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WATER USE EFFICIENCY IN TURKEY

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SUMMARY - Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential to making the most effective use of this vital but scarce resource in Turkey's cultivated areas. Enhancements in water use efficiency (WUE) depend on productivity gains, depicted by consistent increases in outputs per unit inputs and the irrigation techniques. Improved water use efficiency in agriculture is important not only for water conservation, but for obtaining high yields. Modern irrigation technologies, such as sprinkler and micro irrigation, are highly efficient and have the potential to increase yields substantially. Unfortunately, the high costs may prevent small farmers from using the systems. Thus, the use of modern irrigation techniques may be restricted to production of high value crops so that the systems may be financially viable. In this work, it is given some experimental results on water use efficiency of cotton, orange, Lemon, strawberry, watermelon using different irrigation methods in the Mediterranean and Southeastern regions of Turkey.

Key words: Water Use Efficiency, Irrigation Methods, Cotton, Orange, Strawberry, Turkey

INTRODUCTION

In semiarid areas of the world, soil water deficits and excessively high temperatures are probably the most common yield-limiting factors in crops. To improve yields, many scientists are seeking means of reducing the effects of drought and making agricultural water use more efficient. Water use efficiency (WUE) generally describes crop production per unit of water use during the growing season. Irrigation accounts for up to 80% of consumptive use of fresh water in Turkey. Most feasible water development projects have already been undertaken. As urban populations grow and industrial and municipal water needs increase, a decrease in irrigation consumption is required to meet needs. At the same time, irrigation accounts for large percentages of agricultural production and thus food. There is a clear need for greater understanding of crop water use and water use efficiency as affected by irrigation method, climate, variety, soils, water quality and management. Improvements in water management and water use efficiency are key to reducing consumption while maintaining production. Current research efforts in Turkey focus on improved understanding of crop water use and its prediction for use in water management and irrigation scheduling; improved understanding of key indicators of crop water status and their use in irrigation scheduling and control; and improved technologies for irrigation scheduling and control for improved water use efficiency.

Techniques and inputs that improve WUE have been extensively researched and tested on research stations and at farm or field levels. The dry areas comprise a region of heterogeneous land and variable weather. It is expected that variability of experimental results caused by uncontrolled factors such as physical and biotic environment, will greatly exceed the variability due to controlled factors. Therefore, localized research results alone can not produce an optimal strategy for maximizing WUE. Dealing with water issues on a basin-wide level will present many problems and constraints that are not so apparent on the farm or research station level. This holistic approach has not yet been given enough attention. When developing water-harvesting projects runoff is often intercepted at the upstream reaches of the catchments, thus depriving potential downstream users. The lack of balance in these systems for equitable water allocation among upstream and downstream users often causes social, economical and environmental problems. Moreover, in many areas socio-political considerations override any optimization of the management of these resources (El- Baltagy, 1997).

The introduction of technologies to increase yield and/or to improve WUE at the farm level not only affect water availability at other parts of the basin in term of quantity, but - maybe more important - the quality as well. This has been reflected in the existing literature, but no approach has been found for assessing the consequences of implementing these technologies and optimizing their use at the macro level. As water becomes scarcer, the need to have a methodology for optimizing water use at the macro level becomes more important. Designing research work at a basin level in combination with appropriate agro-ecological characterization and within a modeling prospective would help in making the results less site specific, more transferable, and environmentally safer (El- Baltagy, 1997).

Unless innovative solutions that satisfy these considerations and optimize the use of water are developed, overexploitation of water resources will continue to threaten the sustainability of the groundwater-based agriculture development.

Turkey is taking the lead in developing a system-wide water-management research initiative for improving WUE in the dry areas. This goal will be achieved by implementing strategies and techniques that have been developed and approved as effective on-farm means for increasing crop production, saving water and potentially increasing water-use efficiency. Among these proven effective WUE-boosting techniques are supplemental irrigation and water harvesting. Other available strategies are related to crop varietals selection, cropping pattern, cultural practices and farm inputs. These techniques and inputs have been tested on research station and/or farm levels. The challenge is to extend the available on-farm techniques for improving water use efficiency to the basin-wide level. To this end, a number of recommendations may be made.

In the following section of the study, brief information about general indicators of geography and climate, soil and water resources, are presented. In the third section, the concept of water use efficiency and results for different regions and different studies are investigated. Methods used and comparable results for different conditions, systems and regions are pointed out in order to evaluate the water use efficiency status in Turkey.

WATER USE EFFICIENCY CONCEPT

Due to rapid increase in the world's population, urbanization, income and consumption choices, and as a result of this process, because of demand for water and deterioration of its quality, today lots of country is faced with important water problems. About 18.25 m^3 per year covers basic human water requirements such as drinking, sanitation, bathing and food preparation. It is estimated that over a billion people had access to less than 50 liters of water a day. According to 2000 year, agriculture accounts for about 75 %, industry uses 15% and municipal domestic uses 10%. It is projected that one third of the countries in water-stressed regions of the world are expected to face water shortages in this century. Decreases of water usage in agriculture can be provided only by increasing the efficiency it means that irrigation water use will result in large water savings.

Agricultural irrigation is important in terms of the increasing the productivity in Turkish arable lands, accelerating the economic growth and decreasing the migration from rural to urban areas. Thus, the efficiency of water use and water conservation in agriculture comes into prominence.

The term efficiency is generally understood to be a measure of the output obtainable from a given input. Irrigation and water-use efficiency can be defined in various ways, depending on the nature of the inputs and outputs considered. For example, one may attempt to define as an economic criterion of efficiency the financial return in relation to the investment in the water supply. One problem is that costs and prices fluctuate from year to year and vary widely from place to place. Another problem is that some of the costs of irrigation, and certainly some of the benefits, can not easily be quantified in tangible economic or financial terms, especially in places where a market economy is not yet fully developed. Often, only the short-term costs and immediate benefits are discernible, whereas the long term advantages or disadvantages are unknown a priori. How can be assign monetary value, fro instance, to the possibility that an irrigation project might save the population of a region from the dire effects of a drought if the frequency or probability of droughts of varying degrees of severity can not be determined?

Quite different from the strictly economic criterion of efficiency is the physiological one i.e. the plant water use efficiency. The criterion here is the amount of dry matter produced per unit volume of water taken up by the plant from the soils. As most of the water taken up by plants in the field is transpired (in arid regions-99% or more) while generally only a small fraction is retained, the plant water use efficiency is in effect the reciprocal of what has long been known as the 'transpiration ratio', defined as the ratio of the amount of water transpired to the amount of dry matter produced (tons per ton). That ratio can run as high as 500 or even 1000 in regions and seasons of high evaporability.

The technical efficiency is what irrigation engineers call 'water use efficiency'. It is generally defined as the net amount of water added to the root zone divided by the amount of water taken from some source. As such, this criterion of efficiency can be applied to complex regional projects, or to individual farms, or to specific fields. In each case, to difference between the net amounts of water added to the root zone and the amount withdrawn from the source represents the seepage and evaporative loses incurred in conveyance to the crop, as well as the loses due to deep percolation below the root zone within the field and to runoff from the field.

From the point of view of water use, some large-scale irrigation projects operate in an inherently in efficient way. In many of the surface irrigation schemes, one or few farms may be allocated large flows representing the entire discharge of a lateral channel for a specified period of time. Where water is delivered to the consumer on a fixed schedule and charges are imposed per delivery regardless of the actual amount used, customers tend to take as much water as they can. This often results in over irrigation, which not only wastes water but also causes project-wide problems connected with the disposal of return flow, water logging of soils, leaching of nutrients, and elevation of the water table requiring expensive drainage. Although it is difficult to arrive at reliable statistics, it has been estimated that the average irrigation efficiency in such schemes is probably well below 50% (and may be as low as 30%). Since it is a proven fact that, with proper management, it is possible to achieve irrigation efficiencies as high as 85% or even 90%, there is an obviously much room for improvement.

Particularly difficult to change are management practices which lead to deliberate waste not necessarily because of insurmountable technical problems or lack of knowledge but simply because it appears more convenient, or even more economical in the short run, to waste water rather than to apply proper management practices of strict water conservation. Such situations typically occur when the price of irrigation water is lower than the cost of labor or of the equipment needed to avoid over irrigation. Very often the price of water does not reflect its true cost but is kept deliberately low by direct or indirect government subsidy, which can be self-defeating.

Open and unlined distribution ditches are used, uncontrolled seepage and evaporation, as well as transpiration, can cause major losses of water. Even pipeline distribution systems do not always prevent loss. Leaky joints resulting from poor workmanship, corrosion, ill-maintained valves, or mechanical damage by farm machinery may cause large losses. Sometimes the damage is not immediately apparent, as when a buried pipe under pressure fails at night, with no one in attendance.

Surface runoff resulting from the excessive application of water ideally should not occur. Sprinkler irrigation systems should be designed to apply water at rates which never exceed soil infiltrability. In the case of gravity irrigation systems, however, it is often virtually impossible to achieve uniform water distribution over the field without incurring some runoff (tail water). Only when provision is made to collect irrigation and rainwater surpluses at the lower end of the field and to guide them as controlled return flow can this runoff water be considered anything but a loss.

Evaporative losses associated with water application include any evaporation from open water surfaces or border checks or furrows, evaporation of water droplets during their flight from sprinkler to ground surface, wind drift of droplets away from the target area, and evaporation from wetted crop canopies (foliage) or from the wet soil surface immediately after irrigation. While some of these water losses cannot be totally eliminated, most can be greatly reduced. Transpiration by weeds is also largely preventable loss.

In the open field, little can be done to decrease transpiration by the crop if the conditions required for high yields are to be maintained. Attempts to use of windbreaks to control wind movement above and through a crop stand does not always produce the desired effect economically.

It appears at present that the greatest promise for increasing water use efficiency lies in allowing the crop to transpire freely by alleviating any water shortages while at the same time controlling all other processes of water loss and obviating the other environmental constraints to attainment of the full productive potential of the crop. This is particularly important in the case of the new and superior varieties which can attain their full potential yields only if water stress is eliminated and such other factors as soil fertility, aeration, salinity, and soil cultivation are optimized. Plant diseases and pests may depress yields without a proportionate decrease in transpiration and water use. All management practices can thus influence the efficiency of water use in irrigation, so the practice of irrigation should not be regarded merely as the provision of water to thirsty crops, but more comprehensively as an integrated production system designed to maximize the efficiency of land, water, manpower, machinery, and energy utilization.

In many parts of the world, far greater returns can be obtained from intensification of production in existing irrigation systems, i.e. by improving methods of water, soil, and crop management, than by building ever new irrigation projects on the basis of the same antiquated and inflexible design. Since it is difficult to convert traditional systems to modern irrigation scheduling, it is important to make decisions affecting irrigation frequencies and quantities in the early stages of planning new projects, before the distribution system is designed and installed and future irrigators are thereby locked into an inefficient pattern (Hillel, 1987).

PRINCIPLES OF WATER USE EFFICIENCY

The term "water use efficiency" originates in the economic concept of productivity. Productivity measures the amount of any given resource that must be expended to produce one unit of any good or service. Thus, for example, labor productivity in a steel mill would be the amount of labor required to produce a tone of crude steel. In a similar manner, water productivity might be measured by the volume of water taken into a plant to produce a unit of the output. In general, the lower the resource input requirement per unit, the higher the efficiency. Throughout this book, improved water use efficiency in its simplest form means lowering the water needs to achieve a unit of production in any given activity (Donald, 2000).

In an environmental resource context, however, the efficiency concept must be extended to include considerations of quality. Any effort to improve water use efficiency should be consistent with maintaining or improving water quality. Taking both quantity and quality into account, therefore, the following definition applies:

Water use efficiency includes any measure that reduces the amount of water used per unit of any given activity, consistent with the maintenance or enhancement of water quality.

Water use efficiency is closely related to, and in several cases overlaps, other basic concepts of current environmental resource management. The best established of these related concepts, perhaps, is water conservation. Water conservation is any socially beneficial reduction in water use or water loss. Put in this manner, water use efficiency is of central importance to conservation. At the same time, the conservation definition suggests that efficiency measures should, in addition to reducing water use per unit of activity, make sense economically and socially.

Finally, water use efficiency has a clear role to play in sustainable development, in other words, the use of the earth's resources by today's inhabitants while assuring that future generations have sufficient capacity to meet their own needs. Improving the efficiency of resource use comprises one means of meeting sustainable development goals.

The importance of efficiency in water use clearly varies across regions and nations, as well as through time. Geographically, for instance, water availability will condition the manner in which use patterns develop. Other things being equal, arid and semi-arid regions require a greater efficiency of water use than humid ones. But simple geographical patterns mask several equally important factors. Economic conditions will often lead to greater or lesser water use efficiency. Many regions in the world have been assisted in their development through public financing of water development. While the benefits or costs of such projects in efficiency terms are often debatable, the main point here is that economic factors can influence water use efficiency. Further, in some cases, where water developments have supported new settlements in dry areas, industrial processes and technologies that use water more efficiently than elsewhere may develop. An example would be the development of recirculation technologies or process changes. Social conditions may also be important in examining the efficient use of water resources. The literature reveals many areas where public education has led to conservation and better use of available water supplies.

Water-use efficiency measures are commonly used to characterize the water-conserving potential of irrigation systems. Alternative efficiency measures reflect various stages of water use and levels of spatial aggregation. Irrigation efficiency, broadly defined at the field level, is the ratio of the average depth of irrigation water beneficially used (consumptive use plus leaching requirement) to the average depth applied, expressed as a percentage. Application efficiency is the ratio of the average depth of irrigation water stored in the root zone for crop consumptive use to the average depth applied, expressed as a percentage.

Crop-water consumption includes stored water used by the plant for transpiration and tissue building, plus incidental evaporation from plant and field surfaces. Leaching requirement, which accounts for the major difference between irrigation efficiency and application efficiency, is the quantity of water required to flush soil salts below the plant root zone. Field-level losses include surface runoff at the end of the field, deep percolation below the crop-root zone (not used for leaching), and excess evaporation from soil and water surfaces. Conveyance efficiency is the ratio of total water delivered to the total water diverted or pumped into an open channel or pipeline, expressed as a percentage. Conveyance efficiency may be computed at the farm, project, or basin level. Conveyance losses include evaporation, ditch seepage, operational spills, and water lost to non-crop vegetative consumption.

Project efficiency is calculated based on farm irrigation efficiency and both on- and off-farm conveyance efficiency, and is adjusted for drainage reuse within the service area. Project efficiency may not consider all runoff and deep percolation as loss since some of the water may be available for reuse within the project.

RESULTS ON SOME IRRIGATION EXPERIMENTS

For activities of WASAMED which is a thematic network in Mediterranean countries, the results from all research activities on irrigation carried out in Turkey have been tried to collect, however, the results of all studies conducted, published data and other activities could not be obtained, because of the deficiencies in our archives system, assessment to all the conducted studies is limited. Statistical aspects of the collected results for the last 10-15 years are given with aim to give information and knowledge in experiences on irrigation science and assessment of past and existing experiences and identifications of relevant gaps and problems in Turkey.

Some studies conducted, in the Mediterranean and Southeastern regions of Turkey, under open-field conditions, many crops, such as strawberry, lemon, orange, and banana, were irrigated using various methods, including the drip technique. The results of these experiments are presented in Table 1.

The first crop, used for drip irrigation experiments, was strawberry in the Mediterranean region of Turkey. The first half of the 1970s was the time of adaptation of drip irrigation techniques in Turkey. Kanber and Dervis (1975) conducted the preliminary work on drip irrigation for strawberry. This experiment was very primitive and made the drip-system irrigation network using ordinary techniques. However, it involved taking no scientific results, only a demonstration for the farmers. Another experiment on strawberry took place in the Irrigation Engineering Department of Cukurova University, using two cultivars, Pochantos and Aliso. The yields of strawberry in the Adana experiments did not show any difference between irrigation methods (Tekinel et al. 1984), but the marketable yield from trickle was higher than that from other methods. An experiment in Tarsus was, again, on strawberry (Kanber et al. 1986). However, in this study, the effects of irrigation methods on yield were statistically different. Water use from trickle methods was 34% more than that in furrow. Yield from trickle irrigation was 12% more than in furrow. However, unmarketable yield decreased 17% with drip irrigation. WUE in trickle irrigation is higher, so it may be argued that higher yield was obtained from trickle method with less water (Table 1).

Table 1. Irrigation water use and yield with various irrigation methods (Source: Kanber and Dervis 1975; Tekinel et al. 1984; Kanber et al. 1986; Cevik et al. 1982; Ozsan et al. 1983)

Crop	Irrigation method	Irrigation water (mm)	Yield (t/ha)	IWUE Kg/da-mm
Strawberry (Adana)	Furrow		7.5	
	Drip	-	11	-
	Sprinkler		9	
Strawberry (Tarsus)	Furrow	400–650	12-13	30–20
	Drip	300–400	13-15	43
Orange (Adana)	Furrow	460–575	24.5-36.7	50–60
	Drip	151–299	20.1-37.3	130–120
	Sprinkler	344–430	31.0-42.4	90–100
Orange (Tarsus)	Drip	115–445	5.9-7.6	50–20
	Sprinkler (under tree)	670–844	13.6-13.3	20–16
Lemon	Furrow	1002–1336	2.2-2.8	2
	Drip	184–277	2.2-2.5	10–9
	Sprinkler (over tree)	1001	2.5-3.4	2–3
	Sprinkler (under tree)	1064–1463	2.5-2.8	2–1

In orange experiments (Table 1), we used Magnum Bonum cultivar. Experimental trees in Adana were 25 years old. The results from Adana indicated that sprinkler irrigation increases the yield in compression with the drip and furrow methods (Cevik et al. 1982). Trickle irrigation's results were insignificant because of the root-development properties resulting from surface irrigation carried out for a long time. The values for WUE of sprinkler method were not higher than those for drip, and they varied 0–1.0. The Tarsus experiments used young trees, observing the growth of trees in trials during 1978–1988. The effects of irrigation methods on growth were found to be insignificant (Eylen et al. 1988). Only 1 or 2 years after planting, trickle method increased the growth. WUE values were low with both irrigation methods. However, they were higher than those from Adana. In contrast, trickle systems were profitable only for areas of more than 50 decares.

Ozsan et al. (1983) also studied effects of irrigation methods on the lemon yield and growth in the same citrus irrigation program. Although tree growth was not affected by the irrigation techniques, the trickle irrigation positively increased the pomological properties. The highest yield resulted from use of the over-tree sprinkler, and the lowest resulted from planting in furrow. WUE was highest in drip irrigation.

After 1988, in the Mediterranean and southeastern regions of Turkey, work started on drip irrigation of some important crops, such as cotton. Cukurova is the place where cotton growing is the widest spread in Turkey.

Yavuz (1993), conducted a detailed experiment to determine suitable irrigation methods for cotton. Yavuz tested three irrigation methods, namely, furrow, drip, and sprinkler.

In addition, this study included various management techniques for each irrigation method. For instance, furrow irrigation comprised ponded alternative furrows (PAF), free-end furrows (FEF), and ponded continuous-flow furrows (PCF). Drip irrigation used two emitter spacings (30 and 60 cm) and two planting techniques, traditional and double row in a single planting bed. Accordingly, the study used four drip irrigation treatments. In sprinkler irrigation, Yavuz evaluated various final irrigation dates and levels. Soil water observations in the free-end furrows determined the irrigation times for furrow and sprinkler methods. Yavuz calculated the amount of irrigation water to use in the plots on the basis of the amount needed to replenish the soil water deficit to field capacity. Drip irrigation used an irrigation interval of 7 days. Yavuz calculated the amount of the irrigation water for drip plots from cumulative free water evaporation, measured from class-A pan between the irrigation intervals.

Yavuz (1993) has tested different surface irrigation methods and compared to performances obtained from drip and sprinkler irrigation methods. Table 2 shows some efficiency components such as application (Ea), requirement (Er), infiltration (Ei), tail water ratio (TWR), deep percolation ratio

(DPR), uniformity of Christiansen coefficient (UCC), distribution uniformity (DU), and water use efficiency (WUE) calculated for different irrigation methods.

Table 2. Performances of various cotton irrigation methods (Source: Yavuz, 1993).

Method	Zi	Ea	Er	Ei	TWR	DPR	UCC	DU	WUE
PAF	375	80	81	100	—	20	89	90	0.49
FEF	653	67	69	100	33	—	94	62	0.40
PCF	722	77	75	100	—	23	91	94	0.35
SI	834	92	85	100	—	8	100	100	0.27
									0.39
	Da	Eu	PELQ	AELQ	Dn				
DTd_2	8	90	91	78	7				0.39
DTd_1	16	82	74	71	12				0.36
DDd_2	9	70	63	61	6				0.54
DDd_1	15	76	68	66	11				0.43

AELQ, application efficiency; Da, average application depth; DD, double-row drip irrigation; Dn, minimum application depth; DT, traditional drip irrigation; DU, distribution uniformity; Ea, application; Ei, infiltration; Er, requirement; Eu, emission uniformity; FEF, free-end furrows; PAF, ponded alternative furrows; PCF, ponded continuous-flow furrows; PELQ, potential application efficiency; SI, sprinkler

In the Table 2, infiltrated water estimated from net infiltration opportunity time, which were obtained flow advance and recession data during irrigation event, was also given. The irrigation methods differed in their performances. The highest application efficiency was in sprinkler irrigation, at 92%. The ponded alternate furrow followed sprinkler irrigation, with 80%. The application efficiency of FEF was 67%, an acceptable value. All irrigation methods had acceptable efficiencies for cotton irrigation.

Cetin (1997) conducted another detailed experiment on irrigation of cotton in Sanlıurfa–Harran Plain to determine the effects of various irrigation methods (furrow, stationary sprinkler, stationary drip, mobile sprinkler, mobile drip, and low-energy precision application [LEPA]) and irrigation water levels on yield, quality, and WUE for cotton between from 1991 to 1994. Cetin estimated the applied water for the methods of drip and furrow using cumulative pan evaporation of 50 ± 5 mm and 100 ± 10 mm at varying time intervals and adjusted coefficients of 0.6–1.8 as increased 0.3 increment (for furrow and drip). For sprinkler irrigation, Cetin calculated the amount of water given to the plots close to lateral line, using 100 ± 10 mm cumulative pan evaporation measured in a time interval and coefficient of 1.8. The results showed that these irrigation methods have significant effects on the yield. Stationary drip gave the highest cotton yield, and the lowest yield from stationary sprinkler (Table 3). Amount of irrigation water stands to cotton yield in a quadratic relation (Figure 1). This figure shows that the yield increased to a peak and then decreased with irrigation water. However, WUEs in drip irrigation were high among the treatments at all water levels. The lowest values were from furrow methods at all water levels.

Table 3. Average irrigation water, yield, and WUEs for various cotton irrigation methods (Source: Cetin, 1997).

Furrow		Stationary sprinkler		Stationary drip		IWUE (kg/ha per mm)		
IR (mm)	Yield (kg/decare)	IR (mm)	Yield (kg/decare)	IR (mm)	Yield (kg/decare)	Furrow	Sprinkler	Drip
624	254	328	216	341	207	4.07	6.59	6.07
937	363	735	291	619	346	3.87	3.96	5.59
1248	385	1106	328	898	438	3.08	2.97	4.88
1561	397	1432	338	1144	489	2.54	2.36	4.27
1872	364	1664	350	1408	490	1.95	2.10	3.48
		1917	333				1.74	

Note: IR, irrigation water; WUE, water-use efficiency.
[a]1 decare = 0.1 ha.

Maximum yield for cotton was 438, 363, and 328 kg/decare from drip, furrow, and sprinkler, respectively, with 898, 937, and 1106 mm of irrigation water. Cetin calculated the amounts of water, using pan evaporation coefficients of 0.87, 0.90, and 1.07. According to these results, the yield from drip irrigation method was 34 and 24% more than those from furrow and sprinkler methods, respectively, and the yield from furrow was 11% more than that from sprinkler. Generally, the mobile irrigation systems (mobile drip and LEPA) gave lower cotton yields.

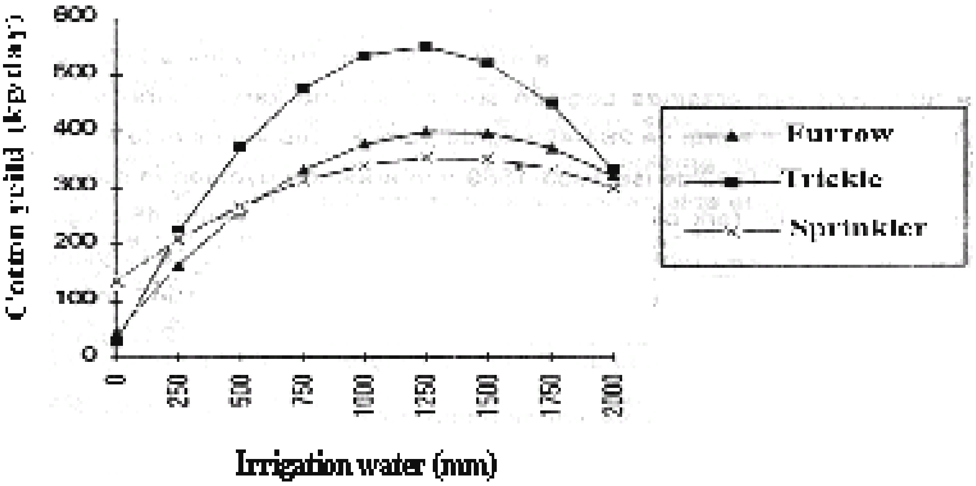

Fig. 1. The relationships between cotton yield and amount of irrigation water for various irrigation methods (Source: Cetin, 1997).

In Cukurova region, Ertek (1998) carried out an experiment to develop a suitable program for drip irrigation of cotton, as well as studying the possibility of using drip systems to irrigate cotton. The study took place in 1994 and 1995. Ertek used Cukurova-1518 variety cotton. The laterals were at 0.7-m intervals (a lateral for every crop row). Ertek determined the amount of irrigation water on the basis of free surface evaporation from a screened class-A pan. The treatment comprised two irrigation intervals (5 and 10 days), three plant-pan coefficients (0.75, 0.90, and 1.05), and two wetting percentages (0.70 and the cover percentage of crop). Ertek applied the first irrigation when the available soil moisture was at 40% in the 120-cm depth of the profile.

Average seasonal irrigation water varied 336–439 mm; seasonal evapotranspiration varied 468–580 mm; and the cotton yield varied 269–320 kg/decare (Table 4). Although the effect of irrigation interval and wetting percentage on cotton yield was not significantly different for the first- and second-year plant-pan coefficient, the interaction of wetting percentage and crop-pan coefficient was significantly different at 5% between the treatments.

Table 4. Some results from drip irrigation of cotton on the Cukurova Plain (Source: Ertek, 1998).

Treatment[a,b]	IR (mm)	IR (%)	ET (mm)	Yield (kg/decare)	TWUE (kg/decare per mm)	IWUE (kg/decare per mm)	IR/ET (%)
$I_1Kcp_1P_1$	336	76	468	269	0.58	0.89	68
$I_1Kcp_2P_1$	360	82	490	279	0.58	0.86	69
$I_1Kcp_3P_1$	383	87	525	297	0.57	0.87	69
$I_1Kcp_1P_2$	370	84	496	283	0.59	0.85	71
$I_1Kcp_2P_2$	401	91	536	318	0.61	0.88	71
$I_1Kcp_3P_2$	431	98	564	299	0.53	0.75	73
$I_2Kcp_1P_1$	336	76	471	287	0.62	0.93	67
$I_2Kcp_2P_1$	360	82	491	292	0.61	0.90	69
$I_2Kcp_3P_1$	383	87	524	307	0.61	0.89	69
$I_2Kcp_1P_2$	376	86	516	311	0.62	0.92	68
$I_2Kcp_2P_2$	407	93	562	320	0.59	0.88	70
$I_2Kcp_3P_2$	439	100	580	317	0.56	0.79	72

Note: ET, evapotranspiration; I, interval; IR, irrigation water; IWUE, irrigation water-use efficiency; Kcp, crop-pan coefficient; TWUE, total water-use efficiency. [a]I_1, 5 days; I_2, 10 days. [b]K_{cp1}, 0.75; K_{cp2}, 0.90; K_{cp3}, 1.05. [c]1 decare = 0.1 ha.

There were significant relationships between plant height, leaf-area index, and development of plant covers, dry matter with both irrigation waters and evapotranspiration. Depending on the treatment, effective root-zone depth for cotton varied 88–111 cm. Total WUE and irrigation WUE varied 0.58–0.62 kg/decare per mm and 0.75–0.93 kg/decare per mm, respectively. The ratio of irrigation water to evapotranspiration was 68–73%. The salt accumulation at 15 cm from the dripper increased in the upper layer and gradually decreased toward the bottom. At 30 cm from the dripper, salt accumulation increased to near the wetted front.

Senyigit (1998) conducted an experiment on watermelon. This experiment studied various irrigation methods (sprinkler and drip), nitrogen forms (liquid and granule) and amounts (based on applied line source sprinkler), and two varieties of watermelon (Paladin and Madera). Senyigit carried out the study at the Research and Production Farm of the Agricultural Faculty of Cukurova University, during the 1996 and 1997 growing seasons.

Generally, Senyigit irrigated the plants at 5–12-day intervals. Free water-surface evaporation determined the amount of irrigation water. Senyigit estimated the irrigation water in the plot with drip irrigation based on an assumed irrigation of 70% per volume of the soil. Only the treatments with sprinkler and liquid nitrogen and with sprinkler and granule and liquid nitrogen had three nitrogen levels, providing a gradient during the irrigation season. The yield losses and WUE for watermelon with various irrigation methods and nitrogen types are given in Table 5. The yield losses as a proportion of marketable yield showed differences between total and marketable yield of watermelon. The highest loss occurred for Madera with sprinkler and granule and liquid nitrogen, at 32%. The lowest loss was for both varieties with drip irrigation.

Table 5. Yield losses and WUE (Source: Senyigit, 1998).

	Yield loss (%)		WUE (kg/decare per mm)	
Treatment	Madera	Paladine	Madera	Paladine
SG	31	23	9.78	7.56
SGL	32	27	9.67	7.18
SL	26	27	8.85	8.59
DL	16	17	12.92	11.11

Note: DL, drip with liquid N; SG, sprinkler with granule N; SGL, sprinkler with granule and liquid N; SL, sprinkler with liquid N; WUE, water-use efficiency. 1 decare = 0.1 ha.

Average WUEs ranged 7.16–12.92 kg/decare per mm. WUEs under drip irrigation were higher than under sprinkler irrigation by an average 27% and 29% for Madera and Paladin varieties, respectively. Similarly, values for Madera were 17% higher than those for Paladin under sprinkler irrigation. Yield-response factor was 1.07 for total yield and 1.49 for marketable yield.

In the experiment, corn was irrigated 6 and 7 times in 1993 and 1994, respectively, and a total of 752 mm to 823 mm or irrigation water were applied to I100 irrigation treatment, in which water use was determined as 999 mm and 1052 mm in 1993 and 1994, respectively. Grain yield obtained from the I100 treatment, 1001.5 kg/da in the first year and 1003.5 kg/da in the second year of the experiment. Yield obtained from the I80 treatment, which received 20% less water as compared with I100, was not significantly different from the full irrigation treatment. Beyond the I80 level, deficit water application resulted in significant yield reduction by affecting both seed mass and kernels per ear. Significant second power and linear relationships were found between grain yield (Y) vs seasonal irrigation (I), and grain yield vs water use (ET), respectively. In the first and second year of the experiment, the yield response factor (ky) was determined as 1.08 and 1.61, respectively. Irrigation water use efficiency (IWUE) and water use efficiency (WUE_{ET}) were found to be between 1.0–2.43 kg/da– mm and 0.22–1.25 kg/da–mm, respectively for the treatments studied (Gencoglan and Yazar, 1999).

Determination of irrigation interval and evapotranspiration of Sanlıurfa pepper was carried out in Harran University Research Area in 2001. In this study three different irrigation intervals used with three crop pan coefficients (Kcp1=1,25, Kcp2=1 and Kcp3=0,75). Irrigation water amount in the treatments varies between 652-1010 mm and seasonal water consumption is between 726-1069 mm. The yield reached between 2444-4703 kg/da in the study. Total water use efficiency (WUE) varies between 2,75-5,22 kg/da/mm, irrigation water use efficiency (IWUE) 3,03-5,81 kg/da/mm were detected (Tas, 2002)

In Turkey, early irrigation experiments on cotton were conducted in 1940s in Cukurova Region (Alap, 1958). Deficit irrigation of cotton was first proposed by Tekinel and Kanber (1979) who investigated crop water requirement and yield production functions of cotton. Their irrigation treatments were such that 60 % of available water was allowed to decrease to start irrigations in the control treatment. Other treatments received a given fraction less water than control (Table 6). They found that a second degree polynomial relation could adequately describe yield response of cotton, which showed that as much as 30 % reduction in irrigation water application did not appreciably hinder cotton yield.

Table 6. Average Yield, IR, ET and Crop Water Use Efficiency (Source: Tekinel and Kanber, 1979).

Treatment	IR mm	ET mm	Yield kg/ha	Yield %	IR/ET	TWUE kg/ha-mm
A (Control)	660	828	3590 a	92	0.80	4.3
B: 80%A	528	728	3840 a	98	0.72	5.3
C: 60%A	394	618	3900 a	100	0.63	6.3
D: 40%A	267	478	3820 a	98	0.80	8.0
E: Dry	-	118	1650 b	42	-	

Another experiment were done in Harran Plain in Southeast Anatolian region by also Kanber et al., (1991) for getting the convenient irrigation program for cotton using the free water evaporation. Here again, 3 irrigation intervals (I_1: 7, I_2: 14 and I_3: 21 days) and four crop-pan coefficients (Kpc_1: 0.7; Kpc_2: 0.9; Kpc_3: 1.1; Kpc_4: 1.3) were tested regarding to obtain the suitable coefficient and irrigation interval for irrigation of cotton. Irrigation water amount given to the plots was estimated using the cumulative pan evaporation occurred during the aforementioned irrigation interval. They found that irrigation water varied from 619 to 1112 mm, whereas evapotranspiration from 1075 to 1504 mm (Table 7).

According to results, the evapotranspiration of cotton was very high and effected by the advection from widespread bare soils placed surrounding of the experimental area. Other side, it was determined that the free water surface evaporation can be used for the irrigation scheduling of cotton. For this purpose, cotton must be irrigated at the 7 days interval and irrigation water amount to be applied to soil can be calculated using crop-pan coefficient of 1.4. In some places where the evaporation losses are very high, chemicals were applied to reduce evapotranspiration of cotton. In this study, the effects of irrigation intervals and antitranspirant doses on evapotranspiration, yield, and water use efficiency of cotton were investigated on the field plots in Harran Plain for 4 years (Kanber et al., 1992). Different irrigation intervals (I1: 7, I2: 14, and I3: 21 days) and four antitranspirant doses (D0: 0; D1: 40 g/ha; D2: 80 g/ha; and D3: 160 g/ha) were tested. The antitranspirant that contains N, N, N-tributtill-3- (trifluoromethyl) benzene methananium chloride as the effective substance was used in sub-plots of the experiment. The antitranspirant application was done in the two times in which the reddish color on the main stem of cotton 5-7 cm reach to the top bud (as the first application) and at the 5-7th days of ball formation (as the second application) during the growing season. The irrigation programs were begun after the first application of antitranspirant and 90 cm soil depth was wetted in irrigation events.

Table 7. Average yield, IR, ET and crop water use efficiency (Source: Kanber et al., 1991)

Treatments	No. Of Irrig.	IR mm	ET mm	IR/ET	Yield kg/da	TWUE kg/decare-mm
I_1Kcp_1	9	671	1091	0.61	233	0.21
I_1Kcp_2	9	819	1256	0.65	285	0.23
I_1Kcp_3	9	965	1381	0.70	341	0.25
I_1Kcp_4	9	1112	1481	0.75	376	0.25
I_2Kcp_1	6	619	1079	0.57	206	0.19
I_2Kcp_2	6	752	1198	0.63	237	0.20
I_2Kcp_3	6	884	1260	0.70	277	0.22
I_2Kcp_4	6	1016	1369	0.74	316	0.23
I_3Kcp_1	3	671	1075	0.62	203	0.19
I_3Kcp_2	3	818	1218	0.67	238	0.19
I_3Kcp_3	3	966	1386	0.70	227	0.16
I_1Kcp_4	3	1112	1504	0.74	235	0.16

Results show that the frequent irrigation increased evapotranspiration (ET) and net irrigation water requirement (IR). The maximum ET and IR values were found to be 1670 and 1555 mm, respectively in treatment I_1 (Table 8). The highest WUE values, although not statistically significant, were obtained from I_2 as 2.41 and 2.69; and from D_1 as 2.34 and 2.60.

Table 8. Results from experiment of antitranspirant doses and irrigation program (Source: Kanber et al., 1992)

Treat	No of ırr.	IR mm	ET mm	IWUE	TWUE	Average Values					
						Yield* kg/da	No of irr.	IR	ET	IWUE	TWUE
I_1D_0	13	1555	1670	2.45	2.28	384a	8 (D_0)	1201 (D_0)	1322 (D_0)	2.51 (D_0)	2.26 (D_0)
I_1D_1	13	1555	1670	2.55	2.36	394a	8 (D_1)	1182 (D_1)	1310 (D_1)	2.60 (D_1)	2.34 (D_1)
I_1D_2	13	1555	1670	2.39	2.23	361a	8 (D_2)	1172 (D_2)	1290 (D_2)	2.54 (D_2)	2.29 (D_2)
I_1D_3	13	1555	1670	2.35	2.18	376a	8 (D_3)	1196 (D_3)	1312 (D_3)	2.49 (D_3)	2.25 (D_3)
I_2D_0	7	1113	1234	2.62	2.34	295b					
I_2D_1	7	1113	1234	2.76	2.48	302b					
I_2D_2	7	1113	1234	2.65	2.36	298b				2.44 (I_1)	2.26 (I_1)
I_2D_3	7	1113	1234	2.74	2.46	304b				2.69 (I_2)	2.41 (I_2)
										2.47 (I_3)	2.18 (I_3)
I_3D_0	5	894	1019	2.45	2.15	223c					
I_3D_1	5	894	1019	2.48	2.18	224c					
I_3D_2	5	894	1019	2.57	2.27	227c					
I_3D_3	5	894	1019	2.38	2.11	209c					

* $S\bar{x} = 20.94$ and 9.77; the yield groups were statically obtained by the orthogonal comparison methods.

The application of various antitranspirant doses had no significant effect both on seasonal ET and WUE values. The irrigation intervals have significant effect on the yield and quality of cotton. The maximum cotton yield was obtained from frequent irrigations. Frequent irrigation applications increased lint length, whereas, infrequent irrigations and antitranspirant doses resulted in shorter and thicker lint.

CONCLUSIONS

The subject of water use efficiency is quite complex and often misunderstood both within and outside the scientific communities. The information presented herein has identified the major factors contributing to improvements in WUE in both the Turkey's irrigated and non-irrigated agriculture sectors. One of the sources of future growth in crop production in Turkey is enhanced efficiency of irrigation and water use. In this paper the investigated studies reflects that the water use efficiency differs by a wide range of supply-side water efficiency practices, such as better system integration, conjunctive use of surface and groundwater supplies and other measures that can stretch existing supplies even further. With the increasing population the water availability is an increasingly critical constraint to expanding food production in many of the world's agroecosystems. In this way because of the water limitations water use efficiency comes into prominence.

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