Drip irrigation management and water saving in protected culture

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GREENHOUSE DRIP IRRIGATION MANAGEMENT AND WATER SAVING

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Abstract: The scarcity of irrigation water in the Mediterranean area highlights the importance of optimizing its use. Protected culture reduces evapotranspiration, relative to open-air cultivation, contributing to improve the use of water. Increasing the water use efficiency, relative to other conventional irrigation methods, is one of the most relevant advantages of drip irrigation, if it is properly operated. An inadequate management of the drip system, frequently due to inaccurate irrigation scheduling or to drippers clogging and the subsequent reduction of the emission uniformity, limits the potential advantages of the drip system. Information on the basic points to achieve a successful management of the drip irrigation systems and to save water in protected cultivation, from a practical point of view, is included.

INTRODUCTION

The profitable use of drip irrigation at the farm level requires the previous development of local information, in order to reach all the benefits from its potential advantages. The high frequency of irrigation and localized water application to only part of the potential root zone are characteristic features of the drip method (Vermeiren et al, 1980), that make their operation and management different to those of conventional irrigation methods (Fereres 1981).

A good knowledge of the basic principles that determine the movement of water and salts under drip irrigation, influenced by the low flow rate and localized water application is necessary for salinity control and good water management. An efficient water use will be reached with a proper irrigation scheduling, that involves to know the crop water requirements.

The localized wetting patterns produced by drip systems can induce limitations to crop nutrient uptake, making necessary to apply the fertilizers through the drip system, operation known as fertigation, injecting them. The small-diameter emitters and the low flow rates induce the accumulation of materials that can clog the system, partially or totally. It is, therefore, imperative to filter water adequately and to prevent clogging problems by injecting various chemicals, depending on the type of clogging.

Greenhouse cultivation reduces evapotranspiration (ET) to about 70% of open field, therefore improving the water use, relative to unprotected cropping (Stanghellini, 1993). Increasing the water use efficiency and productivity, specially relevant objectives in the Mediterranean area, is not just limited to water saving.

This paper summarizes, from a practical point of view, the basic points needed for the successful management of drip irrigation in the Mediterranean greenhouses. Information about water saving, water use efficiency and productivity is included.

WATER AND SALTS MOVEMENT IN DRIP-IRRIGATED SOILS

In drip-irrigated soils, normally the soil water distribution is done through a soil surface wetted area that is small relative to the total soil surface area. In point source emitters, the water distribution into the soil follows a three-dimension infiltration pattern, different from the one-dimension (vertical) infiltration type of conventional irrigation systems, where the soil surface wetted area (through which water penetrates into the soil) is the whole soil surface area (Bressler, 1977).

The high frequency of irrigation, typical of drip systems, involves that the infiltration process prevails, relative to other irrigation systems, over the soil water extraction phase of the irrigation cycle. The discharge rate of the emitter, the hydraulic characteristics of the soil and the evaporation rate from the soil surface determine the size of the horizontal soil surface wetted area through which infiltration takes place (Bressler, 1977). The evaporation rate has practical importance in the infiltration process only when the evaporation is very high and the ability of the soil to conduct water is very low (Bressler, 1977). The size of the saturated soil surface area will increase when the rate of water application is increased and when the ability of the soil to conduct water (dependent on the soil texture, among other factors) is low, with a corresponding decrease in the vertical direction (Figure 1). These aspects have a great importance for the type and density of emitters choices.

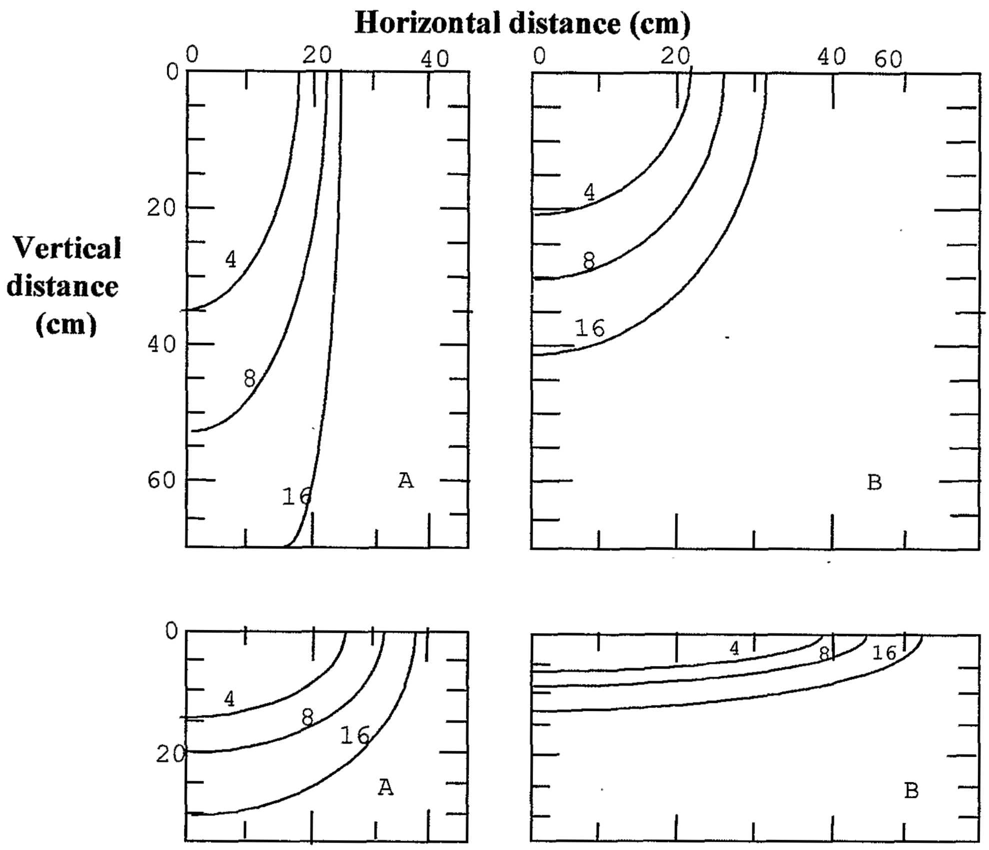

Figure 1. Water distribution profiles from point-source emitters in sandy (up) and loam soils (down), at two rates of water application, A (4 liter/hour) and B (20 liter/hour). The numbers on the curves refer to total quantities of water applied. Adapted from Bressler (1977).

The soil water distribution patterns, for a certain drip-irrigated soil, will be dependent on the discharge rate of the emitter and on the applied water quantities. Though different mathematical models have been developed to predict the soil water distribution patterns, the use of empirical field methods to know the size and volume of the wetted soil is preferable (Vermeiren et al, 1980), previously to the emitter discharge rate choice and to the election of the emitters density, depending on the desired soil wetted volume.

When the emitters are close enough, the wetted soil volumes (wetted bulbs) generated by adjacent drippers overlap. The extreme case of very close emitters are the porous pipes, where the infiltration process follows a bidimensional distribution pattern, as the water source is linear.

Dissolved salts tend to accumulate at the perimeter of the wetted zone, where the water content of the soil is lower, especially at the soil surface. When emitters are close, an isolated saline zone will develop between the drippers lines in the soil surface (Figure 2) and a deep zone of salt accumulation whose location depends on the efficiency of leaching (Figure 2). In these conditions, the rainfall (in open-air systems) will leach the surface salts downwards into the root zone, unless the drip system is turned on in order to keep the salts away from the plant roots. A good drip irrigation management must replenish, with a sufficient frequency of irrigation, the water removed by the crop, so that the soil water content is high enough to induce low soluble salt contents.

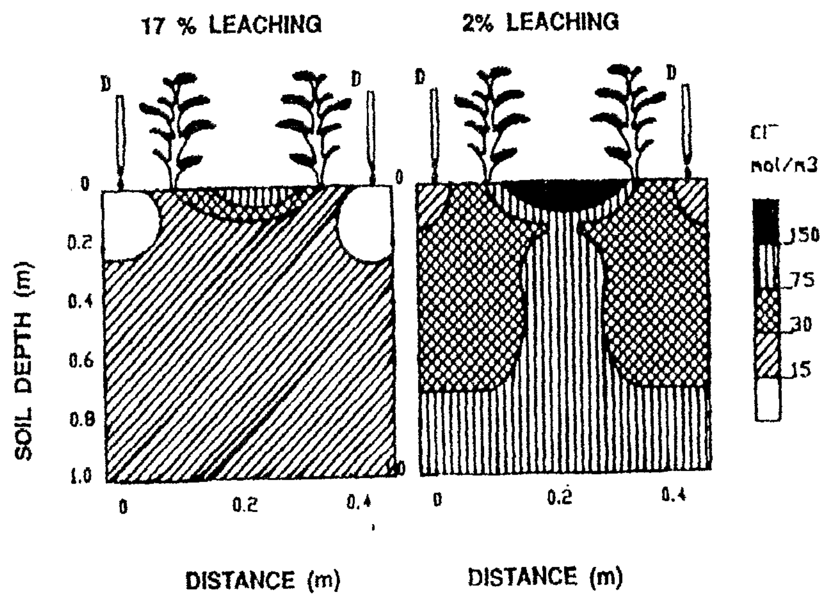

Figure 2. The distribution of salt under a multi-emitter drip system with narrow crop rows after two years and without rainfall. Chloride concentration is the measure of salinity.
Adapted from Fereres (1981).

A conventional irrigation is needed before beginning a new cycle in order to leach the accumulated soil salts away from the root zone, if the rainfall was insufficient in open-air crops or in greenhouses (where it does not penetrate). Other solution, frequently used in greenhouses, is to increase the emitters density; then the infiltration process approaches that of the conventional irrigation systems (vertical infiltration) as the wetted bulbs overlap with those of close emitters. (Bressler, 1977).

GREENHOUSE DRIP IRRIGATION SCHEDULING

The scarcity of water in most Mediterranean areas highlights the objective of optimizing its productivity, with adequate and efficient irrigations, that replenish the root zone soil water deficit and maximize the applied water that is stored in the rooted soil profile and used afterwards by the crop, in order to reach the best yields (Castilla, 1990). As crop respond more to soil water level and irrigation regime than to method of irrigation, information developed for other irrigation methods is applicable to drip systems, in general.

Two basic questions must be answered in drip irrigation scheduling 1). When to irrigate? (Frequency) 2) How much water to apply? The amount of water to be applied must replenish the evapotranspirated water, once corrected by the application efficiency (as far as the soil-water content variations are unimportant, due to the high frequency of drip irrigation). When saline waters are used, the applied water must cover the leaching requirements (Ayers et al, 1976;Doorembos et al, 1976; Stegman et al, 1980; Vermeiren et al, 1980). Other components of the water balance are normally unimportant in drip-irrigated greenhouses (unless the rainfall penetrates inside, as it is the case in flat-roofed perforated plastic greenhouses).

Evapotranspiration (ET) in greenhouses

Evaporation of water requires energy (Figure 3). The availability of energy depends on the microclimate of the greenhouse, being the solar radiation the primary source of energy in the ET process. In an unheated greenhouse, the energy used in the ET process can reach 70% of incoming solar radiation (Hanan, 1990).

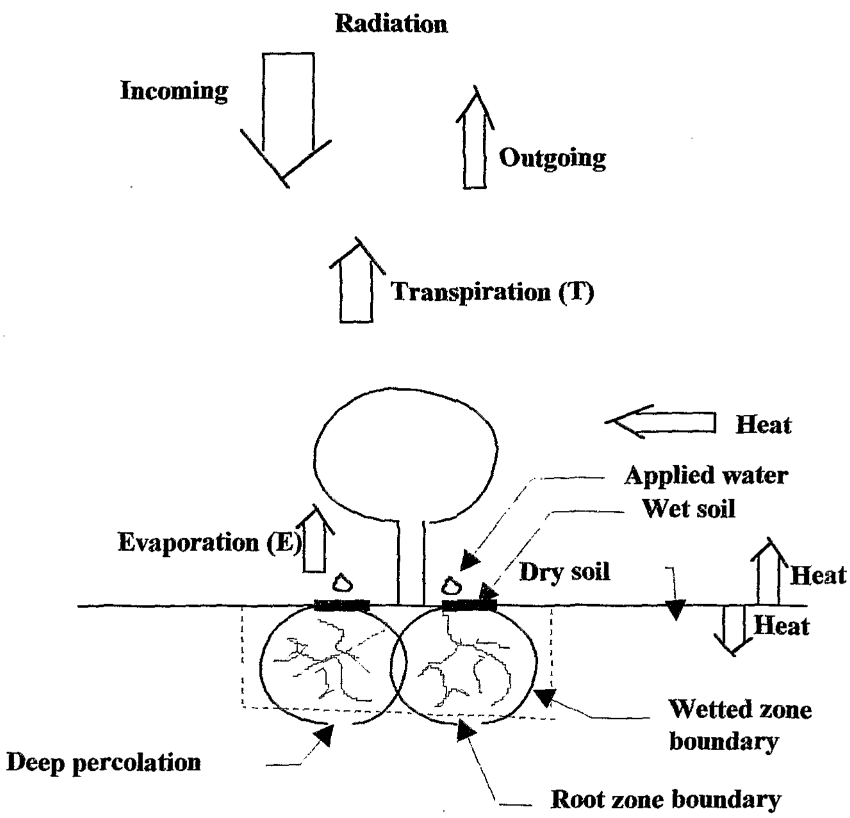

Figure 3. Radiation and water balances of a plant under localized irrigation. Adapted from Ferres (1981)

The amount of ground area covered by the crop is the most relevant factor affecting ET. Evaporation (E) from the soil surface is high following an irrigation, but decreases rapidly as the soil surface dries. The transpiration (T) will increase with the rise of intercepted radiation (and subsequent increase of ground covered by the crop), while soil E will decrease (as the crop progressively shades the soil surface). Other energy sources (greenhouse heating, hot air flow) can increase ET.

Normally, drip-irrigated soils will reduce soil E relative to conventional irrigation methods. Transpiration (T) can be increased with drip irrigation, if soil water content in the rooted zone is more available than with conventional irrigation.

In non-marginal soils (with a good water storing capacity) irrigated with good quality water it is not clear the change from properly managed conventional irrigation systems to drip based on important reduction of ET with drip in crops (like vegetables) that cover the ground early in the cycle. Proper reasons for a change to drip method could be, on the contrary, the bad quality of water, to increase water use efficiency, to profit from the fertigation advantages or, in unheated greenhouses, to avoid copious irrigations that can cool the soil excessively during the winter season.

Crop evapotranspiration (ET_c) or crop water requirements can be related with a reference value "reference evapotranspiration" (ET_o) which is defined as "the rate of evapotranspiration from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water". (Doorembos et al, 1976)

$$\mathbf{ET_c = K_c \cdot ET_o} \qquad (1)$$

The crop coefficient (K_c) is "the ratio between ET_c and ET_o" and depends basically on the crop characteristics, the sowing or planting dates, the development rate of the crop, the length of the cycle, the climatic conditions and the irrigation frequency, especially at the beginning of the cycle (Doorembos et al, 1976).

In Mediterranean greenhouses, the class A pan evaporation method, as well as the radiation (FAO) and Priestley-Taylor methods, have been proposed as the more reliable for ET_o estimation, for periods of several days (Castilla et al, 1990-b). The difficulty of an accurate measurement of the wind inside the greenhouse (Castilla et al , 1990-B) limits the use of the Penman method. The ease of management of the evaporation pan, without sophisticated equipment, is remarkable, but a proper pan placement is necessary.

The crop coefficient figures for different vegetable crops in Mediterranean greenhouses have been estimated (Castilla, 1989; Castilla et al, 1990-B; Lopez Galvez et al, 1990; Martinez et al, 1990; Veschambre et al, 1980).

When using the class A pan method:

$$\mathbf{ET_o = K_p \cdot E_o} \qquad (2)$$

K_p = pan coefficient
E_o = pan evaporation

$$\mathbf{ET_c = K_c . ET_o = K_c \cdot K_p \cdot E_o = K \cdot E_o} \qquad (3)$$

Where $\mathbf{K = K_p \cdot K_c}$ (4)

Recent studies show that K_p inside the greenhouse is approximately 1.0 (Sirjacobs, 1986; Castilla, 1986; Castilla et al, 1990-B), higher than open-air values (Doorembos et al, 1979). The crop coefficient evolution and values for different vegetable crops are presented in table 1. Recent research in the Almeria area (Orgaz, personal communication) confirms the K values detailed in Table 1, pointing that Kp is around 0.8-0.9, but the quantified values of Kc are higher than those described in the literature

(Doorembos et al, 1976; 1979), being the products of both coefficients (Kp x Kc) similar to those indicated in table 1.

These differences could have been induced by a sub-estimation of ETo, possibly affected by the type of grass used in the lysimeters.

Table 1: Evolution of the K values (K=ETc/Eo) in a plastic greenhouse in Almeria, using drip irrigation for the following crops (in the indicated sowing -S- or transplanting -T- dates): A-Tomato (T-16-X), B-Pepper (T-1-IX), C-Cucumber (S-16-IX),D-Melon (S-16-I), E-Watermelon (S:1-II), F-Beans (S:16-IX), G-Eggplant (T:1-X). Cladding material: thermal polyethylene. ET_c: crop evapotranspiration. E_o: class A pan evaporation inside the greenhouse. PER: Period (days after sowing or transplanting)

PER	A	B	C	D	E	F	G
1-15	0.25	0.20	0.25	0.20	0.20	0.25	0.20
16-30	0.50	0.30	0.60	0.30	0.30	0.50	0.35
31-45	0.65	0.40	0.80	0.40	0.40	0.70	0.55
46-60	0.90	0.55	1.00	0.55	0.50	0.90	0.70
61-75	1.10	0.70	1.10	0.70	0.65	1.00	0.90
76-90	1.20	0.90	1.10	0.90	0.80	1.10	1.10
91-105	1.20	1.10	0.90	1.00	1.00	1.00	1.05
106-120	1.10	1.10	0.85	1.10	1.00	0.90	0.95
121-135	1.00	1.00	-	1.10	0.90	-	0.85
136-150	0.95	0.90	-	1.00	-	-	0.80
151-165	0.85	0.70	-	-	-	-	0.80
166-180	0.80	0.60	-	-	-	-	0.80
181-195	0.80	0.50	-	-	-	-	0.80
196-210	0.80	0.50	-	-	-	-	0.80
211-225	-	0.60	-	-	-	-	0.80
226-240	-	0.70	-	-	-	-	0.60
241-255	-	0.80	-	-	-	-	0.60
TOT ET_c	318	322	156	349	290	146	393

The indicated ET_c is described by other authors as ET_m (maximum ET), reached when there are no restrictions in soil-water availability for maximum growth and development of the crop (Doorembos et al, 1979). The real value of ET, depending on the soil-water content of each case, is designed as actual evapotranspiration (ETa). When there is no soil-water restriction, ET_a equals ET_m, while $ET_a < ET_m$ when soil-water is depleted below a certain threshold, limiting evapotranspiration. Some authors recommend the use of values below ET_m for practical management (Villele, 1984).

The net irrigation requirements (IR_n) must replenish the crop evapotranspirated water (ET_c), as rainfall and other components of the water balance are normally unimportant in greenhouses in the Mediterranean area.

The gross irrigation requirements (IR_g) must increase the IR_n, in order to compensate the irrigation efficiency and to leach salts.

$$IRg = \frac{IRn}{Ea\ (1 - LR)} \qquad (5)$$

where E_a = irrigation efficiency coefficient (smaller than 1) and expresses the ratio: water stored in the crop root zone to be used by the crop/applied water.

$$E_a = K_s \cdot E_u \qquad (6)$$

K_s is a coefficient (smaller than 1) which expresses the water storage efficiency of the soil (0.9 in sandy soils, 1.0 in clay or loam soils).

Eu is a coefficient (smaller than 1) which reflects the uniformity of water application (a properly designed and well managed drip system should reach E_u values of 0.85-0.95). This coefficient should be measured for each system regularly (Vermeiren et al , 1980).

LR: minimum amount of leaching needed to control salts with drip irrigation

$$LR = \frac{ECw}{2\ (\max\ ECe)} \qquad (7)$$

EC_w: electrical conductivity of the irrigation water (dS/m)

EC_e: maximum electrical conductivity (dS/m) of the soil saturation extract due to crop withdrawal of soil water to meet its evapotranspiration demand. Typical max ECe values are 12.5 in tomato, 10.0 in cucumber, 8.5 in pepper, 6.5 in bean (Ayers et al, 1984).

Recent research shows that the leaching requirements could be lower than the indicated values (Stegman et al, 1980).

Drip Irrigation Frequency

In conventional irrigation, soil water depletion must be maintained below certain thresholds (available soil water depletion) in order to avoid crop transpiration reductions, that can induce yield decrease. A proper irrigation frequency will avoid excessive depletion. In drip systems, good management will always be based of very high irrigation frequency, even several times each day (Villele, 1984), specially when using saline water, being the water storage role of the soil unimportant relative to conventional irrigation methods.

Different plant and soil parameters have been suggested to schedule the irrigation frequency. A wide range of plant based measurements more or less sophisticated (sap flow, stem diameter, water potential, plant temperature,...) have been suggested to detect stress, using the plant as a biosensor. The leaf water potential method, reliable when used in conventional irrigation systems, is not practical in drip irrigated vegetable crops (Castilla, 1986). Plant temperature based methods of water stress detection are more accurate in greenhouse than in open field (Stanghellini, 1993) but they must be developed and locally adapted. The crop water stress index, based on the higher temperature of the crop when suffering from water stress, has been suggested as a more reliable method (Idso et al, 1981), but it is not easy to use. The spatial variability of soil-water contents in drip-irrigated soils limits the interest of methods based on soil water content measurements ("avaible soil water depletion"). The soil water matrix potential measurement, in drip irrigated soils, using tensiometers is a reliable way for monitoring soil water conditions in the wetted zone, in order to fix the irrigation frequency and to confirm the adequacy of the applied water amount. Two tensiometers, at least, should be placed in each observation point, installed at two depths, a few cm away from the emitter, depending on the soil water distribution and rooting patterns. Other methods for monitoring soil water potential, as gypsum blocks, need a good calibration depending on the composition of the soil solution and have not spreaded.

Wetting the soil profile with preplanting conventional irrigations (for salt leaching, soil disinfection or other purposes) is useful to prevent possible drip-applied water deficits (Castilla et al, 1990-A).

In soilless culture, the irrigation frequency must be several times per day, dividing the daily water requirements, according to the evaporative demand and the water storage characteristics of the substrate. In a first approach, the evolution of solar radiation along the day (that determines primarily the evaporative demand) can be a guide to schedule the irrigations. Various automatic devices have been developed. Some of them are based in maintaining a minimum level of water in the substrate (i.e. using electrodes to activate the irrigation), while other automatic devices use a balance to replace the evapotranspirated water. The simplest method is to preprogram the irrigation time or volume; the conductivity of the drainage water is used to adjust the irrigation dosage and frequency. In Mediterranean greenhouses, recirculating the water solution in soilless culture is very rare.

FERTIGATION

Drip irrigation introduces possibilities for precise application of fertilizer and other chemicals. The restricted root growth necessitates that type of fertilizer application, "fertigation", to prevent nutrient deficiencies.

The high efficiency of water application reached in drip irrigation systems is ideal for the high efficiency of applied nutrients in fertigation (Bressler, 1977). This improved use efficiency of fertilizers (Bar-Yosef et al, 1976), minimal nutrient losses due to leaching (Bressler, 1977), therefore limiting groundwater pollution, better control of the soil solution nutrient contents (Bar-Yosef, 1977), reducing soil solution salinity due to fertilizers and the ease of application, reducing labor and saving energy, are the prevailing potential advantages of fertigation. But some of these potential benefits can reverse into disadvantages when the irrigation system design or management is not correct (non uniform nutrient distribution, over-fertigation, excessive leaching, clogging,...). Therefore, it is most important for a proper fertigation to reach an adequate and efficient irrigation.

Fertilizers

The basical requirements for fertilizers are to be highly soluble, not reacting with other nutrients (when concentrated stock solutions are prepared previously) and being compatible with the elements they will contact after injection into the irrigation stream.

The coatings of some fertilizers can generate scum or sludge in the fertilizer solution. Such residues must not reach the emitters. Periodical removing of scum or sludge, locating the discharge tube a few cm above the bottom of the tank, locating the injection point before the filter in the control head or using wetting agents to prevent scum formation are precautionary measures to avoid emitters clogging.

Uniformity of Distribution

Two types of injectors can be used. The power injector regulates precisely the injection at constant concentration. A cheaper solution is the differential pressure injector, but a uniform distribution is difficult to achieve.

The distribution of nutrients solved in the water into the soil is obviously related with the uniformity of irrigation. The type of fertilizer and soil characteristics will determine the fertilizer distribution into the soil (Bar-Yosef, 1977).

Urea and nitrate will move immediately downward in soil with the water, while ammonium is held by soil particles and will not move so far in the soil profile as nitrate or urea, limiting N leaching (Bacon et al, 1982-b).

Movement of phosphorus in soils is very limited. However, drip irrigation improves notoriously the mobility of phosphorus (P) in soil, relative to conventional irrigation, when it is applied at low rates (Bacon et al, 1982-a). The calcium or magnesium content of the irrigation water may induce precipitates when using P-fertilizers. Acidifying the stock solution can prevent precipitation and the maintenance of a low pH in the irrigation stream is desirable to avoid precipitation problems.

Potassium (K) moves to a limited extent in the soils but drip irrigation improves its mobility (Kafkafi et al, 1980). Clogging is not a problem with the normal K-fertilizers use.

Fertilizer Use Efficiency

Nutrient uptake efficiency is increased in crops irrigated with drip systems, inducing a much higher fertilizer use efficiency. The chemicals form of the nutrient (and balance between them, as the NH_4/NO_3 ratio), its concentration and frequency of application, are relevant aspects of the information that must be developed for an efficient management of fertigation.

Fertilizer Leaching and Environmental Impact

The leaching of nutrients that pollute the groundwater aquifers can be notoriously reduced when fertigation is used, relative to conventional fertilization with surface irrigation. The importance of an adequate and efficient irrigation schedule is remarkable for its influence on a limited environmental impact due to fertilizer leaching.

In soilless systems, the drainage waters should be reused, in order to avoid the detrimental pollution of the aquifers, but the need of low salt content water and the cost of the equipment limit this desirable water reuse in Mediterranean areas where high quality irrigation waters are scarce.

OTHER ASPECTS OF DRIP IRRIGATION MANAGEMENT

Well-designed drip irrigation systems must apply the water uniformly, in such a way that the different emitters discharge almost the same rate. A good management must maintain a good emission uniformity, that is easy to quantify (Keller et al, 1974; Merrian et al, 1978).

Physical, chemical and biological agents can be responsible of the emission uniformity decay, due to clogging. Physical clogging can be prevented with a good filtration of the water and regular flushing of the lines and emitters.

Chemicals clogging are normally originated when the soluble salts precipitate on emitters as water evaporates from emitter surfaces between irrigation runs. Injected chemicals (fertilizers, pesticides) are also responsible for frequent clogging. Most cases of chemical clogging can be solved by acid treatment or injection. Acid injection to reduce the pH of water between 1 and 2 should be adequate, while, in severe clogging cases, emitters must be soaked in dilute acid solution (aprox. 1%) and even cleaned individually (Fereres, 1981). Acids are highly corrosive and extreme caution must be observed with their use. Surfaces in contact with acid solutions should be of stainless steel or plastic, and must be rinsed well after contact with acid.

The biological clogging can be solved with the injection of a biocide followed by flushing to clear the system of organic matter.

WATER SAVING AND WATER USE EFFICIENCY

From the practical point of view, normally the greenhouse grower is not specially interested in water saving. The scarce knowledge about the irrigation requirements among growers induce them to over-irrigate (in order to avoid potential yield reductions), in case of doubt about the quantity of water to apply. A proper information on the irrigation requirements, spreaded at the farm level, can help to overcome this lack of interest to reduce the water demand.

Different measures to save water and improve its use, at the farm level, include reducing the water requirements, increasing the water availability and rising the yields.

The use of mulching (plastic sheet, sand, gravel, ...)has been widely spreaded to limit the evaporation of the soil water and reduce ET. Subsurface drip irrigation can reach similar results. Various cultural practices affect the water demand. The use of transplants instead of direct seeding, multiple cropping, varying plant density, electing the cycles, pruning, trellising are effective, when properly managed, to save water or to increase the yield quantity and quality.

An adequate greenhouse environmental management can reduce the water demand, increase the crop yields and, therefore, improve the water use efficiency. Manipulating ventilation, misting, shading and carbon dioxide (CO_2) injecting are effective techniques for that purpose, but not always possible in the simple and poorly equipped Mediterranean plastichouses (Boulard et al, 1991; Stanghellini, 1993; Castilla, 1994).

Cropping the rainwater from the greenhouse roof is an easy way to increase the water resources specially relevant for its excellent quality. Another way is to make a better use of the water stored in the soil profile ; pulling up the crop immediately after the yield is over (avoiding the soil water exhaustion with no agronomic interest) or managing rationally the complementary irrigations (as those used for soil disinfection) in the watering schedule. Slight deficit-irrigations have been recommended as they do not affect yield in tomato (Villele, 1984), though they can reduce total biomass. When the soil profile is well-wetted before planting, slight deficit irrigation does not influence yield in greenhouse tomatoes and melons (Castilla et al, 1990-C; Castilla et al, 1996). Condensing the water from the saturated air can also help to reduce the fungal disease incidence, but economics are not clear (Boulard et al, 1989).

Maximizing the uniformity of water application is one of the easier ways to save water, at the farm level, too frequently forgotten. The evaluation of the emission uniformity of the drip system should be done periodically. In one study (Orgaz et al, 1986), thirty drip systems were evaluated in the Almeria greenhouse industry; the summary of the results are:A) The uniformity coefficient (UC) varied between 51 and 93%, the average UC being 76%. Only 4% of the systems had excellent uniformity while the UC was unacceptable in 20% of them. B) Applied water was considered excessive in 50% of the farms studied. The subsequent spread of recommendations at the farm level for increasing drip irrigation efficiency and achieve a more accurate scheduling has been effective.

The irrigation efficiency, as detailed in paragraph 3.2, is the engineering definition of the water use efficiency (ratio between the amount of water stored in the crop root zone to the amount of water applied for irrigation). From the agronomic point of view "water use efficiency", a widely used term, implies the yield (photosynthesis, biological or economic) per unit of water (transpiration, evapotranspiration or applied water), as described by Howell (1990), though it should be more correct to name it as "water productivity".

Protected cultivation improves the water productivity due to the ET reduction and larger outputs of protected growing (Stanghellini, 1993). Drip irrigation also increases the water productivity, relative to conventional irrigation in Mediterranean greenhouses (Castilla et al, 1991). The 20 kg of yield per cubic meter of applied water quantified in open field tomato growing in the Mediterranean area (Stanhill, 1980), can be increased to 33 kg. per m^3 in unheated plastichouse (Castilla ET AL, 1990-c), far from the 65 kg. per m^3 obtained in sophisticated greenhouses, with soilless culture and very long cycles, in Holland (Stanghellini, 1994).

The use of recirculating soilless culture can improve the water productivity but the poor quality of water, the high cost of the equipment (for quantifying the ion concentration and disinfecting the recirculating solution) and the absence of proper information, at the farm level, limits its use. Table 2 summarizes the economic yields per cubic meter of applied water (water productivity) in commercial plastichouses in the Almeria area (Spain). In some cases, the agronomic water use efficiency (water productivity) is lower in soilless culture than in soil-grown crops (table 2), showing the need of applied research on this subject.

Table 2. Agronomic water use efficiency or water productivity (economic yield, in kg., per m^3 of applied water) of various drip-irrigated crops, evaluated in commercial unheated greenhouses in Almería (Spain), in conventional soil and soilless cultures, in the autumn and spring cycle (up) and long season cycle (down)

	Autumn		Spring	
	Soil	Soilless	Soil	Soilless
Short Cycle Coops				
Squash	41.0	-	-	-
Green bean	15.0	18.5	20.5	22.0
Cucumber	27.5	43.5	-	-
Melon	-	-	22.5	19.5
Watermelon	-	-	30.5	-
- Long cycle Coops				
Tomato	34.0	29.0		
Pepper	13.5	-		
Eggplant	18.0	-		

Source: Adapted from Carreño-Sanchez et al (1996)

The price of the irrigation water, frequently determined by political reasons, obviously influences the water use efficiency, though its importance is lower in protected cultivation than in open field growing, where the produce income is much lower.

CONCLUDING REMARKS

A well-designed drip irrigation system must be properly managed (avoiding clogging) to preserve a high emission uniformity, in order to reach a good water use efficiency, limiting the environmental impact of leached fertilizers and salts. The use of the class A evaporation pan is a simple and reliable method to quantify evapotranspiration (ET) inside the greenhouses in Mediterranean areas. Radiation-based methods for ET calculation are also adequate. A wide range of techniques and cultural practices to reduce the water requirements, increase the water availability and rise the yields can contribute to save water and improve the water use efficiency and productivity.

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