ELSEVIER

Water Policy 3 (2001) 193–205

Water Policy

www.waterpolicy.net

Water resources management in the Island of Crete, Greece, with emphasis on the agricultural use

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Received 13 September 2000; received in revised form 21 January 2001; accepted 23 March 2001

Abstract

Crete is considered as a semi-arid region. The average annual precipitation is estimated to be 900 mm, the potential renewable water resources 2650 and the real water used about 485 million m^3/yr. The major water use in Crete is in irrigation for agriculture (84.5% of the total consumption) while domestic use is 12% and other uses 3.5%. Crete shows significant regional variations in water availability, especially in coastal, eastern and southern regions due to tourism and agriculture. It has a relatively high per capita water availability, which is slightly lower than that of the country. The demand for irrigation water is high, while at the same time only 31.0% of the available agricultural land is irrigated. The growing water requirements make the rational management of water resources extremely important for development to be sustainable and for the environment to be served. To overcome the water shortage, especially in the future, several measures should be taken for conservation of water resources and protection of the environment. The integrated water resources management, securing water for the future in Crete, should include measures that are purely technical (increase the use of surface water, improvement of distribution systems and irrigation scheduling, recycling, use of water saving irrigation systems, use of reclaimed, and brackish waters, etc.) and socio-economic (pricing, rationalization, extension, training, etc.).

1. Introduction

The techniques of the practice of drainage and irrigation are probably as old as those of agriculture, although the first recorded examples of drainage and irrigation do not precede the Roman Imperial epoch. There are some indications, however, that these drainage and irrigation practices were known long before the Romans. Drains and/or furrows and trenches, conduits,

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PII: S1366-7017(01)00012-5

water-courses named *αμάραι* are mentioned in Homer (*Iliad*, 259). Thus, the names of the Cretan villages Αμάρι (Amari) and *Νέο Αμάρι* (Neo Amari) in Rethymnon probably originated at a time when drainage and irrigation projects were constructed by the Minoans in that region. However, no traces of such projects have been found today, although Angelakis and Spyridakis (1996) believed that the Minoans had practiced irrigation. They assumed that the main region of agricultural production of that time was the Messara valley where irrigation and reclamation projects would have developed. In addition, according to Marinatos (1927), many of today's agricultural crops such as vegetables, cereals, olives, grapes and aromatic species were grown in Minoan Crete.

In the Neopalatial stage (ca. 1700–1450 BC), irrigation practices were of special significance. During periods of drought, people performed various invocations to the gods for rainfall and there is little doubt that farmers at that time had developed advanced irrigation systems. The best known of these are the so-called "Linies" (from the Latin *linea* = line), located in the Lasithi plateau. Here, numerous channels and ditches were joined to form a huge checker board pattern. This system, with proper maintenance and repair work, was used until modern times by succeeding civilizations on the island. It seems likely that the Minyans, another prehistoric people of Greece like the Minoans, introduced this technology to Orchomenos in central Greece. In fact, traces of it were observed there by British engineers during the reclamation project of Kopais lake in 1886. Thus, Minoan could be considered a pioneer of what we call today drainage and irrigation technologies (Angelakis & Spyridakis, 1996).

According to ancient mythology and other evidence handed down, repeated attempts were made at draining the plain and reclaiming arable land, as early as in prehistoric times and in antiquity. In particular, the legendary Minyans whose center was Orchomenos at the western edge of the plain are said to have been successful in doing so in the Mycenaean period (ca. 1600–1200 BC). In the 19th century, researchers collected such information and formed far-reaching theses but investigations of the historic hydraulic engineering remains on site started only gradually. The rapid development of mechanized agriculture and construction activities in the Kopais increasingly endangered what was left of old hydraulic installations (Lauffer, 1984).

In general, on the basis of our present-day knowledge and experience, the greatest respect must be paid to Minoan engineers for having had the courage to develop such a good water resource infrastructure 4500 yr ago with limited technological means and the scarce scientific knowledge.

Horticultural crops have always been the major agricultural activities in the small and medium-sized farms, especially in the Island of Crete. Usually they make the best use of the available agricultural resources and ensure an adequate income, especially in the small farms. Modern horticulture, based on new and sophisticated techniques, is quite different from that of the past and requires a rational use of its resources, especially of water. The major objective of any irrigation project is to make the required water available to the crops in view of eliminating, or at least reducing the unfavorable effects erratic climatic conditions might have on the crops.

An increasing demand for irrigation imposes a rational use of the increasingly limited water resources. This can be obtained through an advance in the knowledge about crop water requirements and irrigation technology and the diffusion of technical information to the farmers, necessary for obtaining high quality yields. This paper presents a historical development of the irrigation practices through the centuries with emphasis on Minoan civilization. In addition, the major irrigated crops, the crop water requirements, the irrigated areas, the potential for waste water reclamation and reuse and the possibility for improvement of water use efficiency are presented. The overall objective of this paper is to describe briefly the existing conditions and problems of water resources management in Crete, as well as the different measures that should be applied to increase the availability of water and to reduce water pollution.

2. Climate

The impact of climate variations on water management and related socio-economical systems has long been the recipient of the interest of various researchers. In order to be able to predict impacts, once climate change occurs, the principle of "the past is the key to the future" has been adopted.

Although the total amount of water on the Earth is generally assumed to have remained virtually constant during recorded history, periods of flood and drought have challenged the intellect of man to develop the capacity to control the water resources available to him. Currently, the rapid growth of population, together with the extension of irrigation and industrial development, stress the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" methodology either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

2.1. Climate in the past

Several studies on climate variations in the Mediterranean region during the Holocene indicate that its climate was affected during summer by a subtropical high-pressure belt, which resulted in hot and rainless weather conditions. During winter the region is dominated by the mid-latitudinal depressions, connected with the westerlies regime which brings cold weather and rainfall. Studies based on fossil pollen analysis suggest that during the Chalcolithic and the Easrly Bronze Age the climate of Crete was more cold and humid than at present. The occurrence in the cores of numerous species characteristic of Central Europe, such as those of the genera *Betula*, *Fracinus*, *Cotylus*, *Carpinus*, and *Tila* which no longer grow naturally in Crete, provides evidence of a cold and humid period. On the other hand, at the end of the Chalcolithic (ca. 3000) and the Middle Bronze Age (ca. 2100–1600 BC), various pollen diagrams studied, reveal a marked decline in deciduous oak and in sensitive Central European tree pollen, such as those of the species of the genera *Betula* and *Tila* (Angelakis & Spyridakis, 1996).

Similar climatic change scenarios have been reported in Israel. Thus, a humid stage affected Palestine during the Early Bronze Age. This was proved by environmental data, such as ^{18}O and ^{13}C, as well as pollen of olive and oak trees in a core in the Sea of Galilee, records of Dead Sea levels and the level of the Nile, and of course the settlement of man in the desert. A humid stage in this region was indicated again during the end of the Late Minoan and the Iron Ages (Issar, 1995).

In this pattern, Paepe (1984), Issar and Makover-Levin (1996) and Issar (1995) concluded the followings: (a) A humid and, most probably, a cold period existed during the Chalcolithic Period (ca. 4500–3000 BC), except for its final year when the climate became warm and dry. (b) A short warm period of the Upper Chalcolithic prevailed around 3000 BC. (c) A cold and humid period existed during most of the Early Bronze Period (ca. 3000–2200 BC). (d) A warm period commenced around 2200 BC (Middle Bronze VI) and extended to around 1500 BC. (e) From ca. 1500 to 600 BC (the Iron Age) there was another cold and humid period. (f) From ca. 600 to 300 BC (mainly during classical and Hellenistic times) the climate was rather warm and dry. (g) During the Roman period a colder and more humid period prevailed. (h) Finally, a warm and dry climate prevailed during the Arab period and reached a peak of high temperatures and drought ca. 800–1000 AD (Fig. 1).

Although little is known of the Early Minoan world, extant evidence points to a sustained cultural growth in this period of Crete's past. Notice that this cultural flowering occurred during cold and humid periods. Thus, the Minoan is universally considered to be one of the grandest and most brilliant of all ancient civilizations. Typical concerns in the construction of the principal Minoan centers appear to be the architectural and hydraulic function of stormwater and wastewater sewerage systems. These coincide with a cold and humid period prevalent at that time. Thus, it is not by chance that the main technical and hydraulic operations associated with catchment basins, surge chambers, manholes, urinals and toilets, laundry slabs and basins and sewerage systems, including disposal sites of the effluent, have been practiced in varying forms since ca. 3000 BC (Angelakis & Spyridakis, 1996).

2.2. Present climate

The present climate of Crete is sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers. The annual rainfall ranges from 300 to 700 mm in the low areas and along the coast (Ierapetra 312 mm, Iraklio 512 mm, and Chania 665 mm), and from 700 to 1000 mm in the plains of the mainland, while in the mountainous areas it reaches up to 2000 mm. Such great climatological differences are due to the complex vertical and horizontal distribution of Crete. During winter that starts in November, the weather is instabilized due to frequent changes from low to high pressures. Precipitation was significantly decreased in the last 20 years in the Messara valley. A reduction in rainfall has occurred in the last two decades in the valley. However, long series rainfall data all over Crete does not show any significant change in precipitation (Markou-Iakovaki, 1979; Macheras & Koliva-Machera, 1990).

Despite considerable high precipitation (600 mm in the plains and 2000 mm in the mountains). It is estimated that from the total precipitation in plains per year about 65% is lost to evapotranspiration, 21% as runoff to sea and only 14% goes to recharging the groundwater. The rainfall is not uniformly distributed throughout the year, and it is mainly concentrated in the winter months while the drought period is extended to more than six months (May to October) with the Class A pan evaporation values ranging from 140 to more than 310 mm in the peak month (Fig. 2).

As noticed, more than one-third of the total precipitation occurs along the northern coast of the island in the three main mountainous terrains (White mountain, Idi, and Dikti). These three mountains extend over an area of 1900 km^2 and consist mainly of limestone masses intensely kasrtic as shown in Fig. 3.

Spring is short because of the cold fronts often affecting the region in March, whereas May is rather warm especially due to the appearance of the first south winds and the disappearance of the

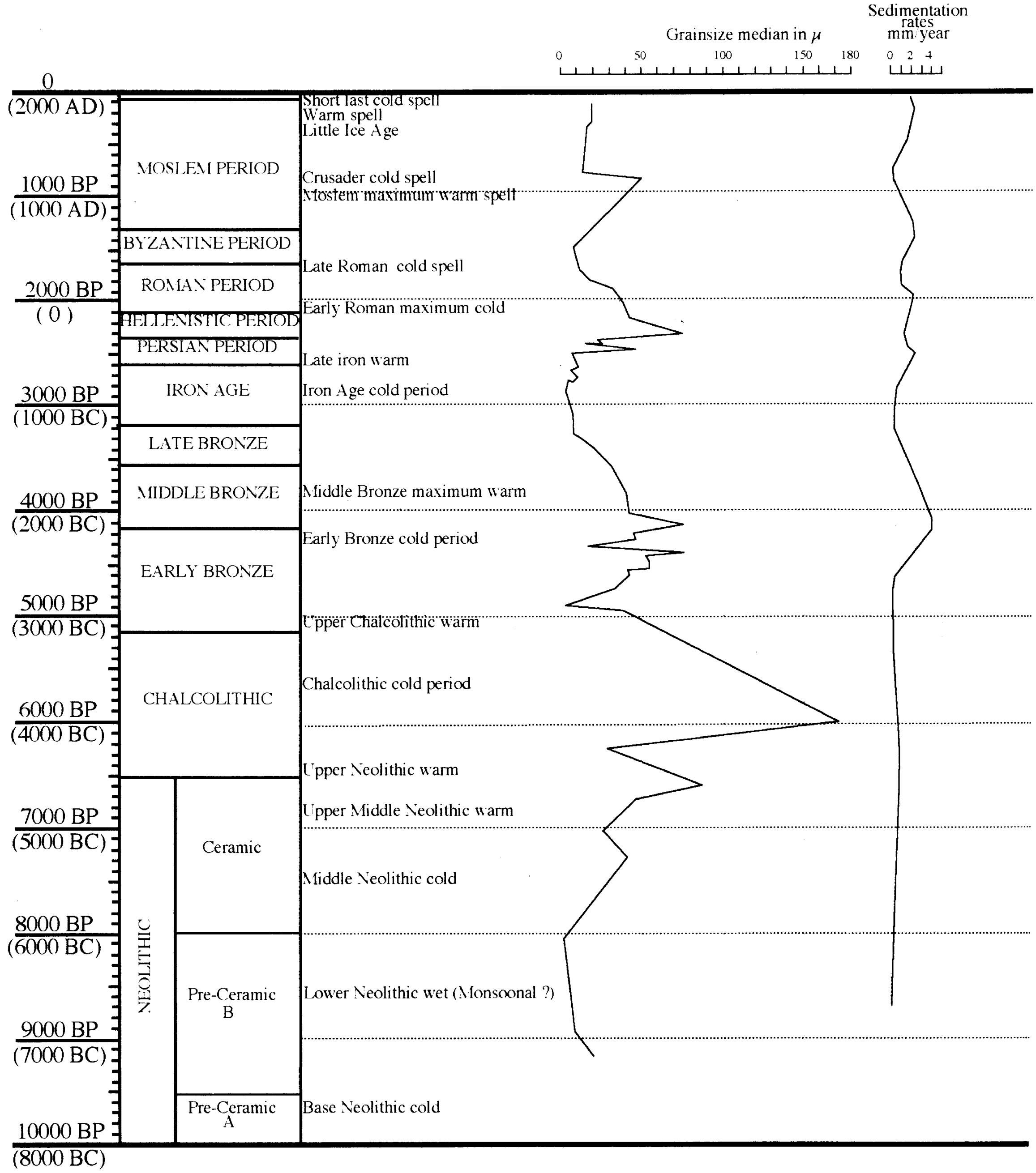

Fig. 1. Correlation between sedimentation sections in Greece (Paepe, 1984).

action of low pressures. North winds are dominant in the island. In summer, the north winds predominate creating very dry conditions, which are also enhanced by the diminishing of low pressures in the Eastern Mediterranean and is only interrupted by some local rainfall of tropical

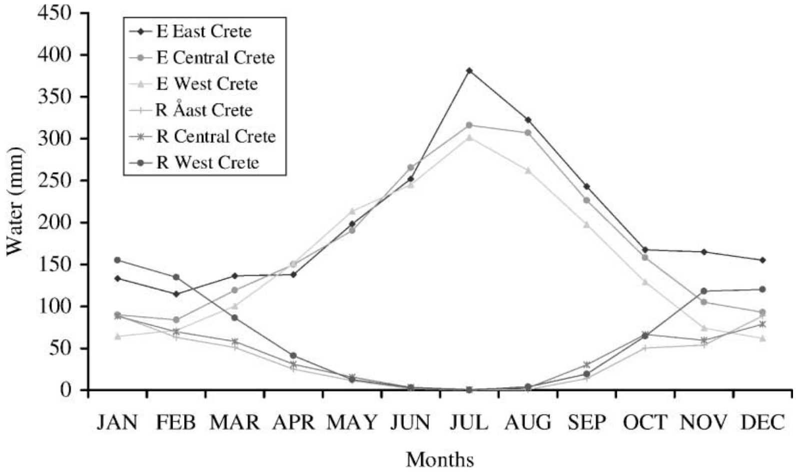

Fig. 2. Average rainfall and evaporation class a-pan in Crete (Chartzoulakis, Angelakis, & Skylourakis, 1997).

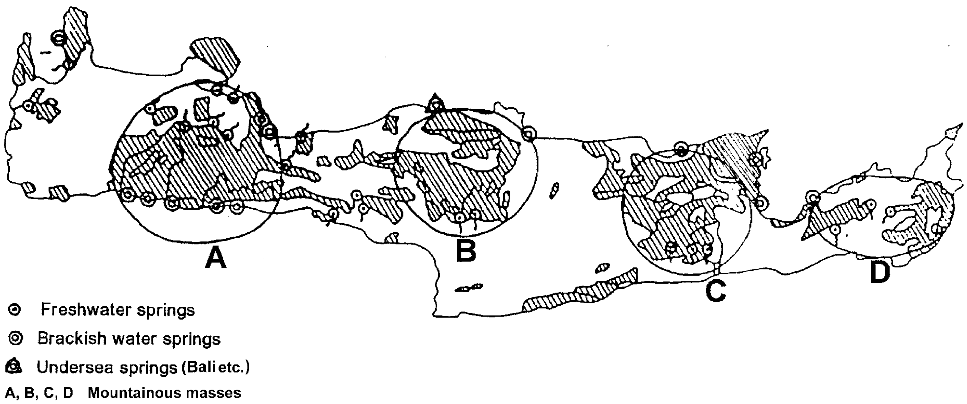

Fig. 3. Map of the main carbonate rocks of Crete with the main karstic springs (A = White Mountains, B = Idi, C = Dikti, and D = Sitia).

origin. Heat waves in the plains during summer may be rather lasting, affected by south winds blowing from Africa. The temperature of the area shows a great variation. Crete lies between the isotherms 18.5–19°C with an annual latitude of 14–15°C. The southern part of the island is warmer than the northern part and the warmest of Greece. During the cold period, temperature increases with decreasing latitude, whereas in the warm period and especially in the period from May to August, temperature increases from the coast to the mainland and particularly in the plains. In winter, the lowest temperatures scarcely fall below 0°C in the plains. During the summer, temperatures greater than 40°C may occur in the lowlands of Crete. The annual temperature has increased in the last two decades by 0.3°C (Angelakis, Cosmas, & Monopolis, 1997).

3. Water resources availability in Crete

The area of Crete is 8336 km^2, the mean altitude 460 m and the total population about 600,000 people. The average annual precipitation is estimated to be 7500, the potential renewable water resources 2650 and the real water used about 485 million m^3/yr (Department of Industry, Energy, and Technology, 1989). It is clear that water consumption constitute only a small percentage, less than 10 and 20% of the annual precipitation and water potential respectively. Although the contribution of the surface water to the potential water resources is about 40% (Fig. 4), the real contribution is about 13%, which means that almost all the water quantity used in Crete comes from subterranean sources (springs, wells, and boreholes).

The major water use in Crete is in irrigation for agriculture (84.5% of the total consumption) while domestic use is 12% and industrial use only 3.5% (mainly for olive extraction plants, packaging plants, livestock, and water bottling companies). Another sector related to water use is tourism (domestic and international), an important economic activity in Crete, which is still significantly increasing. The total number of tourists in Crete in 1999 exceeded two millions, and this number may double in 2025. The tourism industry requires huge quantities of water supply, with peak consumption during the high season and excess capacity in the low season. Furthermore, most of the tourists come from northern European humid cultures and are not prepared to encounter water scarcity.

It should be noted that water availability in average terms is not the limiting factor. Much more important are the significant regional and seasonal variations which Crete shows in water availability and demand. About 70–80% of annual rainfall occurs in three to four months, while summers are usually long and dry. This situation is further worsened by a seasonal and regional variation in water demand. Both agriculture and tourism require increased supplies in late spring, summer, and early autumn, when water is less abundant. Also, domestic use of water increases during dry and hot periods. On the average, Crete has a relatively high per capita water availability, i.e. around 4800 m^3/inh yr, which is lower than that of Greece (6700 m^3/inh yr). However, this value is much higher than that of other Mediterranean regions. For instance, there

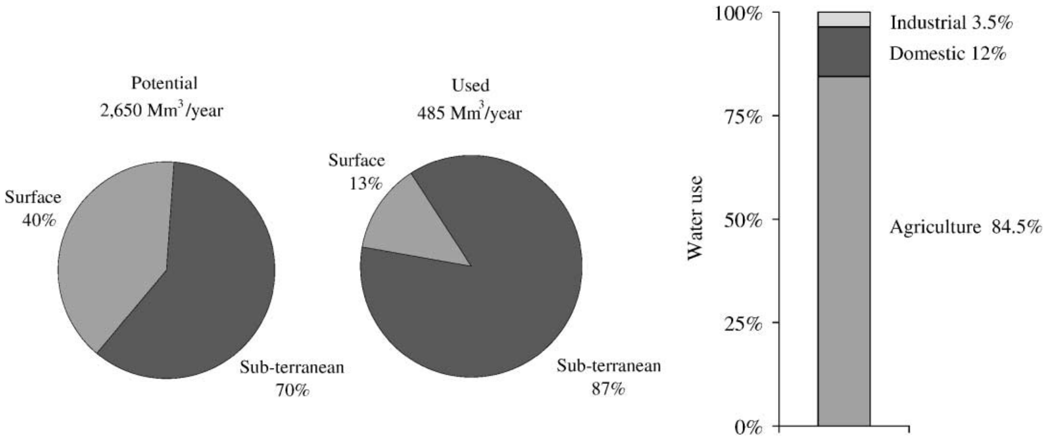

Fig. 4. Water availability and use in the Island of Crete.

are Mediterranean islands with a per capita availability of less than 1500 m^3/inh yr, such as: Cyprus 1285, Balearic islands 500 and Malta 85 m^3/inh yr (Marecos do Monte, Angelakis, & Asano, 1996).

The uneven atmospheric precipitation (spacially and regionally), the continued growth of the population, the rapid growth of the tourist industry and the periodic droughts have forced water services and other water agencies to search for new and reliable water sources. The use of reclaimed or recycled wastewater for various non-potable uses has proved to be the most reliable of sources, like in most Mediterranean countries (Angelakis & Diamadopoulos, 1995). In Crete, it is estimated that, at present, more than 100,000 m^3/d of secondary treated wastewater effluent is produced. Thus, it has been calculated that by reusing the treated effluent of today's existing plants, a 5.3% increase of irrigated area can be obtained (Tsagarakis, Tsoumanis, Chartzoulakis, & Angelakis, 2001). This is related to the availability of nearby agricultural areas and assumes that the relevant infrastructure, like storage reservoirs and distribution systems will be available.

4. Irrigation of horticultural crops

The main groups of crops and the surfaces covered in Crete are shown in the Table 1. The main vegetable crops grown in Crete are fresh tomatoes, cucumbers, potatoes, eggplants, onions, watermelons, melons, cabbages and peppers, while among fruit crops olive covers more than 89% followed by citrus 3.4%, almonds and avocados.

The demand for irrigation water is high, while at the same time only 31.0% of the available agricultural land is irrigated (Fig. 5), a percentage lower than that of Greece (36.3%). As shown in Fig. 5, there was an increase by more than 55% in the last 15 yr, while the average increase at the same time in the country was 25%. For vegetable crops, more than 91% of the cultivated area is irrigated, while the irrigated percentage in row crops was 34.0%, in fruit trees 36.3% and in vineyards 45.1%.

Depending on the size, irrigation projects are constructed by the government, the local authorities or private individuals. The large size irrigation schemes, which involve large hydraulic structures such as dams, conveyors, pumping stations, reservoirs and modern distribution systems are constructed by the governmental Water Resources Services and/or Agencies. The medium size

Table 1
Area and crops cultivated in Crete ($\times 10^3$ ha)[a]

Category	Cultivated area (10^3 ha)	Percentage of the total
Row crops	32.1	9.96
Vegetable crops	8.9	2.76
Vineyards	30.6	9.50
Fruit crops	182.6	56.70
Forage crops	14.2	4.50
Fallow fields	53.6	16.58
Arable land	322.0	100.00

[a] Source: Hellenic National Statistical Service, Preliminary data 1998.

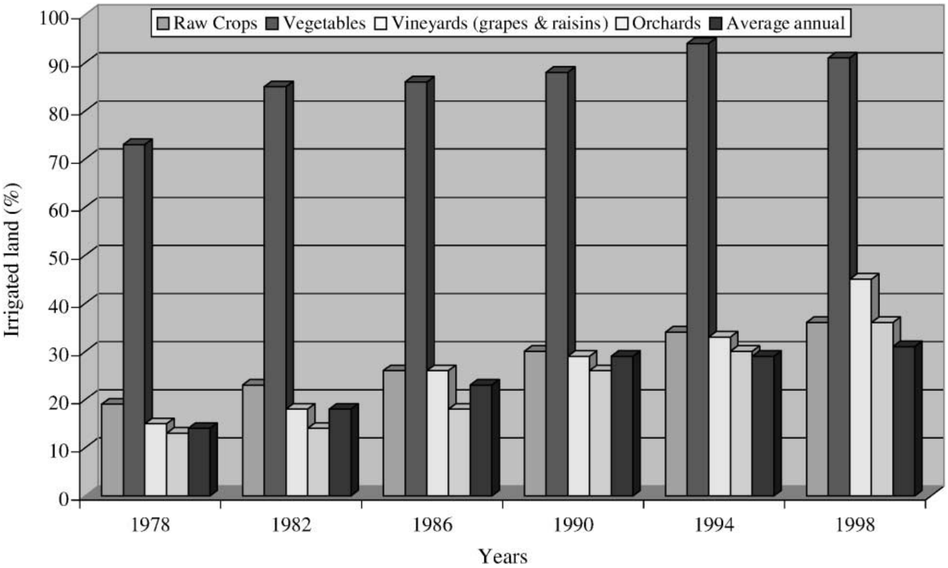

Fig. 5. Irrigated crops (percentage of the total cultivated area) in Crete during the last twenty years. Source: Hellenic National Statistical Service.

irrigation schemes of local importance, are constructed by the government on behalf of the Local Authority (Prefecture or Community) and usually comprise small dams or off stream ponds or boreholes and modern distribution systems. The cost of large and medium size irrigation schemes is financed by the government and farmers are charged per unit of water consumed. The small size irrigation schemes, comprising a single borehole, are constructed by individuals at their own cost and are found mostly in areas overlying aquifers.

The irrigation networks are of modern type made of pressurized distribution systems with delivery of water to the farm outlets. The delivery of water to the farm outlets is done on free or modified demand or on rotation with the appropriate pressure for direct use through modern on farm irrigation systems. Although in most cases irrigation water is distributed to fields through closed pipeline networks, there are major losses (seepage, evaporation, leakage, etc.) from water delivered to the agricultural sites for irrigation (Chartzoulakis, Angelakis, & Skylourakis, 1997). It is estimated that, on average, only 55% of water diverted or extracted for irrigation is effectively used by the crop (Fig. 6). In some cases, the losses are estimated to be as much as 50% of the delivered water (Dialynas, Diamadopoulos, & Angelakis, 1995).

The price of water per cubic meter varies greatly between catchment areas and even within the same catchment area, depending mainly on the managing agency. Cretan farmers operating in publicly developed irrigation projects still do not fully cover operation and maintenance (O&M) or capital replacement costs. So in the large irrigation project of West Crete the price is as low as 0.07–0.08 euros, whereas in community projects it reaches 0.10–0.12 euros and in some private projects it reaches 0.23–0.35 euros. These prices are much higher than in Portugal or in some regions in Spain (OECD, 1999). However, the implementation of a policy of approach between prices charged and real usage cost of water would set the course for achieving re-evaluation of this resource. This policy services as a financial instrument to offset the infrastructure cost and that of

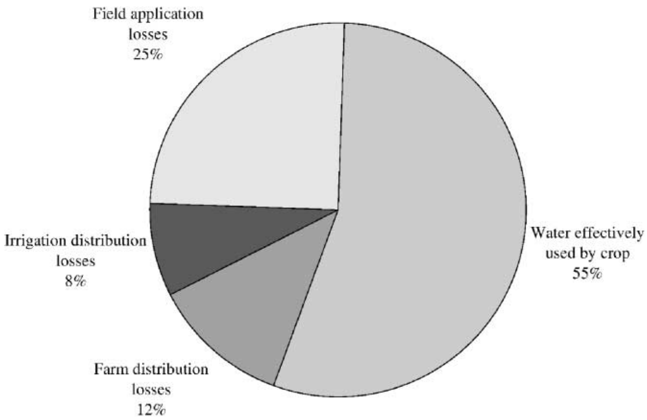

Fig. 6. Average irrigation water losses in the Island of Crete.

environmental restoration and it is a guarantee for rational water usage, with users becoming aware of its shortage. In addition, this policy will serve as a mechanism that automatically selects which production uses, in which areas, are the most important in the allocation of water.

Irrigation scheduling is another aspect of utmost importance for the appropriate irrigation of horticultural crops. It consists of a set of procedures which allow one, for a given crop, to find out when and how much to irrigate. Irrigation scheduling methods are based on environmental, physiological and soil parameters. The continuous technical progress in the irrigation scheduling methods using plant physiological indices (leaf water potential, stomatal opening, changes in diameter of selected organs, infrared thermometry, refractometry of the sap, etc.), although showing important innovations, involve measurements that are complex, time consuming and difficult to integrate and require highly qualified farmers. Since the average size of its irrigated field is half a hectare, the cost of such methods is very high, besides other difficulties, and our farmers do not use it at all.

For vegetables, especially in greenhouses, the analysis of soil moisture (by tensiometers, gypsum blocks or gravimetrically) is the most common method used for irrigation scheduling in Crete, since it assures low cost, simple operation and reliable estimation of soil water status. For tree crops, irrigation scheduling is mainly based on meteorological parameters (mainly Class A pan evaporation and Reference evapotranspiration ET_0). In Chania prefecture, thanks to the Irrigation Department of Subtropical Plants and Olive Tree Institute, information about irrigation to the farmers is given through a weekly bulletin, based on class A pan evaporation. Recently, thanks to new advances in communication, some assistance systems based on agrometeorological approach have been planned, which would permit an efficient exchange of information between Research Institutes, Extension Services and farmers.

Research in irrigation and water management for agriculture in Crete is carried out in the respective departments of two research institutes existing in Crete, the Subtropical Plants and Olive Tree Institute in Chania and the Research Institute for Viticulture, Floriculture and Vegetable Crops in Iraklio, both of which belong to the National Agricultural Research Foundation. Both institutes are involved in national and international projects, and with training courses, seminars and conferences they try to help the farmers to assimilate the new technologies and techniques in the field of water management.

6. Conclusions and recommendations

The necessity for expanding and improving irrigation, in order to ensure sustainable agriculture, is increasing in Crete. Given the severe limitations of exploiting new water resources, the only solution in meeting water requirements is to use of water more efficiently.

Although several important advances have been made over the last several years, significant challenges still remain in the areas of technological, managerial, policy innovation and adaptation, human resources management, information transfer and social environmental considerations. These issues for the Island of Crete, but applicable to most Mediterranean countries, are:

(a) *Water conservation and efficient use*. Since agriculture is by far the largest water user, efficient irrigation management will undoubtedly be a major conservation option for the future. It can be achieved through irrigation requirements and irrigation scheduling techniques, use of localized irrigation systems, salinity management techniques, and reduction of losses from water conveyance systems.
(b) *Water sectorial use*. Any amelioration of conflict and competition among water users will have positive effects in improving efficiency and productivity. Greater efforts are urgently needed to integrate irrigation planning and management with other sectors of economy that impinge on water use.
(c) *Water pricing and cost recovery*. The most important recommendation we can make is the adoption of full-cost pricing of water use and services. It will be the basis for promoting conservation, reducing losses and mobilizing resources. Furthermore, it could affect cropping patterns, income distribution, efficiency of water management, and generation of additional revenue which could be used to operate and maintain water projects.
(d) *Wastewater reuse*. Water resources shortage and environmental concerns have already led to waste water reuse for irrigation. Since waste water reuse has multidisciplinary interlinkage with different sectors such as environment, health, agriculture, water resources, etc., it is necessary for the administrative responsibility of reuse activities to be well defined.
(e) *Water quality management and use of saline water*. It is becoming increasingly as important as water quantity, and is a far more complex task than quantity monitoring. Research has provided much knowledge on the specific interactions of saline waters on soil and plant and various strategies and criteria have been developed for the safe use of such waters for crop production.
(f) *Other cost-effective technologies*. Besides technologies, such as reclamation and reuse of marginal waters, other cost-effective technologies, such as artificial recharge of groundwater, should be considered.
(g) *Technology transfer*. The availability of improved technologies or techniques is however no guarantee for their application. The farmer will play a key role in adopting more efficient and sustainable water management practices. Factors that provide the favorable conditions under

which the farmers may accept and adopt better and more efficient water use practices are clear benefits for efficient water use, investment support, adequate legislation, simple, practical and cost-effective technologies, guidance and advice in introducing efficient technologies.

(h) *Education and training*. Extensive educational programs should be instituted at all levels of society to promote prudent use and conservation of water as one of the indispensable natural resources. The institutional framework for support services and the training of the staff involved in irrigation development, will be the key to the introduction of new technologies in irrigation.

(i) *Development of an integrated water resources plan*. The necessity for establishing an integrated water resources plan similar to that of California, Israel or other regions, with advanced water resources management should be considered. It is of high importance to apply a policy for water resources management which will cover the present requirements but also ensure the future needs.

Acknowledgements

The authors wish to thank Mr. N. Papadoyannakis for his excellent typing assistance, the formatting and printing of this work.

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