

WATER APPLICATION EFFICIENCY AND THE PARADIGMS OF MICROIRRIGATION SCHEDULING IN ORCHARDS

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Abstract: *In contrast to an intensive technical improvement of microirrigation systems during the last decades, methods for irrigation scheduling and management have not been essentially changed since the appearance of microirrigation in the sixties. Currently used approaches originate from those developed for conventional irrigation methods (surface and sprinkler), where soil is considered as 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. It is generally accepted that microirrigation and particularly drip irrigation provides a high application efficiency of 0.90–0.95. Moreover, water losses are rather associated with deep percolation than with evaporation from soil surface. Recent investigations, however, have proven the need for improvement of methodology of microirrigation scheduling and management. In present publication this statement grounds on results from experiments in peach and almond plantations on various soil types carried out at the Fruitgrowing Institute, Plovdiv and at the University of California, USA, in the period 1994–1997. Irrigation water distribution in root zone of peach trees was established under drip irrigation in three soils – Luvisol, Fluvisol and Vertisol. Research objectives were addressed from soil sampling at radial distances of 10 cm, 25 cm, 50 cm, 75 cm and 100 cm from the dripper and by layers of 10 cm in depth to 80 cm. Water use of an almond tree under microsprinkling was estimated by precise water balance in a quarter of root system using neutron probe and tensiometers. Obtained results proved water losses by evaporation, which may 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, 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 soil and climate characteristics.*

Key words: *microirrigation, irrigation scheduling, orchard*

Introduction

Microirrigation has been widely used in agriculture and especially for fruit 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 as 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, application rate I , which has to compensate for crop water use in a given period and for eventual water losses associated with irrigation process, is calculated using the following formula:

$$I = \frac{1}{K_e} K_r K_c ET_0, \quad (1)$$

where ET_0 is the reference evapotranspiration, K_c is crop coefficient, K_r is reduction coefficient and K_e is the application efficiency.

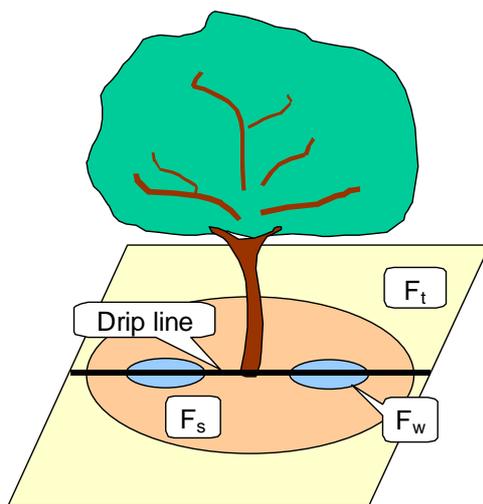


Fig. 1 Illustration of the approach for microirrigation scheduling.

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., 1981). Also, K_r should 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 tree 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, $K_e = 0.90 \pm 0.95$ (Vermeiren and Jobling, 1980; Snyder and Pruitt, 1989b). 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 sprinkler or surface irrigation. Working with micro-lysimeters, Mattiaš 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 and Koumanov et al., 1998) also prove that the evaporation losses during microirrigation may be significant part of the total water applied.

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

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 clarified as a 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 (cultivar "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 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. Soil moisture values were estimated gravimetrically. For more de-

tails see Koumanov et al. (1998).

Table 1. Physical characteristics of the investigated soils

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

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. Trees were of the "Butte" variety, grafted on "Lovell Peach" rootstock, and tree spacing was 4.8x6.6 m. Canopy coverage of the soil surface was 60 %. Trees were irrigated by microsprinklers with an average discharge of 41.7 l/h and a wetted diameter of about 4.0 m., placed midway between trees in the tree row. The soil is with young alluvial deposit, at least 0.60m, 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. 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 (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 sched-

uled using the widely accepted methodology (Eq. 1), based on 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 every one of water applications, as well as daily at about 6:00, 10:00, 14:00, and 18:00 o'clock. For more details about the experiment see Koumanov et al. (1997).

Table 2 Water balance for 0.975 m soil profile with derived application efficiency (K_e) and selected meteorological data for the days of irrigation under microsprinkling of an almond tree.

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

^aWetted area = $4(2.25 \times 2.25) = 20.25 \text{ m}^2$

^bTotal area = $4(2.4 \times 3.3) = 31.67 \text{ m}^2$

^c $K_e = (\text{Change in water storage} + ET_c \text{ from the next day})/\text{Water applied}$

Results and discussion

Drip irrigation of peach trees. The pattern of soil wetting in each of studied soils is shown on Fig. 2. Irrigation water distribution is different in each soil despite of the same irrigation regime. In the alluvial-meadow soil, 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 cinnamonnice-forest soil 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 drip irrigation. According to the experimental results, water infiltrated the smolnitsa at a high rate and the zone of surface overwetting stretched in radial direction to 25-30 cm, i.e. evaporation losses were minimum. Water amount stored in the wetted soil volumes, estimated under an assumption for axisimetry of the bulb, was roughly 59 dm³ in the alluvial-meadow soil, 89 dm³ in the cinnamonnoc-forest soil, and 239 dm³ in the smolnitsa. 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 .

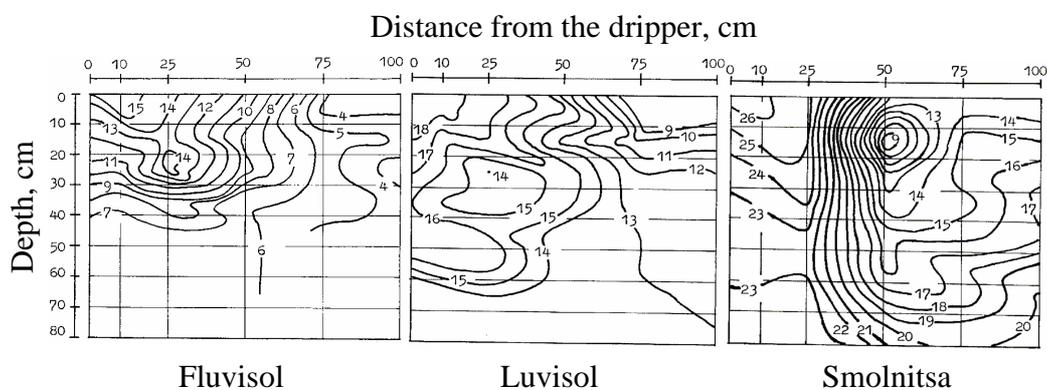


Fig. 2 Fields of soil moisture (gravimetric %) in the investigated soils. 10.07.1996.

Microirrigation of almond trees. The terms of water balance and some meteorological data are given in Table 2. Vertical water exchange through 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 is uncertain, 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. 3. 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 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. Thus, 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. 4).

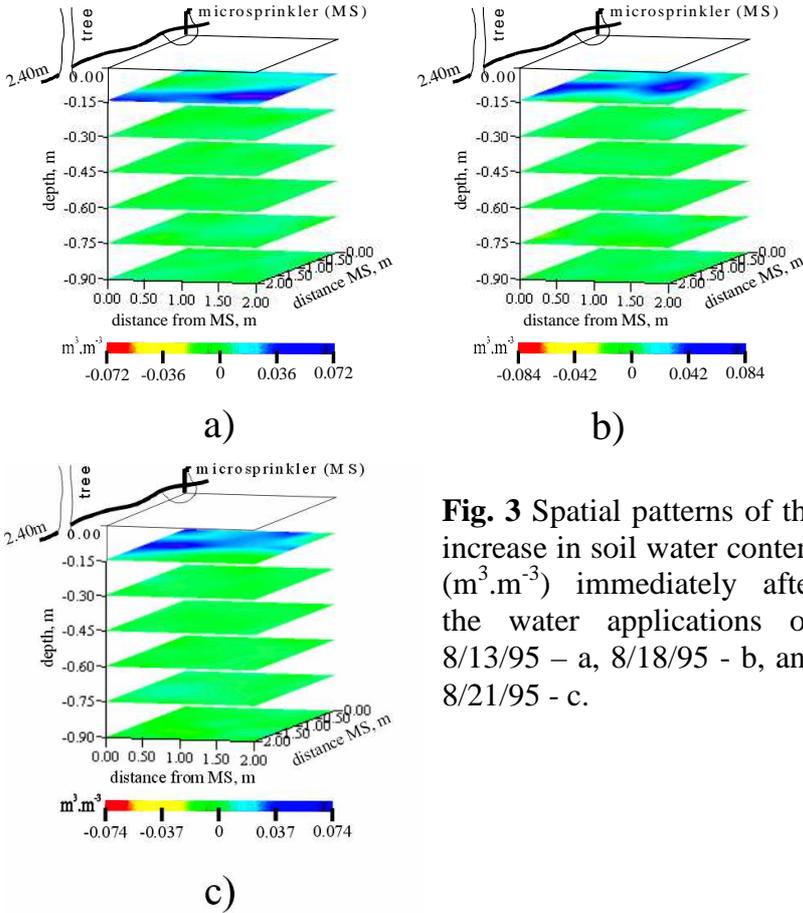


Fig. 3 Spatial patterns of the increase in soil water content ($\text{m}^3 \cdot \text{m}^{-3}$) immediately after the water applications on 8/13/95 – a, 8/18/95 - b, and 8/21/95 - c.

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 al-

though the total area of stomata is only 1 % of the leaf area (Lebedev, 1982).

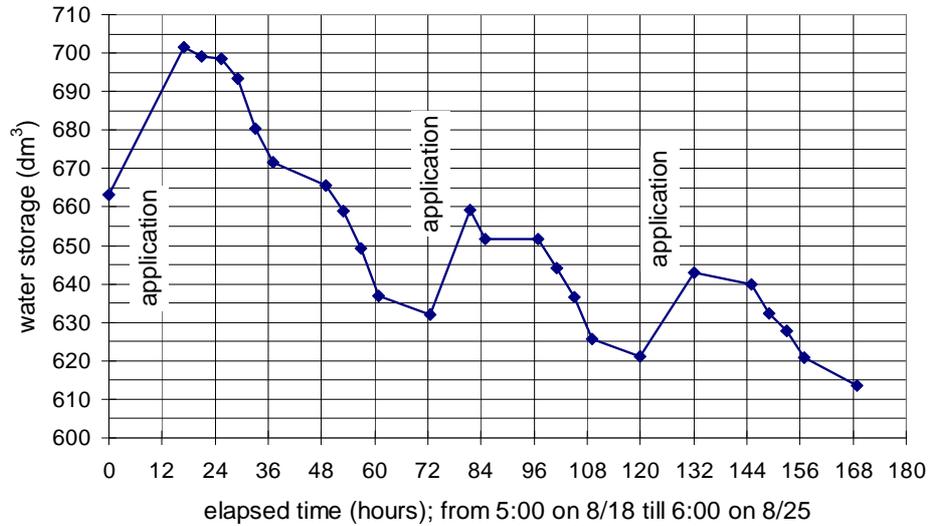


Fig. 3. Changes in water storage (dm^3) in the experimental soil volume ($2 \times 2 \times 0.975\text{m}$) during the period 8/18/95 – 8/25/95.

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 ($K_e = 0.90\text{—}0.95$) 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 re-

duced 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 climate conditions. The widely used methods 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.

References

- Belchev, I., S. Ivanov, P. Petkov. 1979. Kapkovo napoiavane. Zemizdat, Sofia, 112 pp. (Bul.)
- Lebedev, S.I. 1982. Fiziologia rastenii. Kolos, 463 pp. (Ru.).
- Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and drainage paper 56.
- Bralts, V.F. 1986. Field performance and evaluation. In: Trickle Irrigation for Crop Production – Design, Operation and Management (F.S. Nakayama and D.A. Bucks, Eds.), Elsevier Science Publishers B.V., pp. 216—240.
- Fereres, E., D.A. Martinich, T.M. Aldrich, J.R. Castel, E. Holzapflet, and H. Schulbach. 1982. Drip irrigation saves money in young almond orchards. *California Agriculture* 36(9&10): 12—13.
- Howell, T.A., D.A. Bucks, D.A. Goldhamer, and J.M. Lima. 1986. Irrigation scheduling. In: Trickle Irrigation for Crop Production – Design, Operation and Management (F.S. Nakayama and D.A. Bucks, Eds.), Elsevier Science Publishers B.V., pp. 241—279.
- Koumanov, K., D. Dochev, and G. Stoilov (1998). Investigations on fertigation of peach on three soil types - patterns of soil wetting. *Bulg. J. Agric. Sci.*, 4: 745-753.
- Koumanov, K., J.W. Hopmans, L.J. Schwankl, L. Andreu, and A. Tuli (1997). Application efficiency of micro-sprinkler irrigation of almond trees. *Agricultural Water Management*, 34: 247-263.
- Matthiaş, A.D., R. Salehi and A.W. Warrick (1986). Bare soil evaporation near a surface

point-source emitter. *Agricultural Water Management* 11:257-277.

Sharples, R.A., D.E. Rolston, J.W. Biggar, and H.I. Nightingale. 1985. Evaporation and soil water balances of young trickle-irrigated almond trees. *Proceedings, 3rd Int. Drip/Trickle Irrigation Congress, Fresno – USA, Vol. 2: 792—797.*

Snyder, R.L., and W.O. Pruitt. 1989b. Scheduling irrigation. In: *Irrigation Scheduling – A guide for Efficient On-Farm Water Management* (D.A. Goldhamer and R.L.Snyder Eds.). Publication 21454, Div. of Agric. and Nat. Res., Univ. of California, pp. 34—38.

Snyder, R.L., B.J. Lanini, D.A. Shaw, and W.O. Pruitt. 1987. Reference Evapotranspiration (ET_0) and Crop Coefficients to Estimate Crop Evapotranspiration (ET_c) for Trees and Vines. Leaflet 21428, Div. of Agric. and Nat. Res., Univ. of California, 8 pp.

Soil Survey Staff, 1975. *Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys.* USDA - SCS Agricultural Handbook 436, U.S. Government Printing Office, Washington, D.C.

Vermeiren, I., G.A. Jobling. 1980. *Localized Irrigation – Design, installation, operation, evaluation.* FAO Irrigation and Drainage Paper 36, 198pp.