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IRRIGATION SYSTEMS PERFORMANCE: TURKEY COUNTRY REPORT

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SUMMARY - Turkey has 25.85 Mha irrigable area (4.3 Mha is being irrigated) and 106.6 km^3 per year total available water resources. Most of the irrigation systems (96%) are designed, and operated by DSI (State Hydraulic Works) and GDVS (General Directorates of Village Services) based on their surface irrigation methods, 3.38% is being irrigated by sprinkler and 1% by drip irrigation methods. Turkey is a Mediterranean country which has devoted huge resources to implementation of the irrigation projects in the last three decades. However, the chances of implementing such new irrigation projects are decreasing gradually since investment costs are being perceived to be too high. Accordingly, the new situation of the Turkish economy necessitates irrigated agriculture to be more productive and cost effective. Unfortunately, the results obtained from the irrigated agriculture - in terms of yields and farm income - do not seem to satisfy the expectations. This study evaluates the irrigation systems performances (ISP) in Turkey from the standpoint of effective use of water for agriculture. Several irrigation systems located in the different regions of Turkey were evaluated to obtain their system hydraulic, economic and agricultural performance indicators. Results indicated that the hydraulic performance indicators varied region by region according to system type, irrigation method, plant and knowledge of far nears. For instance, water application efficiencies were found to be 29-58% in Central Anatolia, 35-55% in Black Sea, 38-61 in Southeastern Anatolia, 52-84% in Mediterranean, 37-59% in Aegean region. In this work, it is obtained that there are considerable changes in the size of irrigated area and cropping pattern from year to year in all irrigation schemes. It can also be stated that efficient irrigation scheduling has still not achieved properly and this causes too low water application efficiencies with high water conveyance losses.

Key words: Irrigation Systems Performance, Water Resources, Water Application Efficiency, Turkey

INTRODUCTION

A considerable part of the world's food and fiber is currently produced by irrigated agriculture which has experienced significant improvements in terms of both production and yield in the last century. Huge resources are devoted to the implementation of irrigation projects around the world in the last few decades. Numerous irrigation projects have been developed with high investment costs. However, the chances of implementing such new irrigation projects are decreasing gradually since investment costs are being perceived to be too high. Accordingly, the new situation of the world economy necessitates irrigated agriculture to be more productive and cost effective. Unfortunately, the results obtained from the irrigated agriculture - in terms of yields and farm income - do not seem to satisfy the expectations.

The performance evaluation of an irrigation project can be examined in two major components, i.e. the on-farm system, and supply and distribution (off-farm) system. It is obvious that, the off-farm system should be capable of delivering water to farms with sound adequacy, efficiency, dependability, and equity. These parameters are commonly used for controlling an irrigation system performance. The performance of a system can be defined as the measurement of the degree/level of fulfillment of the established objectives (Ait Kadi, 1994). Such a degree/level is expressed by one or several parameters chosen as evaluation criteria or as indicators of the considered objectives. In other words, the definition implies that performance is a relative rather than an absolute concept. It is relative to some objectives which should be defined in advance.

Turkey is a Mediterranean country where considerable improvement in the irrigation development has taken place in the last three decades. This report evaluates the performance of irrigation systems (ISP) in Turkey with the standpoint of effective use of water for agriculture.

In the following section of the study, brief information about general indicators of irrigation - geography and climate, soil and water resources, history of irrigation, regional use of water, and water consumption of some major crops - is presented briefly. In the third section, the concept of irrigation systems performance and results for different regions and different irrigation systems are investigated. Methods used and comparable results for different conditions, systems and regions are pointed out in order to evaluate system performance. In addition, encountered problems in transferred irrigation systems are discussed and relevant recommendations are given. In the fourth section, performance of some selected irrigation systems is examined via several indicators; such as, irrigation efficiency, irrigation effectiveness, and irrigation uniformity for different irrigation systems in different regions.

GENERAL INDICATORS OF IRRIGATION IN TURKEY

Geography and Climate

Turkey occupies a total area of about 78 million ha, of which about 1.1 million is inland lakes. The country forms an elongated rectangle roughly 1,700 kilometers in an east-west direction and 1,000 kilometers north to south. On the east, Turkey has borders with Iran, Azerbaijan, Georgia and Armenia. On the southeast Turkey's neighbors are Iran, Iraq and Syria. On the south and west, the country is surrounded with the Mediterranean and Aegean Sea. On the northwest, Turkey has borders with Bulgaria and Greece. The Black Sea lies in the north of the country. Anatolia, except its eastern parts, is surrounded by seas and has a total coastline of over 10,000 km, including the Thrace and islands. Turkey forms a bridge between Europe and Asia, with about 3 percent of its land in Europe and the rest in Asia.

Turkey is under effect of both maritime and continental weather patterns, which cause extreme geo-climatic diversity when combined with a highly varied topography. The Mediterranean region (southern coastal region) is regarded as sub-tropical, characterized by hot, dry summers and mild, rainy winters. The Black Sea region receives rain throughout the year and lives both mild summers and winters. The Aegean Region (Western Anatolia) has mountains which run roughly east to west (i.e. perpendicular to the coast) and which are interspersed with grassy flood plains. It has also a Mediterranean type of climate with hot, dry summers and mild winters. Central Anatolia is a vast high plateau with an average altitude of 1,000 meters above sea level and a semi-arid continental climate, i.e. hot and dry summers.

The average annual temperature varies between 18-20 ^{o}C on the south coast, falls to 14-15^{o}C on the west coast, and finally in the interior regions, depending on the location of the place from the mean sea level, fluctuates between 4 with 19 ^{0}C. The annual average precipitation is 643 mm, but it varies from 250 mm in the central part to 3000 mm in the Eastern Black Sea region. Seventy-five percent of annual rainfall is received in the winter season. Except for the coastal areas, Thrace and Eastern Anatolia, annual rainfall is less than 500 mm; therefore irrigation is of paramount importance. Generally, agricultural production is adversely affected by the shortage and inconsistency of the rainfall during the growing season. Solar energy, which depends on factors; such as, altitude and seasons, makes it possible to grow arid and semi-arid crops like bananas and citrus. Moreover, it is possible to have 2-3 crops from irrigated areas by allowing 270-day crop growing seasons. However, some crops may be harvested before maturation, particularly in Eastern Anatolia with its 60-90 growing days. The southeast region records very low humidity levels. The coastal regions have quite high levels being in line with precipitation rates. Inevitably, the topographical features are main factors shaping the distribution. The highest average speed of wind is measured in the Çanakkale province, being on the northwest Aegean coast. Moreover, a speed of about 136 km per hour is detected in the provinces of Ankara, Kırşehir and İskenderun. The long-term annual evaporation rates indicate a high rate particularly in the southeast region, which receives almost no rainfall during the summer and reaches more than 2000 mm per year.

Land and Water Potentials

Land Potential

Turkey rooms in most of large land groups found on the earth today with her diverse geological, climatic, vegetation and topographical features. This variety also makes it possible to raise a diversity of crops, many of which are high in their quality.

The total area of Turkey is 77,945,200 ha, separated into 28,059,397 ha of arable lands, 21 506 028 ha of pastures, and common grazing lands, 1 159 207 ha of water surfaces areas, 23,248,297 ha of shrubs, and forests, 3,972,271 ha of residential areas. Of the arable land, 25.85 million ha is irrigable and 2.21 million ha is non-irrigable land. The irrigated area is 4.3 million ha (Table 1).

Table 1. The distribution of Arable Land (Source: GDRS, 2003)

Land	*Area (1000 ha)*	*%*
Arable Area	*28,059.397*	*100*
Non-irrigable Area	2,205.723	8
Irrigable Area	25,853.674	92
Sloped Area	9,341.833	36
Plain Area	16,511.841	64
Arable Area (today)		*100*
Special Farming	1,402.970	5
Irrigated Farming	4,300. 000	15
Dry land Farming	22,356.427	80
Fallow Dry Farming	16,523.184	74
Non-Fallow Dry Farming	5,833.243	26

It should be noted that important changes have taken place with respect to land use. The area, which can be made available for irrigation, is estimated by DSI (State Hydraulics Works) at 8.5 million ha gross area (6.4 million ha for major irrigation projects), of which about 4.3 million ha has already been under irrigation. The remaining area of about 4.2 million ha is yet to be developed for irrigation (Table 2). This does not mean that under present conditions it would be economically feasible to irrigate the whole area. For the Irrigation Master Plan of Turkey, 227 projects covering a gross irrigable area of 2.94 million ha have been analyzed. 139 of these covering a gross irrigable area of 2.07 million ha, or 70 % of the total area reviewed, have an IRR of 8% or more. If that same percentage is applied to the area still to be developed, a potential additional irrigable area of 3.2 million ha will be added.

Table 2. Distribution of Irrigable Land (Source: GDRS, 2003)

Land	*Area, 1000ha*	*%*
Irrigable Land	25,853.674	100
Economically Irrigable Land	*8,500.000*	*33*
With Surface Water Resources	7,900.000	93
With Ground Water Resources	600.000	7
Equipped With Irrigation	*4,300.000*	*51*
Surface Water	3,854.144	90
Ground Water	445.856	10

To be Irrigated in the Future	*4,200.00*	*49*
Surface Water	4,045.856	96
Ground Water	154.144	04

Irrigation development is currently being carried out by the private sector, i.e. farmers and groups of farmers, and the public sector, i.e. DSI and GDRS, General Directorate of Rural Services. Irrigation development by DSI has gradually picked up momentum since 1950 (Table 3).

Table 3. Irrigation area development (in 1000ha) by DSI (Source: DSI, 2001)

Year	*Operated by DSI*	*Operated by Users*	*Total*
1950	123	20	143
1960	185	31	215
1970	521	76	598
1980	755	245	1001
1990	1251	375	1626
2000	1266	422	1689
2001	Projected		2939

Water Potential

One of the most important aspects of land and water resource development programs is the determination of the inventory of the resources. If resources and opportunities are not known accurately before projects are undertaken, the installations will not be feasible and failure will result in most cases.

The average annual precipitation of the country is 642.6 mm, which corresponds to a water potential of 501 km^3 per year. Runoff amounts to 238 mm, an average rate of 37 %, and the remaining 63% is lost to evapotranspiration. A certain amount of the runoff is allocated to meet the water rights and requirements of the neighboring countries. The amount of surface water, which is utilized for consumptive purposes, is in the range of 95 km^3 per year. According to the studies based on groundwater resources, the total safe yield of groundwater resources is estimated to be 11.6 km^3. The potential of total available water resources from surface flow and groundwater would amount to 106.6 km^3 per year (Table 4).

Table 4: Water Potential (Source: DSI, 2001)

Average Annual Precipitation: 643 mm Water Potential from Precipitation: 501.0 km^3			
Surface Water Potential, km^3		*Groundwater Reserves, km^3*	
Annual Flow	186.05	Surfaced Annual Reserve of	12.3
Runoff Coefficient	0.37	Groundwater	9.0
Utilizable potential	95.00	Annual Water Reserved by the DSI	6.0
Actual Annual Potential	31.49	Actual Annual Potential	

In order to regulate the whole surface waters in the country, the construction of 662 dams is required. Thus, it is obvious that the possibilities mentioned above require great amounts of investment and a long period of construction. The water supplies from these dams would be regulated to achieve the following objectives: irrigation of 6,609,382 ha; drainage of 135,801 ha, flood control of 636,794 ha; conveyance of 7,726 km^3 of water to urban areas and generation of 121,484 MKwh of electric power by the hydroelectric power plants with a total electricity capacity of 34,484 MW.

It is clear that water resources in Turkey are considerably limited given tables above about land and water resources potential. Water is a constraint to agricultural productivity in comparison with the extent of existing irrigable land resources. Inter-basin water transfer is possible as a solution, which would be very expensive given the current economic conditions. It can also be noted that the Central Anatolia Region, recognized for cereal production, and some of the inter-zone areas between the coast and central region would be the most profitable areas to implement supplemental irrigation.

Utilization of Water Resources

Total water consumption rose to 42.0 km^3 by the end of 2000 as a result of numerous projects developed by various agencies, including the DSI being the first, in charge of developing water resources. Breakdown of the total figure is as follows: Irrigation (31.5 km^3, 75%); drinking-use water (6.4 km^3, 15%); and for industrial purposes; 4.1 km^3, 10% (Table 5).

32.9 km^3 of 38.9 km^3 of water consumed in 1998 comes from surface water resources while 6 km^3 is provided through groundwater reserves. Sectoral breakdown of utilized surface water resources is as follows: Irrigation (82 %), drinking-use (10 %) and industrial purposes (8%). Corresponding percentages for the utilization of groundwater are 39, 37 and 24, respectively.

Table 5: Actual Water Consumption, 1990-2000 (Source: SPO, 2001)

Year	Total water consumption 10^6 m^3	Potential use (%)	Water Consumption by Sectors, km^3					
			Irrigation		Drinking-Use		Industrial	
1990	30,600	28	22,016	72	5,141	17	3,443	11
1992	31,600	29	22,939	73	5,195	16	3,466	11
1998	38,900	35	29,200	75	5,700	15	4,000	10
2000	42,000	38	31,500	75	6,400	15	4,100	10

History of Irrigation in Turkey

Anatolia located at the crossroads of many antic civilizations has witnessed various water facilities during the last 4,000 years. Central, western, southern and southeastern parts of Anatolia room in many water facilities built by Hittites (2000 BC), Urartu (1000 BC), and rulers in the Hellenistic period, Romans, the Byzantine, Seljuk and the Ottoman. Some of these facilities are even usable today. Remains of other facilities are also visible in many parts of Anatolia as examples of fine engineering skills. The first modern irrigation and drainage facility in Anatolia dates back to 1908-1914 (the ottoman period) as “Çumra Irrigation and Drainage Project” (FNCI, 2001).

The State gave priority to the drainage of swampy areas as a part of combat against malaria, and introduced some small irrigation projects starting with the republican era. Upon the establishment of the General Directorate of State Hydraulic Works in 1954 with the law no. 6200, investments in such projects dam-reservoir construction, pumping, regulation and irrigation networks etc. were intensified. The General Directorates of Village Services and Agrarian Reform were established mainly for the regular extension of on-farm development and land rehabilitation services accompanied by efforts to ensure efficiency in irrigation. In this overall framework, the development of water resources having a flow of more than 500 lt/second fall within the mandate of the DSI while smaller surface flows are developed by the General Directorate of Village Services. In Turkey, 58 to 80 percent of total investments in agriculture in the planned period have targeted the development of land and water resources. In the period 1963-80, 20 to 33 percent of state investment budget was allocated to land rehabilitation and irrigation investments. This share turned out to be much lower (around 10 %) in the 90s (FNCI, 2001). Problems related to the utilization, sufficiency and reliability of water resources have raised serious concerns throughout the world. Consequently, the model “Devolution in Irrigation Management” has come to the fore as the solution starting from the 1950s.

Many countries in Asia, Africa, America and Far East have adopted this model of devolution. The first examples were observed in the USA, France and Taiwan in 1950s, 60s and 70s, respectively.

Devolution secured its place as a national strategy during the 80s and 90s in many countries, including Chile, Peru, Mexico, Brazil, Senegal, Sudan, Somali, Pakistan, India and Turkey. This devolution has been perceived differently in countries. For example, it is merely "transfer" in Indonesia and the Philippines; "delegation of management" in Mexico; "privatization" in Bangladesh; "responsibility sharing" in China and "participatory irrigation management" in Turkey (FNCI, 2001).

Regional Irrigated Land and Irrigation Practices

Irrigation Methods

Irrigation systems constructed by DSI have been mostly designed, operated and based on surface irrigation methods. 95.93% of irrigation area was irrigated by surface irrigation, 3.38% by sprinkler and 1% was irrigated by drip irrigation methods in DSI operated schemes. In Regions I, XI and XII, sprinkling system was also used besides surface irrigation methods with 61.82%, 14.46% and 11.47% shares, respectively. 47.13% of land was irrigated by drip irrigation methods in Region VI. The rest of the regions used only surface irrigation methods.

Transferred schemes displayed quite various irrigation methods, however. On average, 92.09% of irrigated area was irrigated by surface irrigation, 7.03% by sprinkler and 0.88% was irrigated by drip irrigation methods.

Irrigation systems set up by GDRS are planned to irrigate mostly by surface and sprinkler irrigation methods. The latter method is used to irrigate land that have special conditions, for instance, where irrigation water is taken from deep wells of ground water resources.

Sources of Irrigation Water

Land was mostly irrigated by well-sourced water (37.55%), stream water (28.64%) or water from a dam (15.87%) in overall Turkey. However, most of the holdings used well-sourced water (30.35%) and stream water (38.20%). Only 9.25% of holdings used water provided by a dam.

The agricultural regions, Aegean, Mediterranean and Southeast displayed similar patterns like Turkey in percentage distribution of sources of irrigation water. However, the Middle South Region irrigated land mostly with well-sourced water alone (74.24%). Holdings used mostly well-sourced water (38.74%) or stream water (29.28%) in Aegean Region. In Mediterranean, holdings used mostly stream water (37.97%) and well-sourced water (26.63%). In Southeast, holdings used mostly stream water (36.68%) and spring water (32.97%). In Middle South, well-sourced water was used at a share of 58.44%.

Irrigated land developed by DSI varies from region to region. Middle Anatolia and Mediterranean regions occupy the most irrigated area among the others. Table 6 shows the irrigated lands in the regions.

Table 6. Irrigated Lands by DSI (Source: DSI, 2001)

Regions	*Irrigated Lands (ha)*	*%*
Marmara	199,195	8.5
Aegean	401,501	17.2
Mediterranean	540,912	23.1
Southeastern	189,368	8.1
East Anatolia	308,346	13.1
Black Sea	153,471	6.6
Middle Anatolia	547,404	23.4
Total	2,340,197	100.0

Water Use for the Major Crops

Various crops can be grown in different geographic regions of Turkey. The results on irrigation of the crops getting from experiments, which are carried on for long year periods in the different regions, are used in the farmers' guide. Water consumption data is taken by a different method, which is water budget approach in the field plots, as a result of experiment that is arranged to obtain suitable irrigation programs for different crops in different regions. Seasonal water consumption of some main crops for different regions is shown in Table 7.

Table 7. Water Consumption For Main Crops (mm) (Kanber, 1982)

Crops	*Marmara*	*Aegean*	*Mediterran.*	*Middle A.*	*East A.*	*Black Sea*	*SouthEeast.*
Vegetables	560-620	400-800	500-800				490-560
Dec. Fruit	580-680			650-980			
Olive	550-620	620					
Sunflower	400-520						
Cotton		570-800	630-1000				1100-1300
Maize			760-900			700-800	
Citrus		780-890	900-950				
Wheat		570-630	490-600	450-700	400-530		360-730
Potato				560-840	530-930		
Sugar beet				830-1330	630-1000	870-1130	
Pistachio							320-600
Grape		720-820					

The values (results) given in Table 7 are, in general, higher than those in the literature on the water consumption of plants taken from different regions in the world where similar climatic conditions prevail. This difference can be explained by the method used for obtaining ET of crops mentioned before.

IRRIGATION SYSTEMS PERFORMANCE (ISP)

Irrigation Systems/Methods

(i) Farm Irrigation Systems

Farm irrigation systems must supply water at adequate rates, quantities and correct times to meet farm irrigation requirements and schedules. They divert water from a water source, convey it to cropped areas of the farm, and distribute it over the target area. In addition, it is essential that the farm irrigation system facilitate management by providing a means of measuring and controlling flow (James, 1988).

Irrigation water required during the growing season of crops brings to the head ditch of the field by the farm irrigation systems and applies to the plants by irrigation method being used. Thus, the functions of the farm irrigation systems are being carried out by irrigation methods. As it is well known that irrigation methods are defined as the manner in which water is applied to the soil. An irrigation system consists of all engineering structures needed for effective use of water by plant. Irrigation projects include either irrigation system or irrigation method besides irrigated area (Thompson et al., 1980).

Irrigation systems in the irrigation projects can be divided into two sub-systems as to area to be served: Irrigation network and farm irrigation systems. The irrigation network is a great project and covers very extensive areas. Farm irrigation systems serve to one or a few farms and have a small capacity ($Q \leq 0.5$ m^3/s). These systems are located under the tertiary canal to convey and distribute water to individual fields. In addition to the irrigation system, which is settled by using a well, an earth dam or any source to irrigate a field can be accepted as a farm irrigation system.

The farm irrigation system can be classified according to the manner in which water is available to the plants to be used (Thompson et al., 1980). There are two primary ways of diverting surface and ground waters: gravity diversions and pumping plants. Water is conveyed from the water source to cropped areas of the farm in networks of open channels and/or pipelines.

(ii) Application Systems

The application systems can be mentioned as sprinkle, trickle, and surface (gravity) systems, each of which necessitates different conditions for their favorable uses. A system can be successfully applied on a given crop and soil condition while another may not. There are many parameters to be considered while selecting a proper irrigation system. It is important that the farmers have to know the specifications of different irrigation systems.

Sprinkler Systems: This system use sprinklers operating at pressures ranging from 70 to over 700 kPa to form and distribute "rain like" droplets over the land surface. In most common systems; such as, hand-move, solid-set, side-roll, or big gun, a lateral line comes off of the main line to deliver water to the sprinkler nozzles. The position of the lateral may be permanent as in a solid set, or movable as in hand-move and side-roll systems. The spacing between the successive positions of the lateral along the mainline is called “lateral spacing”. The spray area that is wetted by each sprinkler nozzle at a particular operating pressure is designed as the wetted diameter. The wetted diameters are over-lapped along the lateral to promote a more uniform distribution of water application (Cuenca, 1989).

Sprinkler systems apply water efficiently, however, have relatively high capital costs and low labor requirements, and use more energy than other application methods. Sprinkle irrigation is adaptable to many soils and terrains.

Trickle Systems: It can also be mentioned as drip irrigation. Trickle systems differ from the application systems formerly discussed in that the water is applied at a point to a very limited fraction of the total area of a field. This system is the frequent, slow application of water either directly onto the land surface or into the root zone of the crop. It is based on the fundamental concepts of irrigating only the root zone of the crop (rather than the entire land surface) and maintaining the water content of the root zone at near optimum levels. The major difference between trickle systems and most other application systems is that the balance between evapotranspiration and applied water is maintained over limited periods of 24 and 72 hours. Trickle irrigation is accomplished using pressures ranging from 15 to 200 kPa to drip water one-drop-at-a-time onto the land or into the root zone, spray it as a fine mist over portions of the land surface, or bubble it onto the land surface in small streamlets. Waters with high concentrations of particulate, chemical, and/or biological materials that clog trickle system components make trickle irrigation difficult and expensive. Trickle irrigation is adaptable to most soils and terrains.

Surface (Gravity) Irrigation: Most irrigation throughout the world is accomplished via surface (gravity) techniques. Surface irrigation systems generally require a smaller initial investment (except when extensive land smoothing is needed), are more labor intensive, and apply water less efficiently than other types of irrigation systems (Kay, 1989). Surface irrigation systems are best suited to soils with moderate to low infiltration capacities and land with relatively uniform terrain and slopes less than 2 percent. The adaptability of different soil types and topography to methods of surface irrigation is a function of many different parameters. Some scientists have developed many graphs, and tables given information of surface irrigation methods' specifications for various soil, crops and topographic conditions. These tables also specify ranges of required water flows for the different methods, recommended soil characteristics, and comment regarding to installation cost and labor requirements (Booher, 1974).

The Concept of Performance Evaluation of Farm Irrigation Systems

Farm irrigation systems are designed to supply the individual irrigation requirements of each field on the farm while controlling for deep percolation, runoff, evaporation, and operational losses. The purpose of evaluating irrigation systems is fourfold: (1) To determine the efficiency of the system; (2) to determine how effectively the system can be operated and whether it can be improved; (3) to obtain information that will assist engineers in designing other systems; and (4) to obtain information for comparison of various methods, systems, and operating procedures as a basis for economic decision (Merriam et al., 1980, Ait Kadi, 1994). Various criteria have been developed and used for evaluating of irrigation system performance. They include mainly social, economical and technical (hydraulic) indicators of performance of irrigation systems. These are known as the performance criteria of a system. They are, for instance, productivity, social stability, financial and economic criteria, effectiveness, efficiency, equity, reliability, and general welfare criteria (Essafi, 1995).

The hydraulic performance of irrigation systems has been intensively investigated in the technical literature. The hydraulic performance of a farm irrigation system is determined by the efficiency with which water is diverted, conveyed, and applied and by the adequacy and uniformity of the application in each field on the farm to evaluate the irrigation system. Three of the most commonly used criteria are efficiency, effectiveness, and uniformity. In the following chapter, some important hydraulic criteria of performances are summarized.

Hydraulic Performance Indicators

(i) Irrigation Efficiency

In the discussion of any type of irrigation systems, it is useful to have the concept of efficiency to enable comparison of different management strategies for a particular system. If experiences of different irrigation systems are being compared, it is clearly that stated how the efficiencies were derived to see that they actually measure the same value of efficiency. The efficiency of any system is an indicator of the losses, which occur in the system in view of its input and output. In general, efficiency is defined as the ratio of output to input. Thus, the overall efficiency of a farm irrigation system is the percentage of water supplied to the farm that is beneficially used for irrigation on the farm. Irrigation efficiency can be thus defined as by Equation 1.

$$Ea = \frac{Water\ Stored\ in\ the\ Root\ Zone}{Water\ Delivered\ to\ the\ Farm} \times 100 \qquad (1)$$

It should be noted that efficiencies of various parts of a water resources system are described by the foregoing set of relationships. The application efficiency is an indicator of the water losses, which occur in the system at the farm level. These irrigation losses may include operational losses from distribution system, seepage and evaporation losses from canals and farm ditches, deep percolation losses below root zone, tail water losses at field end, and evaporation and drift losses resulting from sprinkling.

It is often useful to examine the efficiency of each system component while evaluating the performance of a farm irrigation system. This allows components that are not performing well to be identified. When testing the efficiency of any irrigation system, reservoir storage efficiency and conveyance efficiency must be considered for obtaining reliable results, as well.

(ii) Irrigation Uniformity

The uniformity of application is used to describe to what extent an application system distributes the water evenly over a field. The spatial variability of the water amounting to the soil can be observed in the variability of crop yield over the irrigated field. In statistics, variability is usually judged through the determination of two statistics: standard deviation and coefficient of variation. One of the most commonly used criteria for evaluation of irrigation uniformity is the uniformity coefficient introduced by Christiansen which can be defined as the Christiansen Uniformity Coefficient (Equation 2).

$$CU = 100 \times \left(1 - \frac{Average\ Deviation\ From\ Mean}{Mean} \right) \quad (2)$$

Distribution uniformity (DU) is another index for the application of uniformity. DU is the ratio, expressed in percent, of the average low-quarter amount caught/infiltrated to the average amount caught/infiltrated. DU is defined by;

$$DU = 100 \times \left(\frac{Average\ Low\ Quarter}{Mean} \right) \quad (2a)$$

(iii) Adequacy of Irrigation

The adequacy of irrigation is the percentage of the field receiving sufficient water to maintain the quantity and quality of crop production at a *profitable* level. Adequacy is defined as the percentage of the field (farm) receiving the desired amount of water or more (Equation 3). This definition requires crop, soil, and market conditions to be specified. The adequacy of irrigation is evaluated using a cumulative frequency distribution.

$$Pa = 100 \times \left(\frac{Area\ with\ Root\ Zone\ \mathrm{Re}\,plenished}{Total\ Irrigated\ Area} \right) \quad (3)$$

When the desired depth of irrigation fills the soil to the field capacity, a term called the *storage efficiency (Es)* is often used as an index to adequacy. The Es is computed using Equation 3a.

$$Es = 100 \times \left(\frac{Amount\ of\ Water\ Stored\ in\ the\ Root\ Zone}{Soil\ Moisture\ Deficit\ Before\ Irrigation} \right) \quad (3a)$$

(iv) Irrigation Effectiveness

This is a term that describes the application efficiency, uniformity, and adequacy of irrigation qualitatively. The desired effectiveness of irrigation, i.e. the desired combination of efficiency, uniformity, and adequacy, maximizes net farm profit. Irrigations with the highest application of efficiency, uniformity, and adequacy are not always desirable, since they do not always maximize net farm profit. Thus, an understanding of the relationship between applications of efficiency, uniformity, and adequacy is needed to identify proper irrigation systems.

Economical Performance Indicators

The International Water Management Institute (IWMI) developed a set of comparative performance indicators with the purpose of the economic assessment of irrigation performance (Molden et. al., 1998). In these indicators, water input-yield relationships are used mainly. The first four basic indicators relate agricultural production to water amount. These indicators allow a comparison of the performance of fundamentally different systems by standardizing the gross value of agricultural production (Değirmenci et. al., 2003). The standardized gross value of production (SGVP) per unit of water consumed is significant especially for areas where water scarcity exists, while output per unit of commanded or cropped area is more important for areas where the land is regarded as a limited source. The four basic indicators are; unit output of cropped area, unit output of commanded area, unit output of irrigation supply, and unit output of water consumed. These indicators are defined by equations given below.

$$T_{crop} = \frac{SGVP}{I_{crop}} \quad (4)$$

$$T_{com} = \frac{SGVP}{A_{com}} \tag{5}$$

$$T_{is} = \frac{SGVP}{I_{ds}} \tag{6}$$

$$T_{wc} = \frac{SGVP}{W_{et}} \tag{7}$$

Where, T is the output per cropped area (T_{crop}), per commanded area (T_{com}), per irrigation supply (T_{is}), and per water consumed (T_{wc}). I_{crop} shows the irrigated cropped area, A_{com} is the commanded area by the irrigation system; I_{ds} is the diverted irrigation supply; and W_{et} is the volume of water consumed by evapotranspiration. SGVP in all equations is the output of the irrigated area in terms of the gross or net value of production measured at local or world prices.

$$SGVP = \left(\sum_{crop} Ai\ Yi\ \frac{Pi}{Pb} \right) P_{world} \tag{8}$$

Where; *Ai* is the area cropped with crop i (ha), *Yi* is the yield of crop i (ton per hectare), *Pb* is the local price of the base crop (USD t^{-1}), and P_{world} is value of base crop traded at world price. SGVP is used for the cross-system comparison, and there exist some differences in local prices at different locations throughout the world. Therefore, a plant must be chosen as a base crop according to its cropping intensity in the study area and its importance in the international markets.

Agricultural Performance Indicators

This group of indicators contains relative water supply, irrigation ratio and water diversion capacity ratio of the system. These performance indicators are assumed to be social indicators or physical indicators of the irrigation systems, as well.

$$\mathrm{Re}\mathit{lative\ Water\ Supply} = \frac{Total\ Water\ Supply}{Crop - Water\ Demand\ (ET)} \tag{9}$$

$$Irrigation\ Ratio = \frac{Irrigated\ Cropped\ Area}{Command\ Area} \tag{10}$$

$$Water\ Diversion\ Capacity\ Ratio = \frac{Diverted\ Water\ Supply}{Planned\ Water\ Supply} \tag{11}$$

There are also some other indicators for the same purpose; such as, realized crop pattern ratio, benefit/cost ratio, planned water supply ratio, sustainable irrigated area ratio, etc.

IRRIGATION SYSTEM PERFORMANCES IN TURKEY

The relevant studies on irrigation system performance were begun almost in 1980s. The first study was carried out on areas that are irrigated by Lower Seyhan Irrigation System, with the support of FAO (Benli et. al., 1987). In this study, monitoring and evaluation of the LSP system were particularly considered. Besides, several irrigation systems in different regions were evaluated to obtain their system performance. Open channel systems, and pressurized systems, like sprinkler and drip, were examined in these studies. Moreover, the irrigation systems, which irrigate land by water that is conveyed from earth dams constructed in the high plateaus, were worked for their performance. In the below section, some results obtained are summarized for different regions.

Mediterranean Region

The study carried out by Benli et al. (1987) assessed the performance of Lower Seyhan Irrigation System in Adana. In the study, the system was tested according to their technical aspects; such as, water conveyance, seepage and tail water losses, irrigation efficiencies, and all system design and efficiency of operation. In addition, the variation of cropping pattern over the years, groundwater observations, dissolved salt concentration of ground water in the peak irrigation months, water use and water balance, etc. were mentioned. Results indicated that water amounting to 50 percent of that is taken from reservoir of Seyhan Dam was available to plants grown on the Seyhan Plain. It means that 50 percent of water is lost and can not be used by the plants. This is caused not only by the irrigation and drainage system development simultaneously, but also by administrative, financial and management problems, the extreme change of cropping pattern, the lock of the land leveling of the irrigated area, etc.

Yavuz (1993) tested three different irrigation methods; namely, furrow, drip and sprinkler, in a field condition. In addition, various management techniques for each irrigation methods were included in his work. For instance, furrow irrigation consisted of pounded alternative furrows (PAF); free end furrows (FEF) and pounded continuous flow furrows (PCF). Drip irrigation applications consisted of two different emitter spacing (d_1: 30 and d_2: 60 cm) and two different planting techniques; traditional (T) and double row (D) in a single planting bed. In sprinkler irrigation (SI), different final irrigation dates and different irrigation levels were evaluated. Table 8 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 besides total infiltrated water during irrigation events (Zi). In the table, infiltrated water estimated from net infiltration opportunity time, which were obtained by flow advance and recession data during irrigation event, was also given.

Similar results were obtained by Önder (1994) from his study on surge and continuous furrow flow in the Tarsus Plain. He found out that surge flow increased the tail water runoff losses, while deep percolation losses decreased. Moreover, the soil and water losses increased depending on the flow size in all treatments used in his field experiment.

A study was carried out by Uçar (1994) on the pressurized system (mini-sprinkler) at the Research and Production Farm of The Agriculture Faculty of Çukurova University. Results indicated that the pressure variation between the first and the last lateral as to the location of control unit was estimated to be 16.7% while distribution coefficient was 67% and storage efficiency varied from 59 to 74.8% during the irrigation season. Additionally, wetted area was determined to be 15.94% and average application rate was 5.5 mm/hr. During the test, 892 mm of irrigation water was applied throughout the season.

Table 8. Irrigation Performances For Different Methods For Cotton (Source: Yavuz, 1993)

Methods	*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				
DTd2	8	90	91	78	7				0.39
DTd1	16	82	74	71	12				0.36
DDd2	9	70	63	61	6				0.54
DDd1	15	76	68	66	11				0.43

Note: Da, average application depth; Eu, emission uniformity; PELQ, potential application efficiency; AELQ, application efficiency; Dn, minimum application depth.

Considered irrigation events used for testing have different irrigation time due to the irrigations that were begun at the different available water level in the root zone. Overall performance of the system has been considered to be acceptable. However, a few simple changes are required for improving system performances.

Gözen and Hakgören (2000) examined the performance of individual drip irrigation systems for the Antalya-Kumluca region with a high rate of greenhouse production. It should be noted that drip irrigation system is used in all greenhouses in the region. In their study, the hydraulics performance indicators were evaluated for selected greenhouses that were constructed at different frameworks and, in which drip-irrigated tomato is grown. The results for selected greenhouses are shown in Table 9.

Table 9. Some Hydraulics Performance Indicators For Drip Irrigation In Kumluca (Source: Gözen and Hakgören, 2000)

Number of Greenhouse	EU_s	Q_{cv}	*CU*	U_s	*Ea*
1	90.49	14	96.38	94.12	90.54
2	87.34	34	93.29	91.74	87.15
3	81.48	29	91.11	88.09	81.09
4	78.23	31	89.94	87.18	74.44
5	90.11	16	95.39	90.00	88.38

The greenhouses that are numbered as 1, 2, and 3 have arch-frame work with 3, 6 and 9 blocks, respectively. The greenhouse 4 is also arc-frame work with 4 blocks while number 5 is mono-block with cradle skeleton. All greenhouses are covered with plastic sheet. According to the results, Emission uniformity (EU_s), statistical uniformity concept (U_s) and Christiansen uniformity coefficient (CU) increased in the greenhouses, which have arc-framework depending on the block number, except emitter flow variation (Q_{cv}). This indicator decreased as the blocks in the greenhouses increased. There is no difference between frameworks of arch and cradle of greenhouses for performance indicators of drip irrigation systems.

Yıldırım and Orta (1993) carried out another study of performance evaluation on drip irrigation systems of nine farms in Antalya Region. In their work, existing drip irrigation systems and water applications were investigated, the system operational plans were prepared and the results obtained were compared to present applications. As a result, it was obtained that the system elements were not designed properly; the infiltration of water has not been supplied because that the equipments required were not placed in the control units. Lastly, system layouts and operations were insignificant in all drip irrigation systems.

Ertek (1998) studied also on the drip system evaluation in a field irrigation experiment. Different irrigation programs were considered in his study for irrigation of cotton, and better performance indicators were found out.

Yazar et al. (1990) studied on the pressurized irrigation system performances in irrigated areas around Seyhan. In the study, hose-reel sprinkler system was considered using various operating conditions; such as, operating pressure, nozzle size, traveling speed and travel lane spacing (Table 10).

Table 10. Some Performance Indicators For Reel-Hose Sprinkler System (Source: Yazar et al., 1990)

Travel Speed [m/h]	Pressure at Nozzle [KPa]	Nozzle Size [mm]	CU [%]	Travel-Lane Spacing [m]	Wetted Diameter, [m]	App. Rate [mm/h]
20	405	17.8	90	52	70	10.56
40	405	12.7	91	36	45	5.81
60	405	12.7	84	43	55	6.74

Overlapped distribution pattern was obtained by catch can data and Christiansen uniformity coefficient, which showed that water distribution was found to be more than 85% if proper operating conditions were used.

A similar study was carried out by Andırınlıoğlu (1993) on a linear moving sprinkler irrigation system used on a private farm located in Seyhan irrigation areas. The system was 650 m in length with 12 towers, including a control unit. The pumping station was placed in the middle of the system. According to the results, water application efficiency did vary between 95 (min.) and 97% (max.), distribution uniformity was 87.2%, system capacity was 7714 L/min, and maximum application rate was 106 mm/h. Fuel, energy and water use efficiencies were found to be 56.1 L/ha, 0.026 l/kg, 0.66 kg/m^3, respectively.

In the last decade, most of the irrigation systems were transferred to water user associations that are responsible for only management and maintenance. Bulut and Çakmak (2001) carried out a study to compare pre and post-transfer of irrigation system performance in Mersin Irrigation Scheme. The performance indicators, which were used for the assessment of water management performance, were grouped in terms of water use, agricultural and economic efficiencies. Results indicated that some indicators increased after the transfer while others did decrease. For instance, water supply ratios were 1.43-1.69 in pre-transfer, and 1.33-1.82 in post-transfer as to total water requirement. Irrigation ratios were 85-93% in pre-transfer; 87-98% in the post-transfer period. Crop production ratios were calculated as 70-113% in the pre-transfer, and as 72-117% in the post-transfer. The ratio of financial efficiency, financial sufficiency, water fee collection ratio and sustainable irrigated area were found out to be 145-320%, 42-93%, 40-54% and 81-93% for the pre-transfer, and 46-297%, 26-59%, 32-143% and 63-70% for the post-transfer of the system. Similarly, field application, conveyance, distribution and total irrigation efficiencies were calculated as 70, 92, 82 and 53%, respectively.

Southeast Anatolia Region

A study was carried out in the area covered by the Southeastern Anatolia Project by Değirmenci et al. (2003) to assess the irrigation performances of some selected irrigation schemes using 6 comparative indicators. These performance indicators were applied to 12 irrigation systems in the project region from 1997 to 2001. The performance indicators were the economic characteristics, i.e. the output per cropped area, output per unit commanded area, output per unit irrigation supply, output per unit water consumed, relative water supply, and the irrigation ratio, etc. The comparative indicators considered in this study were suitable for the comparison of performances among different irrigation schemes. These indicators were calculated depending on the irrigation system as USD1223-9436 ha^{-1}, USD308-5771 ha^{-1}, USD0.2-2.16 m^{-3}, and USD0.45-2.92 m^3, 1.00-5.90 and 7-100%, respectively. The results indicated that the differences among the schemes in the output per unit cropped area, output per irrigation supply, output per unit water consumed and relative water supply were not statistically significant but that the differences in output per unit command and irrigation ratio were statistically significant. It was reported that an information system for monitoring and evaluation, which encompasses all stakeholders, should be set up and irrigation scheduling should be designed for an efficient management of an irrigation system in the area of Southeastern Anatolia Project.

Another study was carried out in the field irrigation of Harran Plain by Kanber et al. (2001). In the experiment of two years, irrigation performance parameters of surface irrigation methods of continuous and surge furrow flow were tested. Different flow rates (less and high inflow) and on and off time (surge) were considered at the 180 m length of the field. Results indicated that surge flow with less inflow rate increased the application efficiency compared to continuous flow (Table 11). Besides, it did not reason to create any problem on the relationship between soil and water in the heavy textured soils. In surge flow, 30 and 43% of water were losses and not available to the cotton crop while these figures were 38 and 53 % in continuous furrows of C_1 and C_2. The average requirement efficiency (Er) was high in all treatments and they were found to be still in acceptable limits. The infiltration efficiency (Ei) was higher in furrows with less flow rates (C_1 and S_1) than those in high flow rate-furrows (C_2 and S_2). The highest wasted water from tail water and deep percolation was obtained in S_2 with 28% of TWR and in C_2 with 33% of DPR. It should be noted that the high DPR and TWR in continuous and surge flows did result with a lower rate of application efficiency. The uniformity coefficients (UCC and DU) ranging from 79 to 94% were within the acceptable limits, except the DU value of S_1. This implies that decreasing the infiltration rate in time resulted in acceptable uniformity coefficients even if there were significant differences in the opportunity of time. However, the lowest DU value was obtained in the S_1 treatment. This can be explained by the result of the higher tail water runoff losses in this treatment.

Table 11. Estimated average irrigation performance parameters (in %) for surge and steady flows (Source: Kanber et al., 2001)

Treatment	*Ea*	*Er*	*Ei*	*TWR*	*DPR*	*UCC*	*DU*
C_1	62	87	86	26	12	90	82
S_1	70	87	88	20	11	89	79
C_2	47	100	60	20	33	94	88
S_2	57	96	64	28	16	89	89

Central Anatolia Region

Çakmak (2001) evaluated the irrigation performance of the water user associations of Konya irrigation scheme. Some irrigation systems in Konya province; such as, Atlantı (10230 ha), Çumra (59,704), Gevrekli (4,438 ha), Ilgın (5,214 ha), Ivriz (32,254 ha), Karaman (15,040 ha) and Uluırmak (20,422 ha) and total 239,302 ha irrigated area, were taken as the sample using data from 1995 to 1999. The economical performance indicators; such as, output per command area, output per cropped area, output per unit irrigation supply, output per unit water consumed, and two agricultural indicators of water supply, and irrigation ratio were used to compare the irrigation schemes. The results indicated that output per command area, output per cropped area, output per unit irrigation supply, output per unit water consumed, water supply, and irrigation ratio were found to be 195-5391 USD/ha 359-6197 USD/ha 0.02-1.29 USD/m^3 0.07-2.25 USD/m^3 0.30-7.83% and 36-104%, respectively.

Yıldırım and Kodal (1990) have studied on choosing a proper system for Konya-Yunak-Gölpınar TOPRAKSU Cooperative, where the area was being irrigated with groundwater resources, between surface and sprinkler irrigation applications. Alternative surface and sprinkler irrigation systems were designed for adequate and limited water regimes, in which the water requirements were supplied completely and with extending irrigation intervals, respectively. The results showed that all alternative projects of both irrigation systems with 9-18 days intervals were found to be inappropriate regarding to the economic factors behind. The highest benefit-cost ratio was achieved at the sprinkler system of adequate water regime. As a result, sprinkler irrigation system with 6-12 days interval was suggested as the investigation area.

Furthermore, water distribution and water use efficiencies in Konya-Alakova pump irrigation system was evaluated by Balaban and Beyribey (1991). The irrigation system was constructed by State Hydraulic Works (DSI) in 1965 to irrigate an area of almost 895 ha. The water conveyance and water application efficiencies were found to be 85 and 48.7 %, respectively. According to results taken from the experiment, a flow diagram was prepared in order to evaluate and monitor the irrigation system.

Kadayıfçılar et al. (1998) studied on the evaluation of the systems around the Nevşehir and Niğde region, where sprinkler irrigation system was widely used particularly for irrigation of potato, according to their water application performances. 25 farms, almost all of which used the sprinkler system, were considered and their irrigation systems and irrigation applications were evaluated. The results indicated that, the considered sprinkler irrigation systems were placed to take into consideration of farms location and whole farm-area shape. However, 24 of which were not operated in convenient pressure and sprinkler headspace, and 40 of which radius of main and lateral lines were not selected conveniently. In the region, excessive water was generally applied while application was not enough to meet the crop water requirement during the overall growing season and not to suffer from stress due to lack of water.

Öğretir (1981) carried out a study on the Çifteler irrigation scheme, which is located in Eskişehir province and where 6110 ha area was irrigated, in order to determine the water conveyance losses and the water application efficiencies. The canals, which convey water, were lined by concrete in the whole system. Water conveyance losses were determined by the inflow-outflow method and water flow was a measure by current-meter. The results showed that water losses by seepage of canals were 0.44-4.29 % of inflow of canals, and average conveyance losses was calculated as to be 1.88% of inflow. Water application efficiencies varied between 32 and 77% according to the irrigation methods used in the area. For sprinkler irrigation systems, it was 66% while 42% for wild flooding.

The same irrigation scheme, which was put into practice by State Hydraulic Works in 1969 partly and in 1974 completely, was evaluated by Alibiglouei and Öneş (1992) for water losses and water application efficiency. As a result of their study, the water conveyance losses and water application efficiencies were found to be as 87.0 and 59.5 %, respectively.

Öğretir and Beyribey (1997) evaluated the Eskişehir irrigation system, which irrigated a net area of 17,500 ha near the Eşkişehir city. In the study, the data for 1984-1995 was used to assess some of the performance indicators; such as, water consumption, agricultural, economic, social, and environmental indicators. According to the results, the project efficiency was found as 55%; water supply ratio on a monthly basis, 2.3; irrigation ratio, 48%; benefit/cost ratio, 2.9; financial efficiency ratio, 95%; financial sufficiency ratio, 26%; fee collection ratio, 83%; and lastly, sustainable irrigation ratio was obtained as 98%.

Marmara Region

Yazgan and Değirmenci (2002) carried out a study using the data of 1992-1996 irrigation results. In the study, 15 different physical, economical and institutional efficiency indicators were applied to Bursa Groundwater Irrigation Project to evaluate the performance of the irrigation system. The study area was about 1,650 ha, and it had 41 deep water-wells, which had an average flow rate of 20-40L/s. Irrigation water was conveyed by 11,775 km long spiral steal pipe and 68,576 km asbestos-cement pipe in the system. The results taken from study are arranged according to performance indicators in Table 12. Foreign currency of dollars was used for calculating the economic indicators, and water consumption of crops was estimated by the Blaney-Criddle method. According to the results from Table 12, water supply ratio varied between 0.6 and 1.09, and irrigation ratio was found to be 57-81%. On the other hand, the realized crop pattern ratio of 71-96%; benefit cost ratio of 2.5-10%; planned water supply ratio of 61-115.3% and water-use per unit area of 5917.3-8701.3 m^3ha^{-1}, water fee collection ratio of 71-100%, sustainable irrigated area ratio of 1.71, out put per unit command area of USD2628.7 ha^{-1}, and out put per cropped area of USD4198.5 were obtained. After the evaluation, it could be said that irrigation planning must be carried out for the sake of farmers, market and water resources and for an efficient irrigation management.

Table 12. Some Irrigation Performance Indicators of Ground Water Irrigation in Bursa (Source: Yazgan and Değirmenci, 2002)

Performance	Indicators	1992	1993	1994	1995	1996
Physical Indicators	Realized Crop Pattern Ratio, %	73.3	71.7	94.5	89.2	96.6
	Planned Water Supply Ratio, %	96.6	72.5	115.3	91.9	61
	Water supply Ratio	0.98	1.03	1.07	1.09	0.60
	Irrigation Ratio	81	57	72	59	67
	Water Use per Unit Area (m^3ha^{-1})	6741.8	7837.4	8701.3	8479.	5917.3
	Benefit/cost Ratio	2.5	2.6	6.4	8	8.2
	Water Fee Collection Ratio	100	99	99	10.0	71
					96	
Physical and	Indicators	*Groundwater Irrigation*			*Open Channel Irrigation*	

Institutional	Sustainable Irrigated Area Ration	1.71	1.40
	Distribution System Per Unit Irr. System	0.83	0.77
	Irr. System per Unit Command Area (ha km^{-1})	29.56	20.26
	Personnel per Unit of System (km $pers^{-1}$)	21.57	59.70
	Personnel per Unit of Command Area (km $pers^{-1}$)	443.7	137.40
Economic	Indicators	1996	
	Output per Cropped Area, \$ ha^{-1}	4198.5	
	Output per Unit Command Area, \$ ha^{-1}	2628.7	
	Output per Unit Supplied Water, \$ m^{-3}	0.8	
	Output per Unit Water Consumed, \$ m^{-3}	0.9	

Black Sea Region

This region has quite enough precipitation rates for the season of crop growing. Irrigation is usually being applied at the local area with water conveyed from earth dams constructed by General Directorate of Village Affair.

Bayrak (1991) evaluated some irrigation systems located at Havza, Vezirköprü and Kavak provinces in the interior of Samsun. In this experiment, water conveyance losses and water application efficiencies were studied. The results revealed that water conveyance losses varied between 0.14 and 3.34 % of the diverted water, and the application efficiency was found to be 70.5 % as the average of all irrigation systems were considered.

Aegean Region

The Great Menderes Basin-irrigation schemes, as it was mentioned before that most of the irrigation schemes were transferred to water user associations (WUA), was also transferred to WUAs. Irrigation networks of the basin were operated also by other user organizations. A study was carried out by Koç (2001) to assess the impact of the water user associations relating to management–operation and maintenance (MOM) of the irrigation schemes. In the study, 4 schemes; namely, Nazilli, Akçay, Aydın and Söke irrigation systems, were considered using a random methodology for survey to investigate the effectiveness of WUA on the MOM. A questionnaire consisting of 5 different topics; that were water delivered, personnel number and maintenance of networks, sustainability of WUA and the collection of fees, was used to analyze the operative performance of the WUA. The results were recorded with respect to the answers of the water users to the questions about irrigation systems management and operations. Average total water users in the irrigation schemes considered lead to the following conclusions with their weights; the sustainability and sufficiency of water amount diverted by WUA was every time good, 71%; bad, 15%; sometimes good, 14%. On and off time of the water diverted by the systems was regarded to be reasonable (63%) and unreasonable (37%) by the water users. In addition, maintenance and repairing of the all systems were adequate for 38 and 72 percent of the water users, respectively. Water users in all systems replied to the question of "how do you find the ability of personnel working in the WUA to deal with the problems related to irrigation?" to be good (80%), not good (19%), and fair (1%). The water price was regarded as being high for 64%, normal for 32%, and cheap for 3% of water users. The opinion of users, generally, was that the transfer of the irrigation systems to the WUA had a very positive impact.

Koç (2003) carried out another study on the irrigation performance of Great Menderes basin irrigation schemes for pre and post-transfer periods, being 1992 – 1994 and 1999 – 2001, respectively. Some irrigation networks, such as, Nazilli, Akçay and Aydın, were studied to assess the management-operation and maintenance (MOM) of the systems. In order to measure and evaluate of the performance of MOM for the selected systems, almost 20 performance indicators were used with weighed average mark method (WAM), and an index system was scored. When high WAM was found, irrigation system was accepted as having a high irrigation performance. Results showed that, the total WAM indexes of irrigation systems for MOM at the pre and post-transfer were found to be significantly not different. However, the economical indicators of MOM increased slightly after the turnover of irrigation system during 1999-2001 (Table 13).

In Aegean Region, another study was made on the Menemen Plain for obtaining irrigation efficiencies by Şener (1978). In this research, two concrete canals of Kesikköprü, P3 and P4 were used in order to determine the water losses and irrigation efficiencies on the irrigated lands during the irrigation events. For this purpose, the amount of irrigation water was measured using constant head orifices at the inlet and outlet of the canals from the beginning of the irrigation season, July to the end of September, being the end of the irrigation season.

Table 13: Average Irrigation System Performance Indicators (Source: Koç, 2003)

Indicators	*Akçay*		*Aydın*		*Nazilli*	
	Pre-transfer	*Post-transfer*	*Pre-transfer*	*Post-transfer*	*Pre-transfer*	*Post-transfer*
Physical	30.97	30.67	34.04	33.01	34.33	33.12
Economic	26.67	31.32	27.20	29.40	27.52	30.28
Social	6.81	7.75	7.86	5.94	8.63	6.90
WAM	70.46	77.68	75.10	75.88	76.47	76.29
Results	Fair	Fair	Fair	Fair	Fair	Fair

Moreover, the area of the land irrigated by each irrigator was also determined. The soil depth of 1.2 m was considered for determining the irrigation water amount that was infiltrated into the root zone after irrigation applications. According to the results, application rates varied between 46 and 287 mm for P3 and 70 and 534 mm for P4 canals, and application efficiencies of irrigation water were 43-65% depending on areas serving to different canals, and irrigation events.

CONCLUSIONS

This country report presents the results of the studies on irrigation performances of irrigation systems in Turkey. The total number of scientific studies, which varies depending on the year, conducted up to now is 87. The results of the first studies were published at 1970s. The number of studies increased rapidly over the years and reached to the top point constituting the 24 percentage of the total during the period of 1990-2000. It must be pointed that different institutions and organizations have carried out all these studies. Most of these studies, 69% of the total were done by universities, and the rest, 31 % by research institutions. Most of the studies have been carried out in Mediterranean and Middle Anatolia Regions with 35 and 32 percent, respectively. Aegean Region with 23 percent comes after others.

According to the results referring to all relevant scientific studies, performance of irrigation schemes located in different regions of Turkey, overall, is not at acceptable levels. This inadequacy can be highly related to the infrastructure, management (agency, joint, and farmer), allocation and distribution procedures (demand vs. supply), and the climate and socio-economic setting. In almost all systems, the whole area can not be irrigated for various reasons; such as, water scarcity, fallow land, socioeconomic reasons, and lack of infrastructure. On the other hand, there are considerable changes in the size of irrigated area and cropping pattern from year to year in all irrigation schemes, referring to all relevant studies. It can also be stated that efficient irrigation scheduling has still not achieved properly and this causes too low water application efficiencies with high water conveyance losses. Water application efficiencies, which have been achieved for different regions and different irrigation methods, are summarized in Table 14 as an example.

Table 14. Results on Water Application Efficiency, Ea, (%)

Regions	*Drip Irrigation Method*	*Sprinkler Irrigation Method*	*Surface Irrigation Method*
Mediterranean	67-84 (Söğüt, 1986)	95-97 (Andırınlıoğlu,	52-59 (Şimşek, 1992)

	87-98 (Bilal, 1997)	1993)	
Southeastern		61 (Oğuzer and Önder, 1988)	86-94 (for blocked furrow, Kanber et al., 1996) 60-70 (for free end furrow, Kanber et al., 1996) 38 (Oğuzer and Önder, 1988)
Middle Anatolia		33.7 (Şimşek, 1992)	48.7 (Balaban and Beyribey, 1991) 29-80 (Ertaş, 1980) 37.9 (Şimşek, 1992) 32-77 (Öğretir, 1981) 23-58 (Oykukan, 1970)
Black sea			35-94 (Bayrak, 1991) 55-87 (Balçın, et al., 2001)

Lastly, Table 15 shows the results taken from irrigation schemes on some irrigation performance indicators; such as, uniformity of irrigation (CU and DU), storage efficiency (Es) dripper emission uniformity (EU), conveyance efficiency (Ec) and conveyance losses (CL).

Table 15. Irrigation Performance Indicators for Different Regions

Regions	*Es*	*DU*	*CU*	*EU*	*Ec*
Mediterranean	56-75 mini sprink., (Uçar, 1994)	98-99 Drip (Bilal, 1997) 82-88 Surface irr (Şimşek, 1992) 87.2 Sprinkler (Andırınl, 1993) 12.1 Furrow (Önder et al., 1992)	40 furrow (Önder et al, 1992) 97.5 Drip (Oğuzer and Yılmaz, 1991)	84 Drip (Söğüt, 1986)	
Aegean					
Souteastern	24 Furrow, 41 sprinkler (Oğuzer and Önder, 1988)	85 Sprinkler (Kanber et al., 1996)	85 Surface and sprinkler (Kanber et al, 1996)		
Middle Anat.	75-80 Surface Irr. (Oylukan, 1972) 85 with land leveling 61-98 Surface irr. (Oylukan, 1970)	37-81 sprinkler (Tarı, 1998)	58-82 Sprinkler (Tarı, 1998)		85 Irr. Canal (Balaban and Beyribey, 1991)
Black sea	17-90 Surface irr. (Bayrak, 1991)				

REFERENCES

Ait Kadi, M., (1994). Performance Evaluation of an Irrigation System Conceptual Framework. *In Advanced Course on Farm Water Management Techniques. Comp. by A. Hamdy.* 7-22 May, 1994. Rabat, Morocco, p. 3-16.

Andırınlıoğlu, A., (1993). *The Performance Evaluation of A Linear Move Sprinkler Irrigation System*. Çukurova University, Institute of Science, Irrigation and Drainage Eng. Department, *MSc*, Adana.

Balaban, A., Beyribey, M., (1991). Water Distribution and Water-Use Efficiencies in Konya-Alakova Pump Irrigation System. *Doğa, Tr. J. of Agric. and Forestry*, 15: 24-34.

Balçın, M., Ağırbaş, N. Karata, H. Güleç, H. ve Aydın, O. (2001). Irrigation Performances of Irrigatiion Scheme of Artova-Çelikli Earth Dam. *Tokat Res. Inst.*, No: 117, Tokat

Bayrak, F., (1991). Water Conveyance Losses and Water application Efficiencies in the Irrigated Areas in Samsun Province. *Samsun Res. Ins. Pub., No. 69/60*, Samsun.

Benli, E., Tekinel, O., Yazar, A., Kanber, R., Çevik, B. (1987). *Ex-Post Evaluation of The Lower Seyhan Project, (Technical Aspects).* FAO Project of TCP/TUR/6652, University of Cukurova, Faculty of Agriculture, Irrigation and Drainage Eng. Dep., Adana

Bilal, A. (1997). *The evaluation of irrigation performances for a drip irrigation system in a citrus orchard in Adana-Yakapınar district*. MSc Thesis, Univ. of Çukurova, Institute of Science, Agric. Structure and Irrigation Dep. Adana, 62 p

Booher, L.J. (1974). *Surface Irrigation*, *FAO United Nations*, Development Paper, No. 95, Rome.

Bulut, İ., Çakmak, B. (2001). Comparison of Pre and Post Transfers of Irrigation System performance in Mersin Irrigation. *Tarim Bilimleri Derg.* Ankara, 7(3): 58-65

Cuenca, R. H., (1989). *Irrigation System Design: An Engineering Approach*. Prentice Hall, Englewood Cliffs, New Jersey: 552p.

Çakmak, B. (2001). The irrigation performance evaluation of Konya irrigation associations. *Tarim Bilimleri Dergisi*, 7(3): 111-117

Değirmenci, et. al., (2003). Assessment of Irrigation Schemes with Comparative Indicators in the Southeastern Anatolia Project. *Turk J. Agric. Forest.* 27: 293-303

DSI (2001). *Evaluation Report on Irrigation Schemes Operated or Transferred By DSI.* General Directorate of State Hydraulic Works (DSI), Ankara.

Ertaş, M.R. (1980). Evaluation of Water Conveyance losses and Water Application Efficiencies in Konya Irrigation Scheme. *Konya Res. Inst.,* No. 67/R, Konya, 53p

Ertek, A., (1998). *Possibility of Irrigation of Cotton by Drip System* (in Turkish). Çukurova University, Institute of Science, Irrigation and Drainage Eng. Dept. PhD thesis, Adana, 140p

Essafi, B., (1995). Farm Water Management: Technical Aspects. *In Advanced short course on: Farm Water Management: Socio-economic and environmental aspects. Comp. by A. Hamdy.*" June 4-18,1995. Adana, p. 1-28

FNCI (2001). First National Congress of Irrigation (FNCI) (2001), *Kulturteknik Dernegi*, Ankara, p. 82-92

GDRS (2003). *Soil and Water Resources of Turkey and Erosion*. General Directorate of Rural Service (GDRS). Ankara.

Gözen, V., Hakgören, F. (2000). Problems and Solution Proposals of the Planning of the Drip Irrigation Systems Used In Greenhouses In Antalya-Kumluca Region. (in Turkish) *Akdeniz Üniversitesi Ziraat Fakültesi Dergisi*, 13(2):145-158

James, L.G. (1988). *Principles of Farm Irrigation System Design*. John Wiley and Sons. Inc., New York, 543 p.

Kadayıfçılar, A., Oğuz, M., Kodal, S. (1998). Sprinkler Irrigation Applications in Nevşehir, Derinkuyu and Kaymaklı Region. *Tarım Bilimleri Derg.,* 4(3):15-23

Kanber, R., (Ed.). (1982). Water Consumption of Irrigated Crops in Turkey. Köyişleri ve Kooperatifler Bakanlığı, *TOPRAKSU Genel Müdürülüğü, Araşt. Daire Başkanlığı,* Yay. No. 35, Rehber, No. 5, Genel Yay. No. 718, Ankara, 630p

Kanber, R., Önder, S, Ünlü, M., Köksal, H., Özekici, B., Sezen; S. M., Yazar, A., and Koç, K. (1996). *The Optimizition of Surface Irrigaition Methods Which are Used For Cotton Production and Their Comparision witt Sprinkler Irrigation*. Final Report for Prime Ministry of Turkey, GAP-RDA, No: 18, GAP Pub., No: 96, General No: 155, Adana, Kanber, R., Köksal, H., Önder, S., Kapur, S., Sahan, S. (2001). Comparison of Surge and Continuous Furrow Methods For Cotton In The Harran Plain. *Agric. Water Manage.* 47:119-135

Kay, M. (1989). *Surface Irrigation*. Cranfıeld Press, Oxford, 139 p.

Koç, C. (2001). Performance of Water User Associations in the Management-Operation and Maintenance of Great Menderes Basin Irrigation Network. *1st National Irrigation Congress,* 08-11 November, 2001 Antalya, p. 71-76

Koç, C. (2003). Measurement and Evaluation of Performance Management-operation and Maintenance of Great Menderes Basin Irrigation Network in Before and After Turnover. *Third National Irrigation Congress,* 16-19 November, 2003 Aydın, p. 484-492

Merriam, J.L. (1965). A Management Control Concept for Determining the Economical Frequency of Irrigation. *AASE Annual Meeting,* Paper No.65-206:1-10

Merriam, J.L., Shearer, M. N., Burt, C.M. (1980). Evaluating Irrigation Systems. In *Design and Operation of Farm Irrigation Systems*. Ed. M.E. Jensen, ASAE Monograph No. 3, Chap. 17, St Joseph, MI, pp. 721-760

Molden, D.J., Sakthivadivel, R., Perry, C.J., and de Fraiture, C. (1998). Indicators for Comparing The Performance Of Irrigated Agriculture Systems. *IWMI Research Report* 20, 26p

Oğuzer, V., Yılmaz, E. (1991). Damla Sulama Sistemlerinde Kullanılan Yerli ve Yabancı Kökenli Bazı Damlatıcıların Hidrolik Özellikleri Üzerine Bir Çalışma. *Doğa-Tr. J. of Agricultural and Forestry,* No: 15, 121-128

Oğuzer, V., Önder, S. (1988). Urfa-Harran Ovası Koşullarında Soya Bitkisinin Karık ve Yağmurlama Sulama Yöntemlerinin Proje Ölçütlerinin İrdelenmesi. *3. Kültürteknik Kongresi,* 20-23 Eylül 1988, No: 1, Adana, p. 273-284

Öğretir, K. (1981). Water Conveyance Losses and Water application Efficiencies in the Çifteler Irrigation Network. Topraksu Araşt. Enst. Yay, No. 165/124, Eskişehir, 20p

Öğretir, K., Beyribey, M. (1997). The Evaluation of Irrigation System Performances of Eskişehir Irrigation Scheme. *Eskişehir Res. Inst.* 34p

Önder, S.,Kanber, R., Köksal, K. (1992). Different Approaches which are used for obtaining the performance of Furrow irrigation methods*. Fourth International Congress on Irrigation and Drainage Eng. (Kültürteknik),* 24-26/6/1992. Erzurum,

Önder, S. (1994). *Comparison of Surge And Continuous Furrow Flows Under Çukurova Conditions*. Çukurova University, Institute of Science, Irrigation and Drainage Eng. Dept. PhD thesis, Adana, 273p

Oylukan, Ş. (1970). The Obtaining of Irrigation Efficiencies for Eskişehir-Alpu Irrigation Scheme. *Eskişehir Res. Inst.* No. 67/R, Eskişehir, 40p

Oylukan, Ş., (1972). Seepage losses from the canals of irrigation scheme in Eskişehir-Alpu and Its Effect on The Ground Water Level. *Eskişehir Res. Inst.* No. 96, 87/R, Eskişehir, 57p

Söğüt, A. (1986). Irrigation Performance of Drip Irrigation Systems which are Used for Orchard Irrigation. MSc Thesis, Univ. of Çukurova, Institute of Science, Agric. Structure and Irrigation Dep. Adana, 51 p

SPO (2001). 8th *Five-Year Development Plan*. Report by the Special Commission on Water Basins and Management, *SPO*, Ankara.

Şimşek, H. (1992). A Study on the Field Irrigation Efficiencies in the Niğde-Misli Plain. *Proc. Of IV. National Congre for Agric. Struc. And Irrigation,* 24-26 Haziran 1992, Erzurum. p.161-174

Tarı, A.F. (1998). The Evaluation of Performances of Sprinkler Irrigation Systems Used in Konya-Ilgın Plain. T.C. Tarım ve Köy İşleri Bakanlığı Köy Hizmetleri Genel Müdürlüğü APK Dairesi Başkanlığı Toprak ve Su Kaynakları Araştırma Şube Müdürlüğü, Ankara, p. 220-238,

Thompson, G. T., Spiess, L.B., Krider, J.N. (1980). Farm Resources and System Selection. In *Design and Operation of Farm Irrigation Systems*. Ed. M.E. Jensen. ASAE Monograph. No. 3, Chap., 3, St Joseph, MI, pp. 45-73

Uçar, A. (1994). *Evaluation on the Performance of Mini-Sprinkler That Is Established In an Orchard At The Çukurova Region*. MSc Thesis, Univ. of Çukurova, Institute of Science, Agric. Structure and Irrigation Dep. Adana, 62 p

Yavuz, M.Y. (1993). *The Effects of Different Irrigation Methods on the Yield and Evapotranspiration of Cotton*. University of Çujurova, Institute of Science, Irrigation and Drainage Eng. Dep. PhD thesis, Adana, 196 p.

Yazar, A.,Oğuzer, V., Alagöz, T., Diker, K., and Gencoglan, C. (1990). Performance Of A Traveling Hose-Reel Sprinkler Machine Under Various Operation Conditions. *Doga, Tr. J. of Agric. and Forestry,* 14:352-359

Yazgan, S., Değirmenci, H. (2002). Efficiency Indicators in Irrigation Projects' Performance Evaluation: A Case Study on Bursa Groundwater Irrigation Project. *Turk J. Agric. Forest.* 26:93-99

Yıldırım, O., Orta, H.A. (1993). Evaluation Of Some Drip Irrigation Systems In Antalya Region. *Doga, Tr. J. of Agric. and forestry,* 17:499-509

Yıldırım, Y.E., Kodal, S. (1990). Comparison of Sprinkler and Surface Irrigation Systems in Konya-Yunak-Gölpınar Irrigation Ptoject. *Doğa, Tr. J. Of Agric. And Forestry,* 14:534-542