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WATER USE EFFICIENCY AND WATER PRODUCTIVITY IN GREECE

A. Karamanos*, S. Aggelides, P. Londra****
* Laboratory of Crop Production. Agricultural University of Athens, 75 Iera Odos, 11855 Botanicos, Greece. E-mail: akaram@aua.gr
** Laboratory of Agricultural Hydraulics. Agricultural University of Athens, 75 Iera Odos, 11855 Botanicos, Greece. E-mails: ags@aua.gr and v.londra@aua.gr

SUMMARY – This work presents a summary on water resource availability in Greece with an emphasis on irrigation water use since about 85% of water withdrawal is for agricultural purposes. Irrigation methods, crop water requirements, crop production and crop water productivity data are elaborated are discussed. The state of art of research and agricultural activity as related to Water Use Efficiency (WUE) and Water Productivity (WP) in Greece is analyzed by means of: the hydrological aspects and agronomic management strategies, the eco-physiological aspects and sustainability including social, economic, environmental and political measures. Furthermore, the initiatives and activities to improve Water Use Efficiency and to increase food production by using less water are reported.

Key words: irrigation, water use efficiency, crop production.

INTRODUCTION

Greece has a population of about 11,000,000 and occupies an area of 131,962 Km^2. The types of land use are:

a. Arable 30%
b. Forest 19%
c. Pastures 43,4%
d. Others 7,6%

The cultivated area is 34,638 Km^2 out of the total arable area of 38,986 Km^2. The irrigated land occupies 14,305 Km^2 with the following percentage of cultivations (National Statistical Service of Greece, 2001):

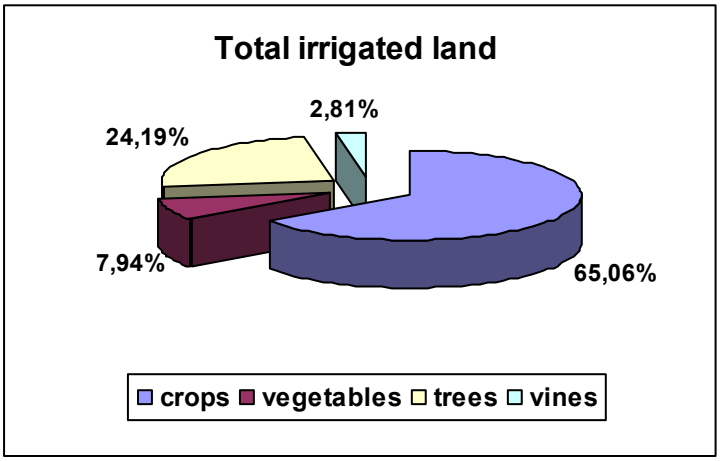

Fig. 1. Total irrigated land: percentage of cultivation

The climate is typically Mediterranean with all the subtypes of Mediterranean climate due to topographical relief, from the warm and dry type (e.g. Cyclades) to the alpine type (mountainous areas above 1500 m).

The annual precipitation ranges from 400 mm in Athens and Cyclades islands to more than 1500 mm in the high mountainous areas with values of 700 mm in Eastern Greece and 1000-1200 mm in Western Greece and the Ionian islands.

The total annual precipitation is estimated to be 116,689 hm^3 with 50.9% (59,371 hm^3) and 31.9% (37,190 hm^3) to be lost by evaporation and runoff respectively and only 17.2% (20,133 hm^3) infiltrated into soils. The total water consumption was estimated at 5,500 hm^3/year increasing by more than 3% annually (Ministry of Development, 2002).

The major water use in Greece is for agricultural purposes (85%) whereas the domestic and industrial uses are 13% and 2% respectively. The increased demand for water cannot always be met despite adequate precipitation. Water imbalance is often experienced, especially in the coastal and south-eastern regions, due to the temporal and spatial variations of precipitation. This results from the increased water demand during the summer months and the difficulty of transporting water due to the mountainous terrain.

The irrigation methods used in Greece are surface, sprinkler and drip irrigation. The general trend is to abandon gradually surface irrigation and move on to more efficient methods like the sprinkler and drip irrigation (Fig. 2).

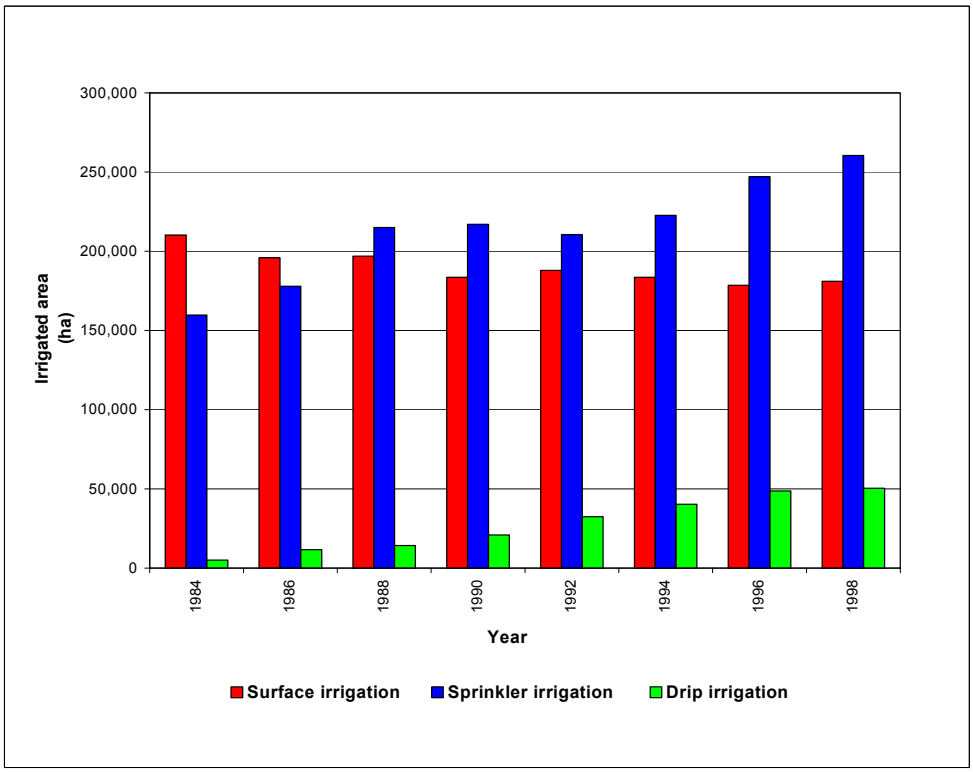

Fig.2. The trends of irrigation methods used in common reclamation works

It is accepted that the water application efficiencies for surface, sprinkler and drip irrigation are 75%, 85% and 90% respectively. The water conveyance and distribution efficiency is 70%, 85% and 95% for transportation of water with earthen, concrete channels and pipelines respectively (Ministry of Agriculture, Land Reclamation Service, 1991).

The amounts of annual reference evapotranspiration (ETo) have been calculated in national level and ranged from 1058 mm in Northern Greece up to 2015 mm in the arid and semiarid zone of South-eastern Greece.

The irrigation requirements depend on the crop and the local soil-climatic conditions and they reach 170 mm for vines in the temperate regions of Northern Greece (Thessaloniki) and 440 mm for maize in the warm and wet regions of Southern Greece (Pyrgos) (Ministry of Agriculture, 1990).

To meet these requirements, irrigation has been extended (irrigation covers 40% of the total cultivated area) under common reclamation works and private irrigation systems. The water sources used differ between public and private networks. The public networks mainly use surface water, while the private ones use underground water.

The maximum calculated crop water requirements reach a value of 4,089 Km^3 of water and the actual water use is 6,833 Km^3. This means that the Total Water Use Efficiency is 60%. This low value is due to a poor land levelling, the aged water distribution systems, the high percentage of surface irrigation systems and transportation and distribution of water (Tsanis et al., 1996).

In Greece, there are values of crop water productivity in terms of crop production (kg) in relation to the volume (m^3) of water used. These values come from irrigation experiments conducted in several parts of the country on behalf of the Ministry of Agriculture. The values given below are a representative selection and refer to "good" years, i.e. in seasons when crops gave the best production for the region (Ministry of Agriculture, 1990).

Table 1. Crop production, water use and crop water productivity in Greece (Source: Ministry of Agriculture, 1990)

Crop	*Production* (kg/ha)	*Cubic meters of water used for actual evapotranspiration-ETc* (m^3/ha)	*Crop water productivity* (kg/ m^3)
Maize	12000	4980	2.41
Cotton (not ginned)	3550	4500	0.79
Industrial tomato	97000	3900	24.87
Watermelons	43000	3570	12.04
Vines	14800	1850	8.00
Potatoes	30000	4800	6.25
Lettuce	36000	4600	7.82

WATER USE EFFICIENCY AND WATER PRODUCTIVITY

The state of research and agricultural activity as related to Water Use Efficiency (WUE) and Water Productivity (WP) in Greece can be focused in the following three aspects:

- The hydrological aspects and agronomic management strategies of WUE and WP.
- The eco-physiological aspects of WUE and WP.
- Sustainability and economic aspects of WUE and WP.

The hydrological and agronomic management aspects of WUE and WP

- Agricultural and irrigation engineers facing the problem of rational irrigation planning, rarely have at their disposal extensive information on soil-plant-atmosphere system. Therefore, there is demand for simpler approaches to estimate actual evapotranspiration. The attempts that have been made in Greece related to the above issue are:

✓ The crop coefficient (Kc) for sweet shorgum was estimated under the conditions of Biotia area (Dercas et al., 1996).

✓ Poulovassilis et al. (1998) compared the estimated heat flux densities obtained through the various methods used with actual heat flux densities, as these are measured into the soil profiles. The comparison was encouraging and therefore heat flux densities calculation methods may be used for following heat flow into the soil profile.

- ✓ Another attempt to help rational irrigation planning was made by Anadranistakis et al. (1999a), who estimated actual and maximum evapotranspiration for neutral instead of actual atmospheric stability, employing a model based on the equation of Shuttleworth and Wallace (1985).
- ✓ Anadranistakis et al. (2000) investigated two parametarizations of the aerodynamic resistance control vapor transfer and they have applied to an evapotranspiration estimating model in order to find out their effect on the estimated (separate) values of transpiration and evaporation throughout the biological cycle of a crop.
- ✓ A semi-empirical approach was proposed for estimating actual water losses from crops (cotton, wheat and maize) assuming that the ratio of actual to maximum evapotranspiration (ET/ETm) is an exponential function of the water content in the root zone (Poulovassilis et al., 2001).
- ✓ Spanomitsios and Paraskevopoulou-Parousi (2001) showed that the comparison of strawberry plant transpiration rates with a linear equation of transpiration rate and the simplified form of Penman-Monteith equation agreed well with the last equation.

- Furthermore several attempts have been made by studying the reference evapotranspiration equations under the arid and semi-arid conditions in Greece.

- ✓ The results of the comparative evaluation of reference evapotranspiration estimated according to seven different versions of the Penman method were presented. The Penman 1963 VPD#3 was considered as the most reliable for the climatic conditions of Copais (Greece) (Poulovassilis et al., 1996).
- ✓ An attempt was made to estimate the wind function parameters, entering the aerodynamic term of Penman equation for hourly evapotranspiration estimates. Useful results were obtained concerning the possibility of using the Penman equation in estimating hourly or daily reference evapotranspiration (Kerkides et al., 1997).
- ✓ The establishment of a relationship between G/RN and L both for day and night was attempted during the development of a wheat crop, under varying soil moisture regimes (Anadranistakis et al., 1997).
- ✓ An attempt was made to estimate the wind function parameters entering the aerodynamic term of Penman equation for hourly evapotranspiration estimates. Useful results were obtained concerning the possibility of using the Penman equation in estimating hourly or daily reference evapotranspiration (Kerkides et al., 1999).
- ✓ The Penman-Monteith method for estimating reference evapotranspiration (ETo) is considered as the most reliable. Using measurements from the Copais (Greece) area, the expression of Rn as a function of Rs and of Rs as a function of the daily sunshine duration (n) is attempted, considering that G is a portion of Rn. Then ETo is calculated both with measured and estimated Rn. The comparison of the corresponding ETo values was proved satisfactory (Alexandris, 2000).
- ✓ A new empirical equation for estimating hourly reference evapotranspiration ETo is proposed. For the calibration of the proposed model, data collected from Copais (Greece) and from CIMIS equation (Davis Sacramento, CA) were used (Alexandris and Kerkides, 2003).

- For an appropriate irrigation scheduling, the atmospheric demand for water vapor, the soil characteristics and the plant specific features, i.e. the soil-plant-atmosphere continuum as a dynamic system, should be considered. In semi arid regions, such as Greece, rainfall is unevenly distributed over the year. More than 80% of the mean annual precipitation falls during the months October-February. Meanwhile during the dry seasons of spring and summer tourist mobility is at its peak, exercising a substantial pressure on good quality water reserves. The fact that irrigation is also required mostly in spring and summer means that water allocation and water use efficiency are very important. It is therefore necessary to develop models to conveniently estimate actual Crop Water Requirements.
  For the Mediterranean countries the future challenge will be the increase in food production using less water. In Greece many attempts has been made to this direction. Some of them are:

- ✓ Louizakis (1994) estimated the water requirements and water productivity for tobacco in Greece.

- ✓ Crop water requirements were determined using the Penman-Monteith method with climatic data from meteorological stations in Greece and the USDA method. It was found that the total irrigation requirements for Greece for the year 1991 were ranged from 3073 to 4069 Mm3/yr (Tsanis et al., 1996).
- ✓ A relationship between maize yield and water consumption has been developed in Thessaloniki plain during a four year experiment. Maximum yield was attained when the depth of applied water ranged from 700 to 900 mm (Panoras et al., 1997a).
- ✓ The same relationship in the same place but for winter wheat (cv. Yecora) was established after a five year experiment. It has been shown that maximum yield was attained when the amount of applied water ranged from 400 to 500 mm and the best application time of water was the second and the third critical stage of the winter wheat (Panoras et al., 1997b).
- ✓ Water productivity and water requirements were studied for cotton (cvs Zeta-Z and Korina) in Central Greece for the year 1997 (Polychronidis, 1998).
- ✓ Anadranistakis et al. (1999b) represented a model for estimating crop water requirements throughout crop development. The model has been validated with meteorological and crop data collected from experimental fields of the Agricultural University of Athens. The results taken from three crops (cotton, wheat and maize) against soil moisture profile changes were very satisfactory. The agreement between observed and estimated evapotranspiration was within 8%.
- ✓ Crop water requirements were studied for sorghum during a two-year experiment in Central Greece (Dercas and Liakatas, 1999).
- ✓ An estimation of the total water requirements in the Prefecture of Larissa irrigated both by private and public boreholes and by surface waters during the year 1999 by using FAO Penman-Monteith method was carried out (Sakellariou-Markantonaki and Vagenas, 2003).

- Saving irrigation water in arid and semiarid zones where there is scarcity of water is a demand of major priority. The method of irrigation ultimately chosen must be the best as far as the water use efficiency is concerned. The water related efficiencies from water conveyance, storage, distribution and application must be high. Some works related to this subject are:

- ✓ Water use efficiency was studied under the soil-plant-atmosphere conditions of Greece by Poulovassilis et al. (1991) and they proposed measures to increase it.
- ✓ Papamichail and Papadimos (1996) studied the water use efficiency for graded border irrigation.
- ✓ The same authors (Papamichail and Papadimos, 1996) studied the water use efficiency for furrow irrigation used for irrigation.
- ✓ Ampas (1998) studied the irrigation efficiency in furrows used for row crops. He found that the calculation of inflow rate at each time step maximizes the application efficiency.
- ✓ Mayropoulos (2001) studied water use efficiency and he recommended several measures at technical, economic and legislation level.

The eco-physiological aspect of WUE and WP

- Here there are some aspects of the actual situation of research and agricultural practices concerning crop water productivity in Greece.

- ✓ The water productivity of potatoes was studied experimentally in the region of Attika and it was found to be 6.25 kg/m3 (Aggelides et al., 1984).
- ✓ The water productivity of vine (Cardinal) was studied experimentally in the region of Attika and it was found to be 8.0 kg/m3 (Panagiotou and Aggelides, 1987).
- ✓ Poulovassilis et al. (1993a) studied the crop water productivity reduction due to irrigation with brackish groundwater.
- ✓ The crop water productivity of sweet sorghum was experimentally studied in Copais area with a high water table. Results showed a high crop water productivity due to the small amount of irrigation water Dercas et al., 1994).

- ✓ The crop water productivity of sweet sorghum was studied in relation to plant density (Dalianis et al., 1996). It was found that decreasing plant density increased water productivity.
- ✓ The water productivity of winter wheat (cv. Yecora E) was studied in the plain of Thessaloniki and it was found that the maximum yield was attained when the amount of applied water ranged from 400 to 500 mm (Panoras et al., 1997).
- ✓ Crop water productivity and water use efficiency were studied for sweet sorghum (cv. Keller) by Dercas et al. (1998). They found a good relationship between dry matter yield and the quantity of applied water.
- ✓ The water productivity of cotton was studied and compared with water consumption (evapotranspiration, ET), simulated by GOSSYM, a simulation model of cotton growth and yield (Gertsis et al., 1998).
- ✓ The water productivity of lettuce was studied in the area of Achaia (Peloponnese) and it was found to be 7.82 kg/m3 (Aggelides et al., 1999).
- ✓ The water productivity of two varieties of sweet sorghum (cvs Keller and MN 1500) was studied after two-year experiments in Boeotia. Drip irrigation was applied. The water productivity was very high (Dercas et al., 2000).
- ✓ Water productivity of Medicago sativa studied by Lazaridou and Noitsakis (2002) in pure and mixed crop grown with grass. It was found that water productivity exhibited higher values during early spring in relation to the measurements of the remaining period and in the mixed crops despite their smaller productivity compared with pure crop.
- ✓ Fisarakis (2002) studied the reduction of growth observed at relatively low salinities, often before the appearance of visible symptoms. The unfavorable effects of salinity on grapevines were increasing as the level of salinity increased and were demonstrated in terms of a reduced plant growth, bunch number, berry size and yield.

Sustainability and economic aspects of WUE and WP

- This issue contains social, economic, environmental and political measures that add additional importance to the sustainability of agricultural production. Some of these works are:

- ✓ Poulovassilis et al. (1993b), studying sea water intrusion in the area of Irria (East Peloponnese), found the same results as in the case of Argolis.
- ✓ Poulovassilis et al. (1994), studying sea water intrusion in the area of Argolis, showed that the salinity status of the soil is correlated with that of the ground water used for irrigation and that both of them affect adversely crop yields according to their sensitivity.
- ✓ A comprehensive study has been undertaken for in Argolis (Peloponnese) in an attempt to identify the factors which caused soil degradation due to salinity and to promote remedial measures (Poulovassilis et al., 1996).
- ✓ This study presents the climate change, the water availability, the crop water requirements, the improvement of water use efficiency and the necessity of high priority in water resources policy (Chartzoulakis et al., 1997).
- ✓ Mimides et al. (1997) studied ground water degradation due to the sea intrusion in the region of Irria (East Peloponnese). Various softwares such as SURFER, MINEQL and DUROV diagram were utilized.
- ✓ The plain of Argos in Southern Greece was investigated for sea water intrusion, ground water pollution and the suitability of ground water for irrigation purposes (Alexandris et al., 1998).
- ✓ An attempt was made to assess the effect of irrigating tomatoes with saline water in a greenhouse (Kerkides et al., 1998).
- ✓ The influence of low quality irrigation water to agricultural production was studied by Giannoulopoulos et al. (2002).
- ✓ Kountouras and van Leeuwen (2002) studied the environmental effects on grapevine grown in the Nemea region and especially a) the vine water status and physiological parameters and b) vegetative growth, fruit ripening and yield.
- ✓ An initiative for Mediterranean water policy is presented to overcome water competition between agriculture and tourism in Cyclades and especially in Naxos island (Epp et al., 2003).

- ✓ Chartzoulakis and Psarras (2005) studied the current trends and predictions for the future climate changes in the area of Crete and discuss the factors that will most probably limit or enhance photosynthesis and productivity of the most important tree crops in a semi-arid Mediterranean environment.

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