Howell et al., 1986). However, the results of some investigations do not support such rather optimistic statements. Howell et al. (1986) note that the frequency of the wetting may result in cumulative evaporation losses as large as those commonly associated with sprinkling or surface irrigation. Working with micro-lysimeters, Mattiaŝ et al. (1986) found that the evaporation from bare soil surface under single dripper was 33-40 % of the water supplied during seven-day lasting permanent irrigation. According to Fereres et al. (1982) the water savings potential of drip irrigation is maximum the first two years of the orchard, then declines as trees grow and probably becomes very limited after the sixth year. More recent results (Koumanov et al., 1997; Koumanov et al., 1998) also prove that the evaporation losses during microirrigation may be significant part of the total water applied.

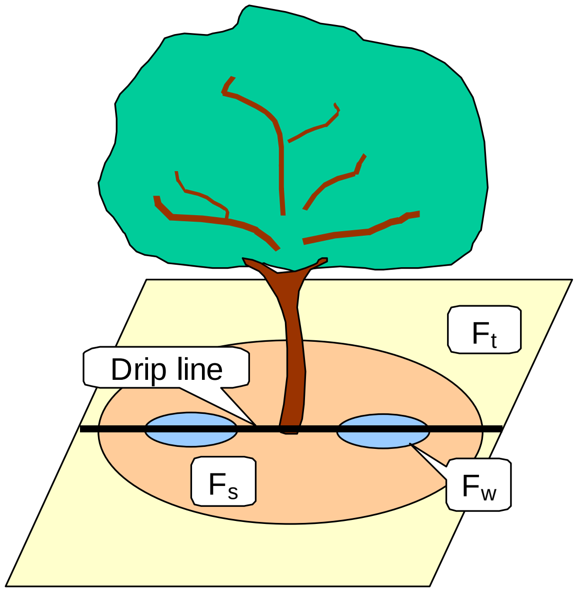


Fig. 1 *Illustration of the approach for microirrigation scheduling.*

Present paper analyzes the inconsistency of the widely accepted methods of microirrigation scheduling, especially for perennial crops, and offers some approaches for improving of these methods. Results presented are from experiments with peach and almond trees on various soil types carried out respectively at the Fruitgrowing Institute – Plovdiv, and at the University of California – Davis, USA, in the period 1994-1997.

1 MATERIALS AND METHODS

Drip irrigation of peach trees. This study was conducted in lysimeters with dimensions 2x3x1 m on three soils substantially differing in their water and physical characteristics: alluvial-meadow soil – *Fluvisol*, cinnamonic-forest soil – *Luvisol* (chromic), and smolnitsa – *Vertisol*. Texturally they are classified as sandy loam, clay loam, and clay respectively, using the USDA-classification (Soil Survey Staff, 1975). The values of some soil characteristics are given in Table 1. In the spring of 1994, single peach trees (cv. *"Redhaven"* on *GF-677* rootstock) were planted in each of the lysimeters. Plants were supplied with water and fertilizers through a drip-irrigation system: one emitter per tree, with an average discharge of 4.6 L/h, and located 0.75 m apart from the tree trunk. Irrigation regimes were the same for all trees. The spatial pattern of irrigation water distribution in the soil was established in 1996 – the third vegetation of the trees, by soil sampling 20 hours after the water application. Soil samples were taken by drilling at radial distances of 10, 25, 50, 75 and 100 cm from the dripper and by 10-cm increments in depth down to 80 cm. Soil moisture values were estimated gravimetrically. For more details see Koumanov et al. (1998).

Soil properties	Soils		
	Fluvisol	**Luvisol**	**Vertisol**
Particle density, g/cm^3	2.7	2.6	2.7
Bulk density, g/cm^3	1.43	1.19	1.23
Porosity, %	47.0	54.2	54.4
Field capacity, kg/kg	0.16	0.24	0.35
Content of sand (2 ÷ 0.05 mm), %	64.8	40.0	34.7
Content of silt (0.05 ÷ 0.002 mm), %	24.3	25.8	14.2
Content of clay (< 0.002 mm), %	10.9	34.2	51.1

Table 1. *Physical characteristics of the investigated soils*

Microsprinkling of almond trees. This investigation was conducted in August 1995 in a six-year-old almond plantation located 90 km north of Davis, California, U.S.A, in Sacramento valley. The trees were of the cv. *"Butte"*, grafted on *"Lovell Peach"* rootstock, and tree spacing was 4.8x6.6 m. Canopy coverage of the soil surface was 60 %. The trees were irrigated by microsprinklers – with an average discharge of 41.7 L/h and an effective radius of about 4.0 m – placed midway between trees in the tree row. The soil is with young alluvial deposit, at least 0.60 m, overlaying an old clay deposit within 1.50 m. The surface is a gravely sandy loam with thickness 0.30-0.40 m. The lower layer has an inclusive range of gravely loam and reaches depth of 0.90-1.50 m. Soil porosity decreases with depth and internal drainage is restricted by the clayey substratum. Neutron probe and tensiometers were used for a precise water balance in the root zone of a representative almond tree, Fig.2. The experimental plot covered about one quarter of the wetted area of one micro-sprinkler. In the 2.0 x 2.0 m monitored area, 25 PVC neutron probe access tubes were installed in a square grid of 50 cm spacing to a depth of 120 cm. In addition, eight pairs of tensiometers were installed in a regular pattern between the access tubes at depths of 82.5 cm and 97.5 cm, respectively. The soil water content and the rate of soil water depletion were evaluated for the 0–22.5, 22.5–37.5, 37.5–52.5, 52.5–67.5, 67.5–82.5, and 82.5–97.5 cm soil depth intervals, corresponding to the 15, 30, 45, 60, 75, and 90 cm depth measurements of the neutron probe. After linear interpolation of the tensiometer data across the experimental plot, vertical water fluxes across the lower boundary

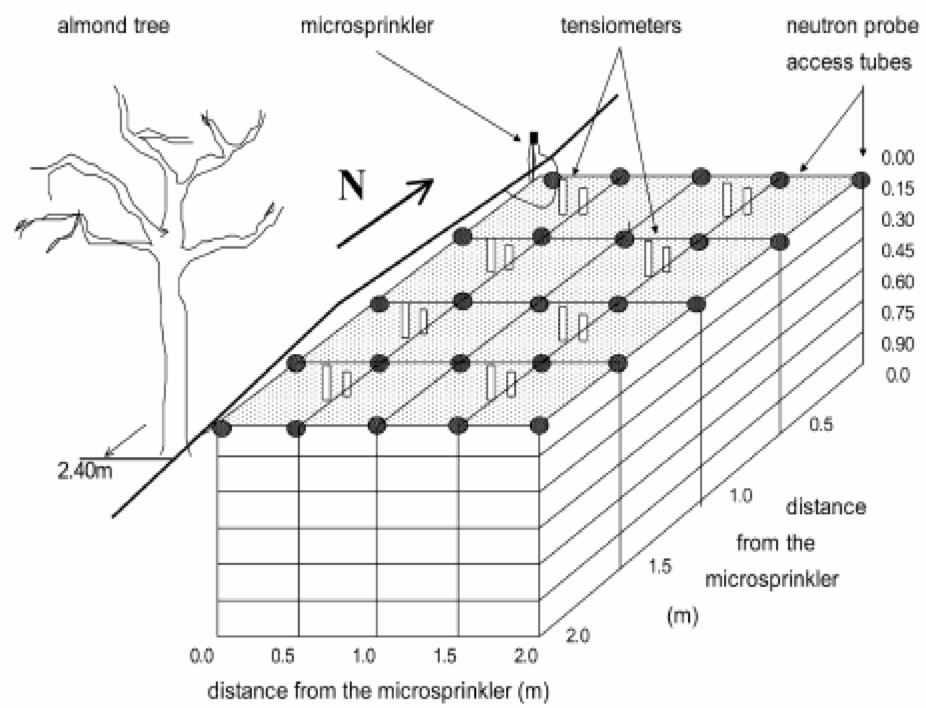


Fig. 2 *Schematic of the experiment*

(90 cm depth) were evaluated for all neutron probe access tube locations. Three water applications were realized in a one-week period – on 18, 21, and 23 August respectively. On all three days, irrigation started at 6:00 o'clock and lasted 7.5 to 13.5 hours. Irrigation was scheduled using the widely accepted methodology (Eq. 1), based on the California Irrigation Management Information System (CIMIS) data. According to the recommendations for microirrigation scheduling in Sacramento valley (Snyder et al., 1987), $K_c = 0.9$, $K_r = 1.0$, и $K_e = 0.9$. Neutron probe and tensiometer readings were taken before and after each of the water applications, as well as daily at about 6:00, 10:00, 14:00, and 18:00 hours. For more details about the experiment see Koumanov et al. (1997).

2 RESULTS AND DISCUSSION

Drip irrigation of peach trees. The pattern of soil wetting in each of studied soils is shown on Fig. 3. Irrigation water distribution was different in each soil despite of the same irrigation regime. In *Fluvisol*, wetting front reached only 30-40 cm in depth. On the other hand, water was more prolific at the soil surface with a radius of lateral wetting reaching 75 cm. The relatively small volume of wetting suggested significant evaporative losses from the increased superficial ponding area. In the more permeable *Luvisol* wetting front reached 60 cm in depth and 50-60 cm in radial direction with the largest radius of soil wetting at depth of 30 cm. The zone of surface ponding was smaller, thus decreasing the evaporative losses, and the wetted soil volume was increased approaching the normal size and shape for this type of irrigation. According to the experimental results, water infiltrated *Vertisol* at a high rate and the zone of surface overwetting stretched in radial direction to 25-30 cm, i.e. evaporation loses were minimal. Water amount stored in the wetted soil volumes, estimated under an assumption for axisimetry of the bulb, was roughly 59 dm^3 in *Fluvisol*, 89 dm^3 in *Luvisol*, and 239 dm^3 in *Vertisol*. These values are a quantitative appraisal, though indirect, of the impact of evaporation from the overwetted/ponded areas under the drippers on the application efficiency K_e.

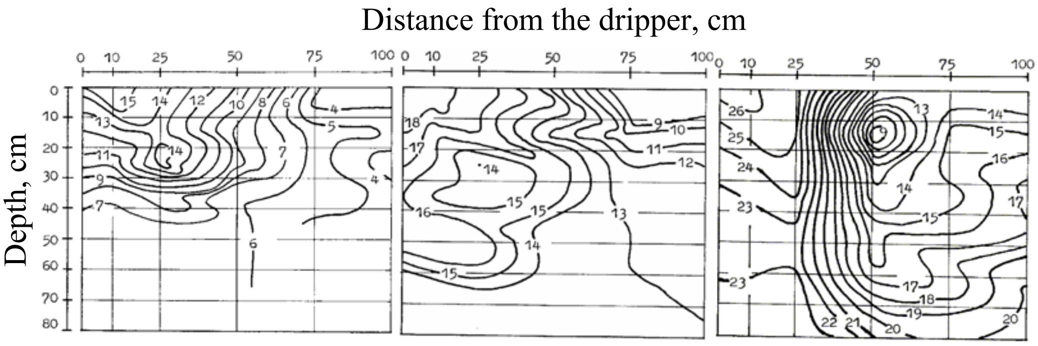


***Fig. 3** Fields of soil moisture (kg/kg 100, %) in the investigated soils. 10.07.1996.*

Microirrigation of almond trees. The terms of water balance and some meteorological data are given in Table 2.

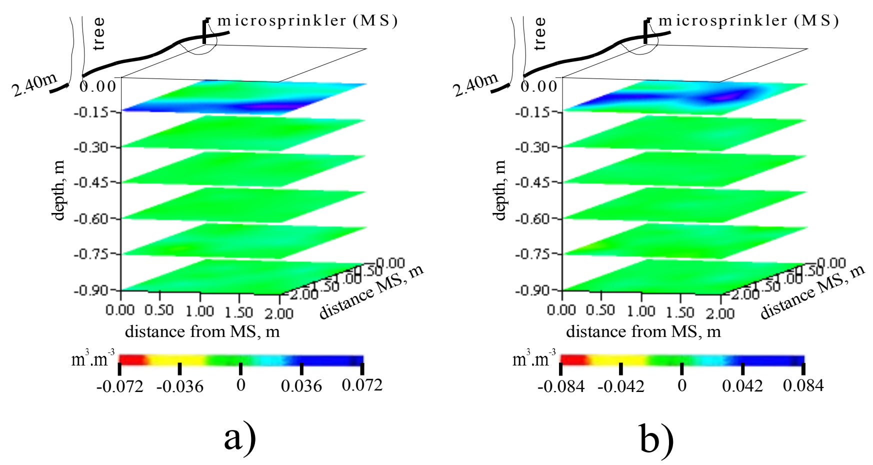
Water balance elements & Meteorological data	Observation date		
	18/08	**21/08**	**23/08**
Water applied/wetted area[a] (mm)	22.9	17.0	17.8
Water applied/total area[b] (mm)	14.6	10.9	11.4
Change in water storage/wetted area[a] (mm)	6.8	3.9	3.5
Change in water storage/total area[b] (mm)	4.35	2.5	2.23
Evapotranspiration ET_c on the next day[b] (mm)	4.1	3.8	3.3
Reference ET_0[b] (mm)	6.3	5.5	6.8
Change in water storage + ET_c[b] (mm)	8.45	6.30	5.53
Application efficiency (K_e)[c]	0.58	0.58	0.49

24-h T_{max} (°C)	33	37	38
24-h T_{min} (C)	14	16	17
Maximum relative air humidity (%)	66	79	81
Minimum relative air humidity (%)	18	21	19
Average wind speed (m/s)	2.0	1.6	2.7

[a]Wetted area = 4(2.25 x 2.25) = 20.25 m^2
[b]Total area = 4(2.4 x 3.3) = 31.67 m^2
[c]K_e = (Change in water storage + ET_c from the next day)/Water applied

Table 2 *Water balance for the 0.975 m soil profile with derived application efficiency (K_e) values and selected meteorological data for the days of microsprinkler irrigation.*

Vertical water exchange trough the bottom of root zone and the evapotranspiration from the dry part of soil volume were negligible. As far as the partitioning between evapotranspiration and evaporation losses during water application was uncertain, the application efficiency was estimated based on the actual ET-values on the next day. According to the obtained results, water applications wetted only the upper 20-25 cm of the soil, Fig. 4. Again, as in the experiment with drip irrigation, significant part of the applied water was lost by evaporation from the overwetted soil surface. These losses resulted in application efficiency values ranging from 0.49 to 0.58, the portions of the application rates spent during the days with irrigation being 70%, 77% and 71%, respectively. On the days without irrigation, the actual daily values of crop coefficient K_c ranged from 0.59 to 0.77 the lower values being estimated in the days before water applications, i.e. it might well be that plants developed some level of water stress. A water balance calculation for the combined 7-day period resulted in a crop coefficient of 1.05. Hence, water balance measurements for a 7-day or longer period overestimate water use by transpiration and crop coefficient values since evaporation losses are neglected on days when water is applied. In turn, the net application rate is insufficient, the actual ET on the days without irrigation is lower than the calculated one, and the water storage in the root zone gradually decreases (Fig. 5).



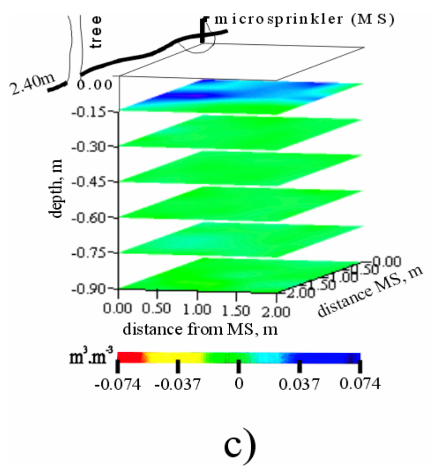


Fig. 4 *Spatial patterns of the increase in soil water content ($m^3.m^{-3}$) immediately after the water applications on 8/13/95 – a, 8/18/95 - b, and 8/21/95 - c.*

From the viewpoint of the commonly accepted belief in high application efficiency of microirrigation, the conjectural, on the basis of drip irrigation results, and the figured, under microsprinkling, values of K_e are surprisingly low and the evaporation losses are too high. However, it is well known from the physics that, because of the peripheral diffusion, the evaporation from great number small surfaces located apart from each other is much more intensive than the evaporation from a large surface with the same area. In case of small surfaces, the evaporation rate is proportional to their perimeter and does not depend on the total area. Thus, the leaves of plants evaporate only two times less than water surface with the same area although the total area of stomata is only 1 % of the leaf area (Lebedev, 1982).

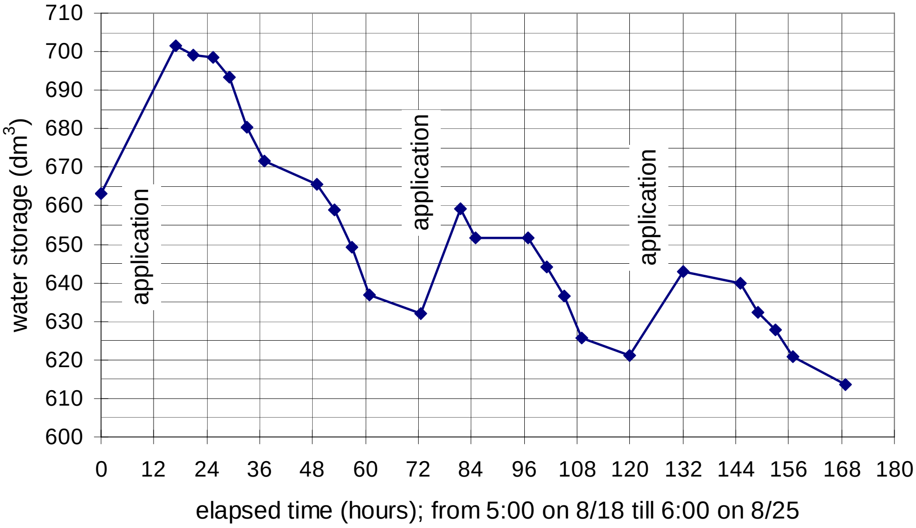


Fig. 5. *Changes in water storage (dm^3) in the experimental soil volume (2 x 2 x 0.975m) during the period 8/18/95 – 8/25/95.*

In fact, current methodology accounts for evaporation losses tacitly including them in the value of the reduction coefficient K_r. Under soil and climate conditions similar to those of K_r estimation, Eq. 1 yields correct results concerning the application rates (Sharples et al., 1985). In accordance with this commonly adopted method, the application efficiency value is predefined as constant (K_e= 0.90-0.95) while the values of K_r have to be obtained experimentally in each case of differing soil properties, climatic conditions or methods of microirrigation. This, however, requires long-standing experiments. It would be more rational if the coefficients in Eq. 1 were given real physical meanings. Thus, for example, the reduction of microirrigation application rate can be directly related to the coefficient of shadowing, i.e. $K_r = K_s$, provided $F_w < F_s$ (Fig. 1). The reason for such an approach is that, generally, non-covered (dry) soil surface does not contribute directly and substantially to evapotranspiration. Of course, this surface has an indirect effect through the advection, but it affects mostly evaporation losses, as it is seen from the experimental results quoted in this paper. The application efficiency K_e can also obtain its actual value if the estimation of evaporation losses is based on universal physical or mathematical models allowing computer simulation of the water evaporation and redistribution in the soil under various initial and boundary conditions. Thus, preliminary investigations, necessary for evaluation of the empirical coefficients, will be reduced to determining of specific soil properties and some climatic characteristics.

CONCLUSIONS

Microirrigation in orchards is associated with evaporation losses that may be unexpectedly high, depending on soil and climatic conditions. The widely used method for microirrigation scheduling does not account to full extent for the evaporation losses. Water losses are tacitly included in the value of the reduction coefficient K_r. This, however, turns K_r into a regional variable and loads the calculation procedure with additional empiricism.

The accuracy in the calculation of application rates could be increased, and the time and labor consumption decreased, if the used coefficients were given their real physical meanings. Thus, the reduction coefficient could be made equal to the coefficient of shadowing, i.e. $K_r = K_s$, and the application efficiency K_e could be estimated based on physical or mathematical models describing evaporation losses as a function of soil and climate characteristics and taking in account the specificity of the used microirrigation technique.

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