Limited Water Supply under Drip Irrigation: an Experience on Tomato in Central Italy

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Summary

Regarding the dramatic water crisis affecting agricolture, an extreme experience on Tomato (*Lycopersicon esculentum*, Mill.) in central Italy was made according to drip deficit irrigation. The trial took place in the growing season 2001, after a first approach to sprinkler deficit irrigation carried out from 1996 to 2000 on the same crop. Under that experimental conditions encouraging results were collected about the possibilities given with regard to marketable yield, crop value and water saving, after the duration of the so-called yield formation period and the different sensitivity of the crop to water stress within that period were displayed. That allowed an evaluation of optimum operating of different seasonal irrigation volumes in terms of quantity, quality and value of the commercial product.
The new experimental cycle aimed to investigate if drip irrigation could improve deficit irrigation performance with regard to crop productivity and/or water saving. The same methodology was adopted; it provided comparison of sub-optimal water supplies with the extremes of the irrigation spectrum and yields check by using the Stewart model and a multiplying model derived from the former. Furthermore, seasonal ky factor under operating conditions was evaluated.
With respect to the previous experience, marketable production was generally equal to or lower than that given by the same water supplied by sprinkling.
Yields estimated by FAO and multiplicative models were quite similar and generally greater than actual yields up to about 20%.
Values of seasonal yield response factor, higher than those from FAO publications and from sprinkler experience, indicated a strong sensitivity of the crop to evapotranspiration deficit and a generalized low water use efficiency. From a qualitative standpoint of view, the characteristics of the marketable production were inferior than those expected under deficit irrigation.
First results suggest that drip deficit irrigation makes crop easily exposed to water stress. On such basis, management parameters such as irrigation size and interval have to be evaluated accurately.
Moreover, the same results should be further investigated in order to clarify in detail some external influence, the most relevant of which is probably the cracking attitude of clay soils under different irrigation methods and managements.

Key words: deficit irrigation, tomato, drip irrigation, ky factor

Introduction

Water scarcity has led agriculture to face a dramatic crisis, mainly based on the idea that crop irrigation requirements would not be affected by water availabilities. Increasing domestic and industrial demand, together with resource decrease, requires a different approach in irrigation management and scheduling in order to increase the efficiency of water used (Kirda, 2002). Scientific community is producing interesting results which could be profitably spent at different level of the irrigation system (Mannocchi and Mecarelli, 1994; D'Urso, 2001; Chalmers, 1986; Smith and Kivumbi, 2002). In the framework of water saving strategies at farm and field level, where farmers ought to actively participate in irrigation practice and management, deficit irrigation could be proposed as a new concept of irrigation scheduling, since that strategy has been already experienced and tested (English, 1990; Falciai et al., 1999; Kirda and Kanber, 1999). On the other hand such an unconventional attitude to water supply could represent a relevant complication for most users, since agreement about some basic aspects is not general. Suitability to deficit irrigation was mostly investigated on annual plants (Winter, 1980; Eck et al, 1987, Rawson and Turner 1983; Musick and Duseck, 1980), less on perennials (Boland et al., 2000; Goldhamer 1999), resulting sometimes in opposite opinions about the same crop (Cavazza, 1992; Domingo et al., 1997).

Regarding method, Stegman (1982) found that Maize yields under 30-40 percent depletion of soil available water between sprinkler irrigations resulted in not statistical differences with trickle irrigation maintaining low water potential in the root zone. Sammis (1980) found that subsurface drip irrigation allows higher water use efficiency under irrigated Potato with respect to sprinkling. Hargreaves and Samani (1984) reported experiences comparing crop performances under trickle, sprinkler and furrow supply, concluding that efficient and uniform irrigation reduces the economic benefits to be derived from deficit irrigation. Rawlins and Raats (1985) noted high frequency irrigation may have benefical effect on yields under full irrigation, questioning how intervals between irrigations will affect yields when deficit irrigation is practiced. Under low-frequency deficit irrigation, abundant applications should not significantly reduce Corn yields from the maximum if water is applied at sensitive growth stages (Quaranta, 1995). English and Nakamura (1989) investigated if the same limited water availability could affect Wheat response according to the irrigation size, concluding that abundant low frequent application can give better results. When high-frequency deficit irrigation is practiced, water amounts are too low to prevent the decline of soil moisture, which therefore will fall to a level at which the crop will experience moderate stress more or less continuously. On the other side, low-frequency deficit irrigation allows soil moisture to fluctuate within a wider range.

Complete irrigation along the future rooting depth will be followed by a long period of extraction, during which the stress experienced by the crop will range from none at all to severe. A subsequent full irrigation will then refill the profile and the pattern will be repeated (Stewart et al., 1975). Whether yields will be significantly different under these two regimes is an essential question. Up to now, research on this matter has been fairly inconclusive. Useful indication can be given by the yield response factor, ky (Doorenbos and Kassam, 1979), which depends on crop type, irrigation method and management, crop stage in which evapotranspiration deficit occurs and crop tolerance of water stress. As ky increases, water use efficiency (WUE) decreases and significant water savings cannot be generated (Kirda, 2002). Moutonnet (2002) showed wide ranges of variation of this

parameter under deficit irrigation, as result from experiences on annual crops in different regions of the world. He pointed out that in spite of the same trend, comparison with tabulated ky showed either different average values or ranges of variation, concluding that field research ought to be extended to other crops, soils and weather conditions.
Not much is available today about the response of Tomato (*Lycopersicon Esculentum, Mill.*) to limited water supplies. Regarding this, a first approach to sprinkler deficit irrigation was carried out from 1996 to 2000 in inland central Italy, aiming to evaluate the agronomical and economical performance of that crop. After Tomato suitability to deficit irrigation was shown and the different sensitivity to water stress within the so-called yield formation period was specified (Falciai et al., 1999), quantitative indications on allowable irrigation water savings and marketable yields were given, together with the ky factor, yield sensibility to irrigation (YS) and water use efficiency (WUE) indexes (Ghinassi et al., 2002). Under those environmental conditions, giving about 40 and 60% less water than the maximum in 1 to 3 irrigations resulted in moderate or minimal yield losses (Y_A/Y_M = 0.87÷0.95 and 0.78÷0.80 respectively), WUE and YS considerably high. Seasonal ky factor was generally smaller than FAO values, meaning less dependence from water deficit as irrigation is properly confined within the yield formation period. Moreover, the quality of the marketable production was generally higher under deficit than full irrigation, this partially or totally compensating for yield reduction.
In order to investigate improvements in irrigation under water scarcity conditions, a new program of field research started in 2001 according to drip deficit irrigation. The goal was to assess if drip irrigation could enhance crop productivity and/or water saving, according to the information collected during the first poliannual experience.

Material and methods

The trial took place in a clay-loam, well drained reclaimed soil, suitable for Tomato cultivation. Moisture content at field capacity and permanent wilting point was 25 and 12 percent respectively. Water table level at the beginning of the cropping season was about 10 metres below the soil surface, not affecting crop water uptake from that moment on.
In spite of the sub-humid climate of that area, irrigation is needed for spring-summer cultivated crops.
As in the previous sprinkler experience, Petoseed Perfectpeel PS 1296 was used, due to its agronomical reliability (Dadomo *et al.*, 2001) and suitability to water scarcity and mechanical harvesting. Hence, cropping operations were those typical in that area. Planting was made on May 23 in coupled rows 40 cm width and 150 cm spaced, resulting in 30,300 plants per hectare. Crop was harvested on September 7.
Based on the results from the sprinkler experience, four deficit irrigation programs (B, C, D, E) were tested with regard to qualitative and quantitative crop response and compared with the rainfed (A) and the fully irrigated (F) treatment. Each treatment was arranged in plots 13 m x 4.5 m and replicated three times.
When irrigation water is limited, the season is to begin with quite high soil water content along the future rooting depth in order to favour root activity, granting protection from future water deficits (Stewart et al., 1975). A small watering was therefore given to all treatments at planting since, as in past years, irrigation should not have been supplied until the beginning of the yield formation period. Under operating conditions it occurs about 50

days after planting. At that time water need increases (Tesi, 1994) and conversely crop sensitivity to water deficit decreases (Falciai et al., 1999).

Irrigation

Ordinary irrigation (F) started towards the end of June and deficit irrigation began two weeks later. Water was supplied by a drip line Aqua Traxx EA5061245, manifactured by Toro Industries, and measured by volumetric counters. Uniformity coefficient was evaluated during the season, resulting higher than or equal to 92%.
Table 1 reports date, corresponding days from planting (dfp) and depth (mm) of each irrigation during the season. For each growth stage, total and mean daily maximum evapotranspiration (ETm) is given.

Table 1. Irrigations in the season.

Period	Stage	ETm (mm)	ETm (mm/d)	Irrigation date	dfp	A	B	C	D	E	F
23-May 20-Jun	Veget.	74	2.5	23-May	1	15	15	15	15	15	15
21-Jun 16-Jul	Flower.			26-Jun	35						11
				29-Jun	38						3
				03-Jul	42						26
				06-Jul	45						6
				10-Jul	49		14	13	13	13	11
				13-Jul	52		18	18	18	18	16
		125	4.8	17-Jul	56		10	11	11	10	9
17-Jul 13-Aug	Yield form.			20-Jul	59		10	11	10	10	9
				24-Jul	63			14	16	14	12
				27-Jul	66			14	14	14	12
				31-Jul	70				11	10	9
				03-Aug	73				11	11	9
				07-Aug	77					14	11
		168	6.0	10-Aug	80					9	7
14-Aug 7-Sep	Matur.			14-Aug	84						12
				17-Aug	87						14
		96	3.8	24-Aug	94						35
Total (mm)		463				15	67	96	120	138	227

The irrigation programs were verified by using the Stewart model, which provided the basic criteria used by the FAO for estimating yield responses to water availability (Doorenbos and Kassam, 1976). The form is:

$$1-Ya/Ym = ky\ (1-ETa/ETm) \quad (1)$$

where:
Ya = actual harvested yield;
Ym = maximum harvested yield under specific environmental conditions;
ky = yield response factor, relating the decline in Ya to the unit decrease in ETa. For Tomato, it is equal to 1.05 over the total growing period in FAO publications;

ETm = maximum evapotranspiration, estimated using class A evaporimeter according to the FAO methodology (Doorenbos and Pruitt, 1977);
ETa = actual crop evapotranspiration.
Estimation of ETa is essential for assessing water deficit in the season. The hydrological balance can be written as:

$$ETa = I + R \pm \Delta W \quad (2)$$

where:
ETa as formerly defined;
I = irrigation;
R = effective rainfall, 132 mm in the season;
ΔW = soil moisture variation along the soil profile.
Soil water was measured by gravimetric method on samples taken along the 0-100 cm soil profile every week, at planting and harvest.
Moreover, soil water tension in F treament was measured by tensiometers, in order to grant the replacement of crop ETm.
In order to assess the influence of the irrigation timing on the ultimate yield, the following multiplicative model derived from the former (Mannocchi and Mecarelli, 1994) was used.

$$Ya/Ym = \prod_{i=1}^{4} [1-Ky_i (1-ETa_i /ETm_i)] \quad (3)$$

where:
Ya, Ym, ETa ed ETm as formerly defined;
ky = 0.4 for vegetative and ripening period, 1.1 for flowering and 0.8 for yield formation period as proposed by the FAO.
Theoretically, the model links the relative crop productivity at the end of a given period to the performance in the following one.

Results

Yield response

Marketable yield (Yc), discarded yield (Yd), green yield (Yg), berry weight (Bw), solubile fraction (°brix) and optical residue (RO) were investigated.
Results are listed in Table 2. Statistical analysis (Duncan test) is expressed for p=0.05. The same letter means no statistical difference between treatments.

Table 2. Production results

Treatment	Yc (kg/ha)	Yg (kg/ha)	Yd (kg/ha)	Bw (g)	°brix	OR (kg/ha)
A	35,300d	5,300bc	1,900ab	34d	6,5a	2,294
B	50,300c	2,600c	1,300b	46c	5,3b	2,666
C	54,800c	8,500bc	1,200b	46c	5,3b	2,692
D	66,700b	2,800c	3,000ab	50b	4,8bc	3,202
E	57,000bc	7,400bc	1,800ab	56a	4,5cd	2,565
F	81,400a	12,300a	1,100b	55a	4,2d	3,419

When from 50,000 to 80,000 kg/ha, Yc can be considered as satisfactory (Tesi, 1994).
The value of the soluble fraction, that is jointed with the market price, decreases significantly as the fruit weight increases, affecting negatively the market value of Yc when °brix values are below 4.8 (reference year: 1998). OR is the parameter which summarizes the qualitative and quantitative response of an irrigation schedule. Due to scanty rainfalls, equation 2 expressing seasonal ETa can be used, resulting in values reported in Table 3.

Table 3. Seasonal hydrological balance

Parameter	B	C	D	E
ETa (mm)	333	354	400	382
ETa/ETm (%)	72	76	86	82
Water deficit (mm/m)	130	109	63	81

Seasonal evolution of mean soil moisture content along the 0-100 cm profile for each treatment is given in Figure 1.

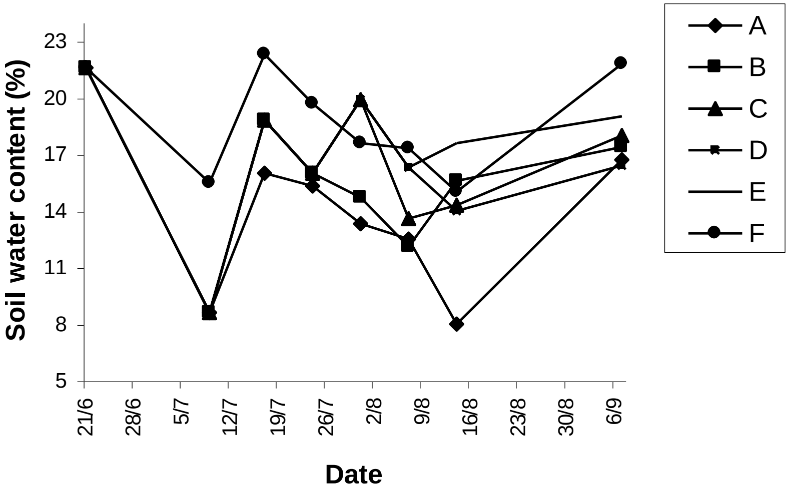

Figure 1. Evolution of mean soil water content along the 0-100 cm profile.

The picture shows that available soil water is depleted when deficit irrigation season begins. However, as the soil moisture near the surface decreases, more moisture is extracted from lower depths.
According to the typical pattern of water uptake under dry conditions in the topsoil (Israelsen and Hansen, 1962), the root system is more active in the lower portion of a soil profile.
Under such assumptions and on the basis of soil samples, it can be stated that water was still available at that time.
Moreover, F yield can be taken as Ym since no water deficit was experienced as shown by tensiometer readings of Figure 2. As a result, the Stewart formula can be adopted using seasonal ky.

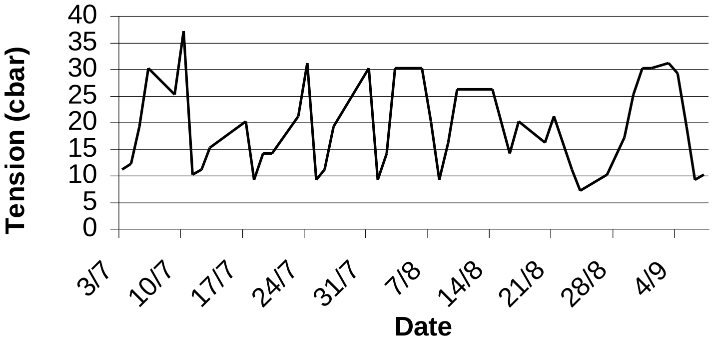

Figure 2. Soil water tension in F treatment

In order to use the moltiplicative approach, ETa for specific growth stages was calculated using the FAO method (Doorenbos and Kassam, 1979). The form is:

$$ETa = \frac{Sa * D}{t}\left[1-(1-p)e^{-\frac{ETm*t}{(1-p)Sa*D}+\frac{p}{1-p}}\right] \quad (4)$$

where:
ETa and ETm as formerly defined;
Sa = available water (mm/m);
D = root depth;
Sa*D = total available soil water over the root depth;
$t \geq t'$, where t' is the time (days) during which ETa=ETm;
p = fraction of total available water during which ETa=ETm.

Yields evaluation

Assuming $Ym = Y_F$ = 81,400 kg/ha, expected yields were estimated by the FAO method (Ya_F) and the multiplicative approach (Ya_M). Results are listed in Table 4, compared with the actual yields (Y_{2001}).

Table 4. Expected yields by FAO and multiplicative model.

Treatment	Y_{2001} (kg/ha)	Ya_F (kg/ha)	Ya_F/ Y_{2001}	Ya_M (kg/ha)	Ya_M/ Y_{2001}	Ya_F/ Ya_M
B	50,300	57,400	1.14	57,800	1.15	0.99
C	54,800	61,300	1.12	64,300	1.17	0.95
D	66,700	69,800	1.05	65,100	0.98	1.07
E	57,000	66,400	1.16	67,600	1.19	0.98

Expected yields are generally overestimated in a very similar way by both models, except D estimates that are quite close to the actual yield but resulting in the highest Ya_F/Ya_M ratio. It seems that both models are working properly when evapotranspiration deficit is quite constant during either the whole season or a given period.

Considering the irrigation method, the ky factor resulting from the current experience and the sprinkler seasons 1999 and 2000 (Ghinassi et al., 2002) is reported in Table 5.

Table 5. Seasonal ky factor under drip (ky_d) and sprinkler (ky_s) irrigation.

Treatment	ky_d	ky_s	
	2001	2000	1999
B	1.36	0.86	1.00
C	1.42	1.11	1.29
D	1.29	1.00	0.81
E	1.76	0.49	0.62

Apart from the absolute values, information deriving from Table 5 is that irrigating part (C, D) or all the yield formation period may result in opposite response of the crop to evapotranspiration deficit. This in turn can be read by YS and WUE indexes. The first relates the performance of a given treatment to the irrigation extremes. The form is as follow:

$$YS = [(Y_n - Y_A) / (Y_F - Y_A)] * 100 \tag{5}$$

where:
Y_n = actual yield of a given treatment (kg/ha);
Y_A = actual yield in rainfed conditions (kg/ha);
Y_F = actual yield under full irrigation (kg/ha).

WUE indicates the yield per unit of irrigation water:

$$WUE_n = (Y_n – Y_A) / I_n \tag{6}$$

where:
Y_n and Y_A as formerly defined;
I_n = irrigation water depth of the given treatment.
Values of YS and WUE are in Table 6, together with those from 1999 and 2000 under sprinkler irrigation (Ghinassi et al., 2002).

Table 6. YS and WUE in drip and sprinkler deficit irrigation.

Treatment	YS (%)			WUE (kg/ha*mm)		
	2001_d	2000_s	1999_s	2001_d	2000_s	1999_s
B	32	33	41	220	416	840
C	42	56	22	200	348	450
D	68	58	57	260	366	588
E	47	88	75	160	370	514
F	100	100	100	200	260	411

Values of both indexes are considerably better under sprinkler irrigation.

Discussion

The first approach to drip deficit irrigation gave fairly positive productions. However, in the same experimental conditions, sprinkler deficit irrigation under low frequent, massive water supply allowed better performances in terms of water use and quality of the marketable yield. Checking yields performed under drip irrigation through the FAO and the multiplicative model, showed high values of the ky factor, this meaning high crop sensitivity to the evapotranspiration deficit. Comparison with the ky values from 1999 and 2000 experiences suggested lower fluctuations of the yield under different conditions of relative evapotranspiration under sprinkler deficit irrigation, this meaning less sensitivity of the crop to evapotranspiration deficit. This attitude could come from the method and the way irrigation is managed, especially in cracking soils like that of the experimental field.
These observations are confirmed by YS and WUE indexes. The first suggests that, under operating conditions, drip irrigation could not be suitable for deficit practice. The same from the very low values of WUE. Future investigations should set irrigation parameters, namely depth and interval, and soil type suitable to drip deficit irrigation. Moreover, assessment of crop behaviour under deficient water supply ought to consider sub periods and related ky to be used in the framework of a dynamic model.

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