Water resources use optimisation in the Mediterranean basin

Caliandro A., Rubino P., Stellacci A.M.

in

Rana G. (ed.), Mastrorilli M. (ed.), Albrizio R. (ed.).
WEMED workshop: how to advance the knowledge on water use efficiency in the Mediterranean region ?

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 72

2007
pages 47-56

WATER RESOURCES USE OPTIMISATION IN THE MEDITERRANEAN BASIN

A. Caliandro, P. Rubino and A.M. Stellacci
Dipartimento di Scienze delle Produzioni Vegetali, Università degli Studi di Bari,
via Amendola 165/a, 70126 Bari, Italy

SUMMARY - Agriculture uses about 60% of the total available water resources, but this amount is not sufficient to meet crop irrigation needs and it is going to decrease due to the growing demand for domestic and industrial uses. A strategy to increase water availability for the agricultural sector is to improve overall water use efficiency, on average lower than 50%, by increasing the value of the highest number of its components.

In this paper, the main groups of factors affecting water use efficiency have been analysed, and some important actions to be adopted in order to increase the single components have been described and supported by numerous experimental results. In particular, in relation to the engineering aspects, the importance of the correct dimensioning of the irrigation networks, of the water delivery on demand, of the definition of the variables relative to the irrigation method and of the water pricing per volume used, has been highlighted; in relation to the agronomic aspects, the role of the correct dimensioning of the irrigation variables, of the evaluation of the interaction with other agronomical practices, of the adoption of controlled water stress and supplementary irrigation, has been stressed; finally, the importance of the crops choice in relation to their intrinsic water use efficiency, to their response to irrigation water, crucial also, together with the economic response, to define the optimal allocation of the available water resources, has been stated.

In the end, some important research needs, according to the Authors, have been reported.

Key words: water use efficiency; engineering, agronomic, crop aspects.

INTRODUCTION

It's well known that about 60% of the total available water resources is used in agriculture, mainly for irrigation, and that this percentage is greater in the Mediterranean countries. Nevertheless, the available water is not sufficient to meet the actual irrigation needs and in the future the current availability is going to decrease due to the growing water demand for domestic and industrial uses.

It's also known that the overall use efficiency of the water utilised in agriculture is quite low and on average is lower than 50%. Consequently, in the future, to increase water availability and to meet crop water demand will be necessary to improve the overall water use efficiency and to use non conventional waters.

A strategy to increase the overall water use efficiency consists in increasing the value of its individual components. According to Hsiao (2005), the overall efficiency (E_{all}) derives from the product of eight components (conveyance E_{conv}-, farm E_{farm}-, application E_{appl}-, evapotranspiration E_{et}-, traspiration E_{tr}-, assimilation E_{as}-, biomass E_{bm}- and yield E_{yld}- efficiency)[1] relative to the different steps of water transport from the source to the root zone and to the plant; due to the multiplicative effect, although the single values may be high, the overall efficiency can be much lower. For this reason, to increase the overall use efficiency the best way is to improve the greatest number of its components (Hsiao, 2005).

The overall efficiency values can be affected by: engineering aspects (characteristics of the irrigation networks, type of water delivery, irrigation methods adopted); type of water-pricing (per hectare and crop

---

[1] $$\frac{W_{fg}}{W_{vo}} x \frac{W_{fd}}{W_{fg}} x \frac{W_{rz}}{W_{fd}} x \frac{W_{et}}{W_{rz}} x \frac{W_{tr}}{W_{et}} x \frac{m_{as}}{W_{tr}} x \frac{m_{bm}}{m_{as}} x \frac{m_{yld}}{m_{bm}} \quad \frac{m_{yld}}{W_{vo}} \quad E_{all}$$

where: W_{vo} is the water diverted out of the reservoir; W_{fg} is the water at the farm gate; W_{fd} is the water at the field edge; W_{rz} is the water retained in the root zone; W_{et} is the water removed by evapotranspiration; W_{tr} is the water taken up by the crop and transpired; m_{as} is the mass of carbon dioxide assimilated by photosynthesis; m_{bm} is the plant biomass produced; m_{yld} is the harvested yield.

or per water-volume); agronomic aspects (suitability of the irrigation variables, fertilization, crop system, etc.); crops characteristics (crop water response to irrigation).

ENGINEERING ASPECTS

Irrigation networks characteristics and type of water delivery

Irrigation networks characteristics may influence water use efficiency both for their constructive aspects and for the suitability of their dimensions to the actual irrigation needs of the crops present on the territory. The constructive characteristics may directly influence the conveyance efficiency (E_{conv}): water losses along the transport are minimal if the water flows in pressurised pipes, greater if it flows in lined open channels, much greater, if the irrigation networks are made up by unlined open channels, with consequent high evaporation and leakage losses; as a consequence of these situations, the conveyance efficiency values can be high or very poor. Irrigation networks dimensions not corresponding to the irrigation needs of the crops present on that territory (for instance, when the crops are different from those considered during the network planning), though don't directly influence the conveyance efficiency, can reduce the yield efficiency (E_{yld}) by supplying amount of water lower than maximum crop evapotranspiration (ETc) or ET of maximum income. Moreover, due to the variation of the crop irrigation needs along the time, irrigation networks planned for water delivery on demand may result not more adequate and not able to meet crop needs, obligating to adopt the rotation delivery. In this case, the delivery interval not always corresponds to the most appropriate irrigation interval for the soil type and the crops present on the territory and plants can undergo to water stress with consequent reduction of the yield efficiency. In addition, farmers may apply irrigation volumes higher than the optimal, causing water losses for deep percolation and poor values of the application efficiency (E_{appl}). Then, shifting from the water delivery on demand to the rotation delivery both the yield and the application efficiency could decrease. Besides, the rotation delivery doesn't allow to adopt localised irrigation methods, characterised on average by high application efficiency, unless the water supplied at each interval is stored and afterwards distributed. Anyway, this solution causes a cost increase and a reduction of the farm efficiency (E_{farm}) due to the water losses from the storage by evaporation and leakage. In relation to the suitability of the irrigation networks, it could be very useful to evaluate the economic convenience in improving the existing ones in function of the income deriving from the water use efficiency increment.

Irrigation methods

A step of the efficiency chain improvable at relatively low cost is the water application efficiency that varies, also consistently, among the irrigation methods and within each of them.

It is known, in fact, that passing from surface irrigation methods (furrow, border and basin) to sprinkler irrigation, to low pressure localised methods, as drip irrigation, and to capillary sub-irrigation, the application efficiency may vary from values lower than 50%, to values of about 70-80% and values even higher than 80-90%, respectively. Moreover, within each irrigation method, the application efficiency can vary in relation to: the irrigation units dimension (for instance, borders width and length, furrows length), the type and slope of the soils and the unit flow, for the surface methods; the rain intensity in relation to the soil infiltration rate, the length of the jet and the spatial arrangement of the sprinklers in the field, for sprinkler irrigation; the distance between the drippers, their discharge and the laterals length, for the low pressure localised methods.

The border and the furrow irrigation methods, characterised by low application efficiency due to the water distribution modality, adopted on suitable soils and crops (deep clay soils, with low and uniform slope and crops with deep root system, conditions that imply low water infiltration rate in the soil, high watering volumes and long irrigation times) and with appropriate dimensions of the irrigation units, of the unit flows and of the watering volumes, allow to obtain application efficiencies even equal to 70-80% (Caliandro and Marzi, 1972; Caliandro and De Franchi, 1974; Tarantino and Rubino, 1982). Following these strategies, water distribution along the irrigation unit (border, furrow) is sufficiently uniform and water losses for deep percolation and runoff are limited (fig 1).

On the other hand, the sprinkler irrigation, even generally allowing high application efficiencies, can give low values due to: rain intensity higher than soil infiltration rate, with water losses for runoff, as it is often observed with mechanical-move sprinkler laterals (ranger and centre pivot); high wind speed, that distorts the sprinklers pattern, mainly of those with long jet; non optimal sprinklers spatial arrangement.

For example, in windy areas, sprinklers arrangements with high water overlapping (square and rectangle) should be used, whereas in un-windy areas disposition with low overlapping (triangle) can be adopted. Therefore, an appropriate choice of the irrigation plants and of the irrigation method variables allows improving the application efficiency without further costs.

The low pressure localised irrigation, characterised by water transport from the source to the plants in pressurised pipes and by drippers with uniform discharge, should guarantee an elevated farm efficiency; in addition, if the watering volumes are proportionate to the soil physical characteristics and to the root systems depth, the localised irrigation should allow a high application efficiency; finally, if the irrigation intervals are such that water stress is avoided, the localised irrigation allows also to realise high assimilation efficiencies (E_{ass}) and then high overall water use efficiency. However, even this irrigation method, if it is not correctly adopted because of limited technical knowledge, both engineering and agronomical, can give low efficiency values.

Therefore, it is confirmed what previously affirmed or that the application efficiency is influenced both by the irrigation method and by the modality of its planning and management. In any case, on average, drip irrigation allows to realise high values of application efficiency with consequent crop yields higher than those obtained with other irrigation methods such as sprinkler and furrow (fig. 2) (Tarantino and Rubino, 1982).

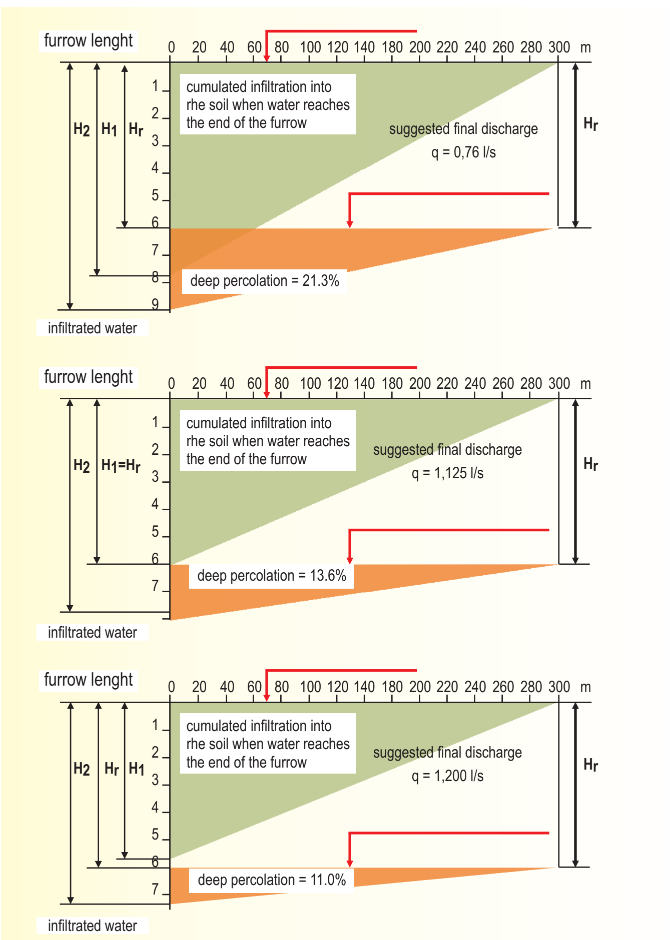

Fig. 1. Amount of water infiltrated during the watering along a 300 m length furrow on a silt-clay soil, adopting unit flows of 1, 2 and 3 l s^{-1}

H_r = watering volume (cm);

H_1 = amount of water infiltrated in the soil at the top of the furrow (cm) when the water stream reaches the end of the furrow;

H_2 = amount of water infiltrated in the soil at the top of the furrow (cm) at the end of the watering. (Caliandro, 2004)

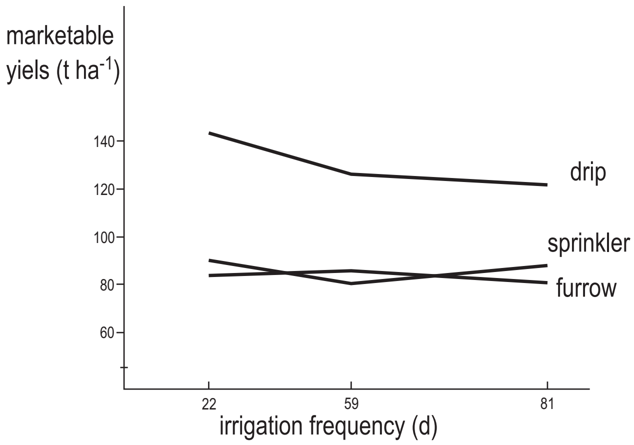

Fig. 2. Effect of irrigation methods and frequency on processing tomato marketable yield. Seasonal irrigation volume was the same for the three compared methods (Tarantino and Rubino, 1982).

Actual water use laws and type of water-price

The actual water use laws and the type of water-price can indirectly influence - water use efficiency, because if the water is considered a public good and its use is subject to authorization with defined rules and costs, it is carefully used and wastes are limited; when the water use is not subject to limitations, it is usually not very accurate and wastes can be even very high; as a consequence of these situations, the efficiency values will result high or very poor, respectively.

The type of water-pricing generally can be: a) per hectare and per crop, independent from the amount of water used; b) per water-volume. In the first case, as the measure of the water withdrawals is not necessary, farmers are not careful in avoiding wastes and the efficiency is generally low. With the second type of water-pricing, as the irrigation cost increases with the increase of the water volume used, wastes are limited; moreover, farmers are more aware of the amount of water used, being the irrigation systems provided with volumetric meters; in these situations the water use efficiency results usually high.

Researches carried out in Apulia (Italy) on public irrigation water management have shown the usefulness, in order to reduce water consumes and to improve the water use efficiency, of the volumetric water-pricing, even differentiated: lower prices for minimum volumes compatible with crop irrigation needs; higher prices for volumes exceeding the minimal.

Moreover, for a more rational water use and for the management of on demand pressurised irrigation systems, new delivery devices have been developed in the last years, based on micro-processor systems, that allow to regulate water withdrawals. These devices are successfully installed and used in some Southern Italy irrigation schemes (Altieri *et al.*, 1999).

AGRONOMIC ASPECTS

Irrigation variables

The irrigation variables (irrigation interval and watering volume) can affect some steps of the efficiency chain: from the application efficiency to the yield efficiency. It's well known that to define the irrigation time, i.e. to find when in the root zone the Readily Available Water (RAW) is depleted, the following methodologies can be used: monitoring of the soil water content in the root zone; monitoring of the plant water status; soil water balance through the estimated crop daily evapotranspiration. The three methodologies can give wrong estimates due to: un-accuracy of the instruments used; approximations of the models adopted; soil water spatial variability when the soil water status monitoring is requested. For instance, as the water balance is concerned, the lack of accuracy can derive both from the method used to compute the crop reference evapotranspiration (ETo) and from the crop coefficients (Kc) adopted. If the irrigation time is not correctly defined, irrigation water can be applied when the matric potential is lower or higher than the limit one. In the first case, the water stress could cause a reduction in the assimilation efficiency (E_{as}), in the biomass conversion efficiency (E_{bm}) and in the yield efficiency (E_{yld}). In the second case, instead, the irrigations would be more frequent, determining higher water losses through soil evaporation with a consequent reduction of the transpiration efficiency (E_{tr}).

On the other hand, a non correct computation of the watering volume, due, for example, to a non accuracy of the soil retention curves (subjected also to variation along the time because of soil compaction), or a non correct definition of the rooted layer, could lead to values higher or lower than the optimum ones. As a consequence, in the first case, deep percolation would occur, with a reduction of the application efficiency (E_{appl}); in the second situation, a progressive depletion of the RAW, which could lead to a reduction of assimilation, biomass conversion and yield efficiencies.

Therefore, considered the crucial role of these two variables, it would be useful to deep the knowledge on: the evolution of the soil retention curves from the beginning to the end of the crop cycle for the herbaceous crops and along the time for the tree crops; the crop root systems evolution; the mathematical models to estimate the water balance and the ETc; the crop coefficients determination in relation to the local conditions; for instance, for localised irrigation methods, Kc could be computed considering the transpiration, the evaporation from the wetted soil surface and the evaporation from the remaining soil surface.

Interaction between irrigation and other agronomical practices

Water use efficiency can be affected also by other agronomical practices. It is known that crop response to irrigation is enhanced in fertile soils and this shows that when water is not a factor limiting the yield, some other factors, such as nutrients content, bad soil structure, high weeds seeds or pathogens presence in the soil, could limit it. So, the knowledge of the interactions between irrigation and other yield factors, in different pedo-climatic environments, could bring also noticeable contributions to the improvement of the agronomic aspects of the water use efficiencies.

Moreover, some agronomical techniques limiting the evapotranspiration, such as the cultivation under glasshouses and plastic tunnels in order to yield out of the crop season, the covering with anti-hail nets and with plastic films for protecting the crop and anticipating or retarding its cycle (for instance, table grape in Apulia, Southern Italy), or the mulching, can contribute to increase some water use efficiency components, from the E_{tr} to the E_{yld}.

In relation to the effects of the mulching on the dry biomass WUE (the slope of the straight-lines in fig. 3), the results of a research performed in weighing lysimeters on melon show that dry biomass efficiency of the mulched crop increased of the 104% respect to that of the control without mulching (Cantore *et al.*, 2005).

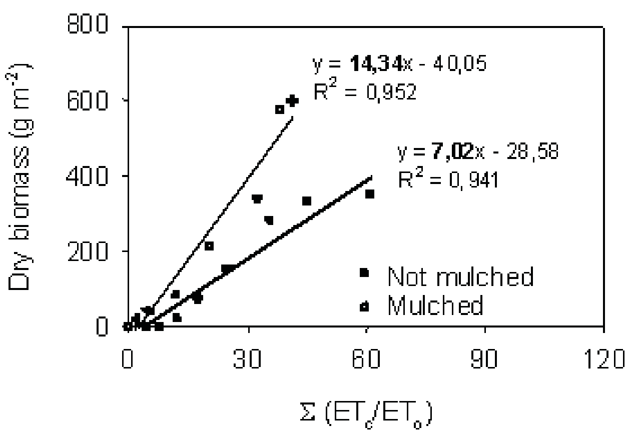

Fig. 3. Melon dry biomass use efficiency as affected by mulching (Cantore *et al.*, 2005).

Controlled water stress and supplementary irrigation

Since crops are more sensitive to water stress during some phenological stages, the partition of the carbon assimilates between fruits or grains and vegetative parts can be modulated by the water status of the plant, then by the irrigation scheduling. Generally, optimal plant water status during low sensitive stages to water stress induces more vegetative growth and reduces E_{yld}, while mild or optimal water status during stages sensitive to water stress may address the biomass to fruits and grains and improve E_{yld}. For this reason, to save water, particular attention has been giving to studies on controlled water stress based on the different sensitivity of the phenological stages of the crops. Several researches on this subject showed the validity of this strategy for saving irrigation water.

Researches carried out in Northern Italy for studying controlled water stress on peach orchards showed that, inducing water stress during the phenological stages from small fruits formation (diameter of 3-4 cm) to stone hardening (phase 2) and from harvesting to leaves falling (phase 4) (fig. 4), yield did not decrease and on the contrary it tended to increase (fig. 5), in comparison to the fully irrigated crop

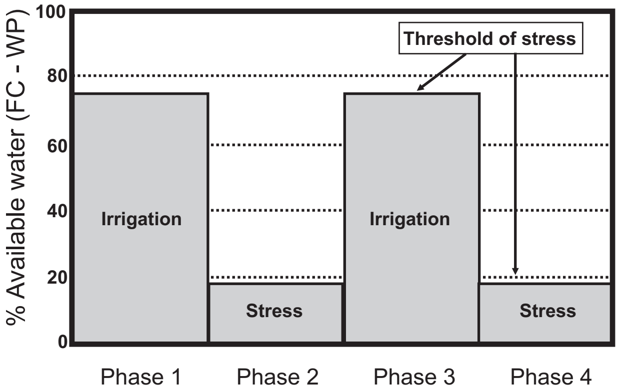

Fig. 4. Controlled water stress on peach orchard during the phases 2 and 4 (Mannini, 2004).

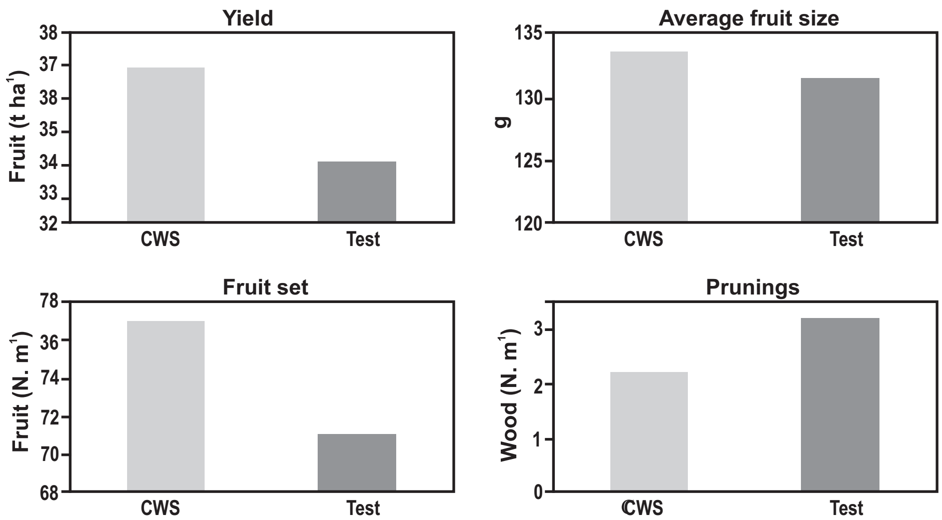

Fig. 5. Productive and vegetative effects of controlled water stress on peach orchard (Mannini, 2004).

In addition, in the following year the blooming increased while the pruning wood decreased, and the seasonal irrigation volumes decreased between 56 and 68% for medium-early and early cultivars, between 20 and 23% for late cultivars (Table 1) (Mannini, 2004).

Table 1. Percentage of seasonal irrigation volumes saved by controlled water stress on peach in comparison with normal irrigation regime (Mannini, 2004).

SOIL	Inter-row tilled			Inter-row grass covered		
	Early cultivars	Medium early cultivars	Late cultivars	Early cultivars	Medium early cultivars	Late cultivars
Sandy	44	38	20	38	34	20
Loam	58	59	20	52	46	23
Clay	68	56	22	60	51	23

In Southern Italy, studies on controlled water stress have been carried out also on herbaceous crops, but with results different from those achieved with the peach-trees. The results of a 4 years investigation on grain corn, suspending one or two irrigations during different phenological phases: - vegetative growing,- tassel emission, - beginning of milky ripening, - beginning of waxy ripening, showed that all phases were sensitive to the water stress, even though the most sensitive phases coincided almost always with the tassel emission and, in dry years, with both tassel emission and vegetative growth. These results indicated that, in Southern Italy corn needs a full irrigation regime (Caliandro and De Caro, 1973).

In Mediterranean climate, the great yearly rainfalls variability contributes to the instability of the agricultural production, particularly of the rainfed autumn-spring crops as wheat. A strategy to stabilize yields and improve rainfall use efficiency consists in adopting supplementary irrigation. Experiments have been carried out on some wheat cultivars grown in three different localities of Southern Italy (Policoro -MT, Gaudiano PZ- and Valenzano -BA), watering the crop at the critical phenological stages (at sowing, at booting, and at both sowing and booting). The results indicate that, particularly in dry years, one irrigation after sowing with a water volume of 770 m^3 ha^{-1} (for example in Policoro in 1986) was sufficient to increase yield from 2.02 to 4.7 t ha^{-1}, while all additional irrigations did not determine further significant yield increases (fig. 6) (Caliandro *et al.*, 1989).

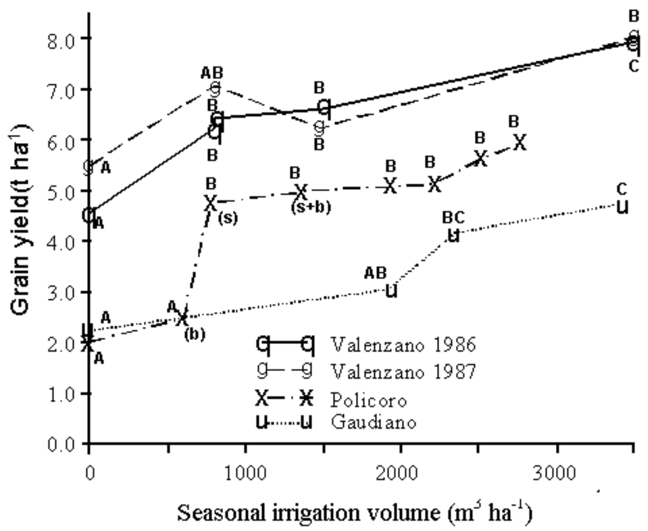

Fig. 6. Wheat yield under different irrigation regimes. Values assigned with the same letter are not significantly different at 0.01 P, according to the SNK test. (s): irrigation only at sowing; (b): irrigation only at booting stage; (s+b): irrigation at sowing and booting (Caliandro *et al.*, 1989).

CROP CHARACTERISTICS

Crop aspects effects on water use efficiency

Generally, the efficiency of any production process may be defined as the ratio of input to output, both measured in quantitative units. The units to use depend on the different situations, and if the units of both numerator and denominator are the same the efficiency is unit less (Hsiao, 2005).

As previously mentioned, the overall efficiency (E_{all}) of the irrigation water can be thought as the result of the product of eight sequential efficiencies. Taking into account only the efficiencies concerning the agronomic aspects, leaving out the conveyance and consumptive ones, crop WUE can be defined by different expressions reported in literature, dependent on time and space scale. When the time scale coincides with the crop cycle and the space scale with the canopy, equations that consider the above ground biomass or marketable yield are used.

$$dry.biomass\ WUE = \frac{\sum_{t_0}^{t_f} above\ ground.dry.biomass}{\sum_{t_0}^{t_f} (E + T)} \qquad yield\ WUE = \frac{\sum_{t_0}^{t_f} yield}{\sum_{t_0}^{t_f} (E + T)}$$

From these equations can be easily seen that the ratio increases if the evapotranspiration (E+T) decreases; while the evaporation from the soil can be diminished by appropriate agronomical techniques (hoeing, weed control, mulching, plant density, growing system adopted), the transpiration, instead, can be decreased by choosing appropriate crops, since it is tightly dependent on the intrinsic features of the plants.

Results of researches carried out in weighing lysimeters in Southern Italy for evaluating the dry biomass WUE of crops like brassica raab, broccoli, wheat, artichoke, sugar beet, celery and pepper, can give some contributions to improve biomass or yield use efficiency. For this purpose, regression lines were computed for each crop, approximating the data of dry biomass versus cumulated ETc standardised respect to the "class A" pan evaporation (E). The dry biomass WUE values (the slopes of the regression lines) were compared and the straight lines were clustered according to their slopes in three different groups: 1) sugar-beet with a value of 11.6 g m^{-2}; 2) pepper and brassica raab with an average value of 8.2 g m^{-2}; 3) wheat, artichoke, celery, broccoli with an average value of 6.5 g m^{-2}.

Crop yield response to irrigation water

The knowledge of the crop yield response to the irrigation water, besides giving information about the crop yield potential without water limitations, provides also useful means for improving water use efficiency. For these reasons, in the last decades in Italy, promoted also by the Group of Irrigation Studies (GRU.S.I.), a great activity of research has been carried out on herbaceous and tree crops yield response to different seasonal irrigation volumes. Results on different herbaceous crops obtained in Southern Italy are reported. Most of the researches were carried out in this area, because the yields are greatly affected by the limited rainfall (uneven throughout all the year and variable among the years), crop water requirements are relatively high and the water use efficiency assumes great importance in order to save irrigation water.

The results are reported in fig. 7 and refer to autumnal and spring sown sugar beet, shell bean and dry bean, tomato, pepper, egg-plant, spring and summer sown grain corn. In order to compare the results obtained in different years, the seasonal irrigation volumes, relative to each treatment, have been reported as percentage of ETc, and the yields of each crop as percentage of their maximum yields. Moreover, to better interpret the results, the mathematical model elaborated by Mitscherlich and modified by Giardini and Borin (1985) was approximated to the available experimental data, putting ***k***=0. The fitted curves (fig. 7) highlight that the utilization of natural water resources (rainfall and ground water) by crops, indicated by the ***b*** coefficient, increased as the cropping cycle extended into the rainy season.

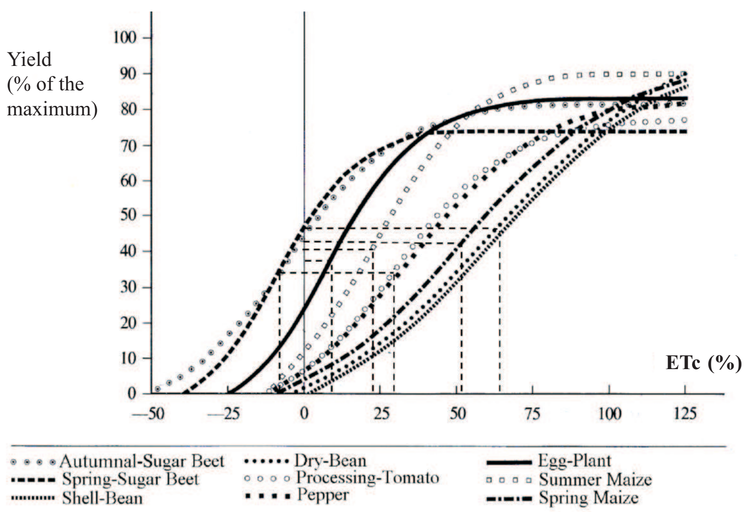

Fig. 7. Trend of some herbaceous crop productions, expressed as percentage of the maximum obtainable yield, in relation to the seasonal irrigation volumes, expressed as percentage of Etc. The regression curves have been obtained approximating to the experimental data the Mitscherlich model modified by Giardini and Borin. Negative values (*b*) indicate the amount of natural water (precipitation, groundwater and soil water content) utilised by the crops (Venezian Scarascia *et al.*, 1987).

Natural water used by summer cycle crops (shell and dry bean) is only 2-5% of ETc and rises to as much as 50 % with crops sown in autumn (autumnal sown sugar beet).

The crop response to water, indicated by the values of the water action coefficients ***c*** (fig. 7 and table 2), was instead related also to intrinsic crop characteristics, in fact, the highest values were obtained by spring sown sugar beet and eggplant (32.7 and 30.4 ha/%ETc 10^{-3}, respectively), followed by spring maize (27.6 ha/%ETc 10^{-3}). Though this crop could use only a little amount of natural resources, being a C4 crop, it was more efficient. Moreover, autumnal sugar beet, that even had the highest natural resources availability, showed a ***c*** value of 23.1 ha/%ETc 10^{-3}.

Accordingly, the greatest yield increments (flex points, x_f = (1-bc)/c) were observed with seasonal irrigation volume of about 61-62% of ETc for shell and dry bean (typically summer crops), with 34.6 and 29.6% for pepper and tomato, with 20.8 and 9.8% with corn as the main crop (spring-summer crop) and eggplant, and without irrigation for sugar beet (as spring and autumnal crop). The corresponding yields ranged among 34 and 46% of the maximum and the highest were obtained by summer maize, shell and dry bean (42.7, 43.6 and 45.9, respectively), soon followed by spring maize (41%).

Table 2. Parameters of Mitscherlich equation, flex point coordinates and seasonal irrigation volumes at 100% of ETc

	Equation-parameters			Flex point coordinates			Seasonal irrigation volume at 100% of ETc
	Ym	b	c	Water volume		Yield	
	(% of the max yield)	(% of the ETc)	(ha / %ETc 10^{-3})	% of ETc	m^3 ha^{-1}	(% of the max)	(m^3 ha^{-1})
Tomato	78.5	13.9	23.0	29.6	1435	35.3	4734
Pepper	84.9	15.1	20.1	34.6	2004	38.2	5800
Spring maize	91.0	15.4	27.6	20.8	994	41.0	4181
Summer maize	94.9	10.0	16.4	51.0	1603	42.7	3085
Egg-plant	82.9	23.1	30.4	9.8	441	37.3	4795
Shell-bean	96.9	2.2	15.8	61.1	1898	43.6	3109
Dry-bean	102.0	4.9	14.9	62.1	2121	45.9	3413
Spring sugar beet	75.9	39.1	32.7	-8.6	-	34.2	7193
Autumnal sugar beet	82.0	49.4	23.1	-6.2	-	36.9	4961

In conclusion, the crops that make the best use of water resources are crops sown in autumn or early in the spring, which can use the highest amount of natural resources, and those that show a high water response (WUE).

When irrigation water is limited and more than one crop is being irrigated simultaneously, including crops that respond rapidly to irrigation (like sugar beet and corn as main crop) and crops that show a gradual response (pepper, tomato, corn for forage, shell bean) then, the latter group of crops should be irrigated more than the former. However, to better define the allocation of limited water resources in order to maximize farm income, the crop water response should be evaluated in economic terms. In fact, expressing the yields as incomes and applying suitable mathematical optimisation models, it is possible to optimise in economical terms the water use efficiency of the crop system adopted within the farm or within the irrigation district.

RESEARCH NEEDS

In reviewing the state of the art about water resources use optimisation in the Mediterranean basin, chances of improvements relative to the different chain steps of the overall efficiency have come out. The overall efficiency can, in fact, be improved both by applying knowledge already acquired and by yielding new ones with ad hoc researches. But, very often the available knowledge, due to different reasons (high costs, strict local rules, limited worker technical level, obsolete infrastructures), are not being adopted; therefore, they should be more widely diffused also through the technical advisory services.

The main aspects that should be studied and evaluated are:

1. the usefulness, for WUE, of measuring the amount of water used in agriculture and applied by the farmers to each crop;
2. the effect of the type of delivery (on demand or rotation) and of the water-pricing on WUE;
3. the effect of the interaction between irrigation and other production factors on WUE;
4. the effect of the allocation of the available water resources among the crops both of the farm and of the irrigated district on WUE;
5. the effect of the controlled water stress on WUE;
6. the definition of new methods to compute crop coefficients;
7. the use of tertiary treated municipal waste-waters for increasing water availability.

REFERENCES

Altieri S., Martire G. and Nardella L., 1999. Completamento funzionale del distretto 10 nel comprensorio sinistra Ofanto. Bonifica, 1:51-56

Caliandro A., 2004. Le tecnologie irrigue. In: Irrigazione sostenibile, la buona pratica irrigua. Progetto Editoriale PANDA, ed. L'informatore Agrario, 5:67-85

Caliandro A., Marzi V., 1972. Determinazione di alcuni parametri nel metodo irriguo per infiltrazione da solchi in terreno limoso-argilloso. Atti Giornate di Studio Prima Sez. CIGR, Firenze, 129-153

Caliandro A., De Caro A., 1973. Ricerca dello stadio critico al quale è particolarmente importante l'intervento irriguo per il mais da granella. Annali della Facoltà di Agraria dell'Università di Bari, 26:591-624

Caliandro A., De Franchi S., 1974. Determinazione di alcuni parametri nel metodo irriguo per scorrimento superficiale su spianata. L'Agric. Jonica, 9(5-6):3-21

Caliandro A., Rubino P., Steduto P., Sisto L., Tarantino E., Perniola M., 1989. Influenza del regime irriguo sulla produzione di alcune cultivar di frumento duro in tre ambienti dell'Italia meridionale: primi risultati. Irrigazione e Drenaggio, 4:147-152

Cantore V., Boari F., Albrizio R., De Palma E., 2005. Influenza della pacciamatura sui consumi idrici e sull'efficienza d'uso dell'acqua del melone. Proceedings of SIA Conference, Ricerca ed innovazione per le produzioni vegetali e la gestione delle risorse agro-ambientali, Foggia, 20-22 September 2005

Giardini L. and Borin M., 1985. "Proposta metodologica per l'esame delle curve di risposta produttiva all'irrigazione". Rivista di Agronomia, XIX, 4, 239-250

Hsiao T.C., 2005. A systematic and quantitative approach to improve Water Use Efficiency in agriculture. Proceedings of Water, Land and Food Security in Arid and Semiarid Regions, 6-11, Valenzano, Bari, September 2005

Mannini P., 2004. Le buone pratiche agricole per risparmiare acqua. I supplementi di Agricoltura 18. Regione Emilia-Romagna, Assessorato Agricoltura, Ambiente e Sviluppo Sostenibile, p.178.

Rubino P., Cantore V., Mastro M.A., 1999. Studio dell'efficienza dell'uso dell'acqua di alcune specie erbacee in un ambiente dell'Italia meridionale. Riv. Irr. e Dren., 46, 2: 39-46

Tarantino E., Rubino P., 1982. Confronto tra metodi e regimi irrigui su coltura di pomodoro da industria nel Metapontino. L'Irrigazione, 29(2):17-26

Venezian Scarascia M.E., Caliandro A., Giardini L., Quaglietta Chiarandà F., Rubino P., Giovanardi R., Losavio N. and d'Andria R., 1987. Yield response to different amounts of irrigation water for its best utilization. Thirteenth International Congress on Irrigation and Drainage, Rabat, Morocco, September 1987. Transaction actes, Volume I-D: 189-224